CHALMERS

EVALUATING THE EFFECTIVENESS OF THE ROBUST INDEX TOOL

A study within Volvo Cars Manufacturing Engineering

Master of Science Thesis

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ABSTRACT

One way to improve the quality of a product/process is through Robust Design Methodology (RDM). This study has analysed the Robust Index Matrix (RIM) tool at Volvo Car Corporation and the focus has been to understand how this tool could contribute in the area of robust engineering. The literature used in this study spans from quality management theories to performance indicators with organisational learning finalising the literature study. The findings in the empirical study were divided into three categories, the perception of the tool, how the tool is practiced and the tool itself. By evaluating the results from interviews and internal documents, it was possible to understand how effectively the Robust Index tool reflects the robustness of the evaluated products/processes.

The most important conclusions from this study have been:

- Measuring robustness with the Robust Index tool would need requirements and criteria to be predefined.
- In order to improve the Robust Index tool, the measuring of robustness must be done in a continuous cycle in all phases of engineering.
- The Robust Index tool helps when determining which systems have the highest robustness. This is done by visualising the differences between the systems.

In addition, managerial implications have been found of the Robust Index tool. One way of improving the Robust Index tool in Volvo Cars is to make it more user-friendly and less time-consuming. In this study a new template has been constructed that could make the tool more user-friendly to use and less time-consuming.

Keywords: Automotive, Indicators, Manufacturing, Robust Design Methodology, Robust Index, Robustness, Variation, VMEA, Volvo Cars.

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SHIVA

ABBREVIATIONS

ATACQ	Answer To All Car Questions
BMS	Business Management System
BOP	Bill Of Process
CBP	Commodity Business Plan
CEO	Chief Executive Officer
DFA	Design For Assembly
DFSS	Design For Six Sigma
DMAIC	Define, Measure, Analyse, Improve, Control
DPL	Delprojektledare (Phase project leader)
ECB	Early Claims Binning
FMC	Ford Motor Company
FMEA	Failure Mode and Effect Analysis
FTT	First Time Through
GPDS	Global Product Development System
ISO	International Organization of Standardization
KPC	Key Performance Characteristics
KPI	Key Performance Indicators
KRI	Key Result Indicators
KVAST	KVAlitetssySTem (Quality System)
MOR	Manufacturing Operations Review
NF	Noise Factor
NMP	New Model Program
PI	Performance Indicators
PM	Project Manager

PSS	Program System Structure
PTCC	Program Target Compatibility Checkpoint
RDM	Robust Design Methodology
RI	Robust Index
RIM	Robust Index Matrix
RME	Resident Manufacturing Engineer
RPN	Risk Priority Number
R&D	Research and Development
SDA-M	System Decision Approval - Manufacturing
SPC	Statistical Process Control
TQM	Total Quality Management
TVQ	Total Vehicle Quality
UMC	Unit Manufacturing Cost
VCBC	Volvo Cars Body Components
VCC	Volvo Car Corporation
VCG	Volvo Cars Gent
VCM	Volvo Cars Manufacturing
VCME	Volvo Cars Manufacturing Engineering
VCT	Volvo Cars Torslanda
VMEA	Variations Mode and Effects Analysis
VOC	Voice Of the Customer
VOF	Voice Of the Factory
VOS	Voice Of the System
VRM	Variation Risk Management
VRPN	Variation Risk Assessment and Prioritization

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1 INTRODUCTION

In this chapter, the background and the aim of the study will be presented together with the limitations, and the report structure. An introduction to the company where the study took place is also part of this chapter.

1.1 Background

In the global competitive marketplace *"Quality has always been an important issue to the customer when buying different products"* (Bergman and Klefsjö 2010, p. 19). In turn, companies continuously search for innovative ways to improve the quality of the products in an efficient and systematic way considering customer as the central point. Moreover, customers want their products to be more user-friendly and long lasting, related to as being dependable and reliable (Wang 2005). In addition, for any product to be long lasting it must be *insensitive to variations;* which is otherwise referred to as Robust Design (Arvidsson and Gremyr 2005, Phadke 1989).

During the past decades, there have been lots of methodologies, tools and techniques developed to support the quality improvements of products and processes. One among them is the concept of robustness derived from the Robust Design Method (RDM). Robust Design Methodology was pioneered by Dr. Genichi Taguchi at the AT&T Bell Laboratories and it is sometimes referred to as Taguchi's Methodology (Phadke 1989). Mashhadi (2010) defines Robust Design Methodology as a pragmatic statistical method in order to design products and processes which are insensitive to variation under actual, real-life conditions.

RDM refers to any systematic effort (statistical or non-statistical) to achieve insensitivity (Gremyr 2005b, Arvidsson and Gremyr 2008). Robust design primarily focuses on the reduction of variation in a product (or) process considering it as a system. Any system is prone to be affected by certain factors called noise factors, which "*cause variability in product functions*" (Taguchi, 1986, p. 73). These noise factors gradually deplete the quality of the system. Therefore, it is necessary to control them during the initial phases of the development. The goal of RDM is to deliver products to the customers with minimal sensitivity towards variation over its complete life cycle. Minimising sensitivity is also a way to improve the reliability of the product for a customer throughout its life cycle. According to Andersson (1997), this goal could be reached through a customer-focused product development process, right from the early phases of the development process.

There are numerous methods developed in the past to identify systems that are to be improved. The concepts used in order to describe the efforts to reduce variation in product characteristics are immense; some examples suggested by Arvidsson and Gremyr (2005) are Taguchi methods, quality engineering, parameter design, robust design, robust engineering and robust design methodology. Volvo Car Corporation (VCC, also Volvo Cars) devised a tool called the Robust Index Matrix (RIM), which could be used to evaluate the robustness of a product and process.

Improving the robustness of a product indirectly increases the reliability of the product, which is necessary to compete in today's competitive marketplace. To reach success in today's market, a product that can meet customers' long-term expectation is vital (Yang and Kapor 1997).

1.2 Purpose and research questions

The purpose of this study is to investigate how robustness can be measured, in what ways the measuring can be improved, and to understand how indicators contribute towards securing robustness.

This research is based on a case study of Volvo Cars tool Robust Index Matrix and the purpose of this thesis can be decomposed to two research questions. Firstly,

- How is robustness measured today and how can the measuring be improved?

The first question focuses on measurements, leading to a second research question:

- How can indicators contribute towards securing robustness?

The second question focuses on understanding the role of indicators in the robustness evaluation. In addition, to understand how indicators can contribute towards securing robustness, the perception at Volvo Cars of the current initiative to measure robustness was investigated.

1.3 Limitations

Based upon the overall purpose, the following limitations are considered for this thesis:

- The generalizability in this qualitative investigation is limited since it is based upon a single industry and facilities of Volvo Cars and thereby the findings can be hard to generalise to other industries and companies. However, the tool investigated should be able to use in other companies with modifications.

- The focus of this study has been at Volvo Cars Manufacturing Engineering (VCME) unit in the Gothenburg facility, Volvo Cars Torslanda (VCT), but some information has been gathered from other facilities also, for example Volvo Cars in Gent, Belgium (VCG) and the stamping factory Volvo Cars Body Components (VCBC) in Olofström. Therefore, a possibility is that the findings will only be applicable to the VCME department inside Volvo Cars.

- In addition, the ideas that are presented in this report are not to be implemented by the master thesis students, as it is outside the scope and should be done by VCC employees.

1.4 Volvo Cars Manufacturing Engineering (VCME)

Volvo Car Corporation is a car manufacturer based in Sweden, but owned by the Chinese company Zhejiang Geely Holding Group who bought Volvo Cars from Ford Motor Company in 2010. The vision of Volvo Cars today is "*To be the world's most progressive and desired luxury car brand*" and one goal is to sell more than 800 000 cars in year 2020 (VCC 2012). A part of VCC is Volvo Cars Manufacturing (VCM) with the sub-unit Volvo Cars Manufacturing Engineering (VCME). They are a driver of the Manufacturing Development Process, a part of the Product Creation Process, and VCME's purpose is to "*define, prepare, launch, maintain waste-free, flexible industrial systems and robust products*" (Tharing 2012). This thesis was conducted in the VCME sub-department Total Vehicle Quality (TVQ) that is responsible of technical strategies concerning quality and drives continuous improvements and six sigma projects. The purpose of this department is to lead, support and guide VCME units in their operational quality work to secure that quality targets are met in future models (Tharing 2009).

For "Total Vehicle Quality's" ability to help units within VCME in terms of robust-engineering and robust design, a process called Robust Index (RI) was introduced in 2007. This tool includes something called the Robust Index Matrix (RIM), which is based on measurements. In this study, the measurements are both regarding the measuring procedure and the output from the measuring. The RIM should cover the complete Voice of the Process (which includes the Voice of the System and the Voice of the Factory) and the Voice of the Customer. Voice of the System refers to what kind of complications manufacturing engineers will find on specific components while the Voice of the Factory should consider errors that have happened in the factory, for example audits regarding the same component. The Voice of the Customer is the final part and refers to what kind of un-robustness the customers will experience in terms of warranty claims etc. The purpose of this process is to evaluate different solutions in terms of robustness and to identify what solutions are robust enough, and which later can be implemented in a new project. So far, the Voice of the Customer has not been used and only recently, manufacturing engineers have started to use the Voice of the Factory. In Figure 1 below, Volvo Cars' view of robust design can be seen.

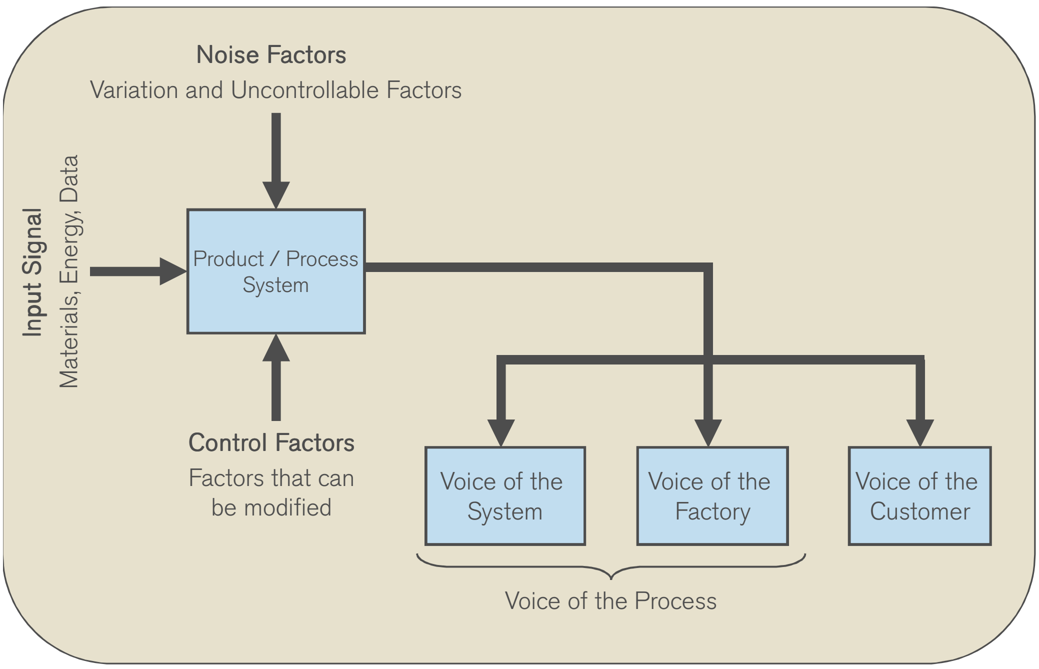

Figure 1, Volvo Car Corporation's way of working with robust design in a simplified way

1.5 Report structure

Next chapter starts with the research methodology and here descriptions of what type of research design are used and how data are collected is presented. To secure the quality of this study, questions regarding reliability and validity will be raised.

The following chapter is presenting the theoretical framework. This framework is closely linked to the fourth chapter where results from internal documents and interviews with employees are described. With the help of the theoretical framework, the results are analysed in the fifth chapter.

In the thereafter-following chapters, discussions and conclusions are presented, which finally lead to some suggestions for future research. As this study has been done inside an organisation, managerial implications mainly directed to the case company will be presented in the eighth chapter.

2 RESEARCH METHODOLOGY

In this chapter, the research methodology used in this study is described. The research design together with data collection is described, and discussions on reliability and validity are provided.

2.1 Research design

Bryman and Bell (2011) describes two different methods when conducting business research; quantitative and qualitative methods. The main difference between the two is that quantitative research emphasises quantification when collecting and analysing data while qualitative research emphasises more on words, and how data is interpreted. However, more differences occur than these presented. The quantitative strategy is often characterised by a deductive approach, which focuses on the testing of theories while the qualitative strategy is generally more inductive. In the deductive theory, the researcher starts with a basis of what is known about a certain subject and from that deduces a hypothesis that have to be empirically studied (Bryman and Bell 2011). This means that observations and findings are an outcome of theory and the theory is tested against the findings. With an inductive approach, the generation of theory is an outcome of the observations and findings. In other words, the findings regarding a certain subject will generate theory that possibly could be used in other similar settings.

In this study, neither the inductive approach nor the deductive approach will be used. Instead, Dubois and Gadde (2002) describe a method called systematic combining which is judged to fit the purpose of this study. This because in this case study, the subject was defined from the start and much information exists in the area of RDM. However, not much information exists of how to measure robustness with indicators. In this research, a theory is used from the beginning to start the observations. The observations will in turn contribute to the theory and a process back and forth between theory and findings will be used. Dubois and Gadde (2002) mean that case studies offer an inter-twined process, which most other literature on case studies does not take into account. They continue to say that case studies often are described as a linear process by other authors. Nevertheless, the linear process is developed mostly for other studies in other contexts, while case study researchers tend to go back and forth between observations and theory. This intertwined process between observations and theory has been used in this study. To explain systematic combining briefly, it is based on a view that empirical observations cannot be fully understood without some theory and vice versa. When the theory has evolved, the search for empirical data will start, which then once again can make your theory grow and make you further expand your empirical observations. Since systematic combining tends to refine existing theories, more than creating new ones it is placed closer to the inductive than the deductive approach.

This thesis has been of a qualitative nature rather than a quantitative nature since interviews have been conducted at the studied company and interpretation of documents has to be done rather than collect quantitative data. The gathered information will also be compared to previous research and in this way refine the existing theory. The research methodology to be followed in this thesis will include a combination of a theoretical study of RDM and an empirical study on the measurement procedure utilised at the studied company.

Bryman and Bell (2011) presents the main steps in qualitative research where you in step one should start by creating your research questions. When these have been done, you should continue to select relevant sites and subjects and in step three, the collection of relevant data starts. After the collection of data, the interpretation of data should start, as a fourth step, and this will result in some conceptual and theoretical work. This step should be tightly connected to the interpretation of the data. The fifth step could either conclude with writing up the findings and conclusions or a tighter specification of the research questions and collect further data for interpretation of the data again has to be done. The whole process can be seen in Figure 2 below, but this is only a general picture of how qualitative research should be outlined. In this study, the loop from "Conceptual and theoretical framework" out to "Interpretation of data" and "Collection of further data" is emphasised since a continuous process back and forth between theory and empirical data has been used.

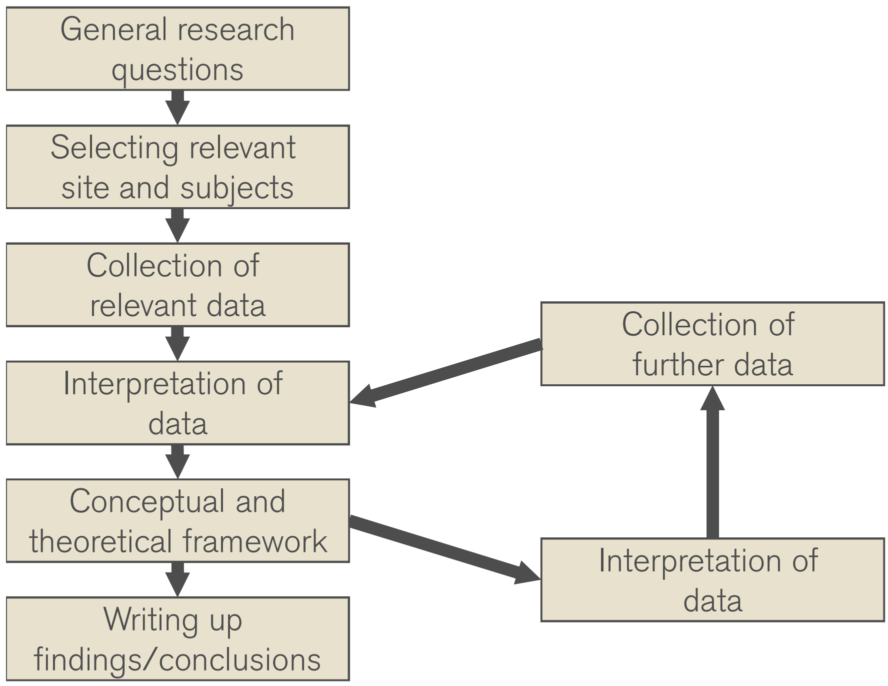

Figure 2, Outline of the main steps in qualitative research (adapted from Bryman and Bell 2011)

2.2 Data collection

When designing qualitative research, four types of methods for gathering information are used; (1) participating in the setting, (2) observing directly, (3) interviewing in depth and (4) analysing documents (Marshall and Rossman 2006). These methods can also be divided in primary and secondary methods of collecting data. The first primary method is studies conducted at the studied company providing a first-hand involvement (Marshall and Rossman 2006). Before this study started at the company, it was decided how much the researchers should be present at the company and to what extent they should be involved in the day-to-day work in the working group at the studied company. In this case, the researchers participated in the setting to a large extent, e.g. weekly meetings, team events and other informative sessions. By constantly being critical to what was presented and use the theoretical framework, the risk of going native in this study should have been minimised.

The second primary method used is in-depth interviewing. Employees at different positions inside the studied company have been interviewed using semi-structured interviews. The purpose of this is to give the interviewee a big leeway and allow the interviewers the ability to ask questions in a different order than scheduled and add questions if appropriate (Bryman and Bell 2011). Unstructured interviews could also have been used instead of semi-structured interviews, where only certain topics to be discussed are written down, but no questions regarding the topic (Bryman and Bell 2011). The reason why unstructured interviews were not chosen was the interest in getting answers in some specific areas. With the semi-structured interviews, the interviewers could prepare more specific questions than what would probably be asked in an unstructured interview. The questions used can be seen in *APPENDIX, Interview guide*, and were formulated and tested together with personnel from the TVQ department. After the interview guide was formulated, the first interview was done as a pilot interview. However, there was no need to add or take away any questions in the guide after the pilot interview, but the phrasing of one question was changed slightly.

People that were interviewed for this study all belonged to the unit Manufacturing Engineering inside Volvo Cars. They were selected with help from the sub-department Total Vehicle Quality and were in different positions within different sub-departments of Manufacturing Engineering. Risks are connected to this, e.g. TVQ could have recommended only people that are supportive of RIM. In addition, the people interviewed could be heavy users of RI, which will give misleading results as well. However, the selection was made to get people from as many departments as possible to try minimising these risks. The different departments were in alphabetical order: Body, New Model Program, Paint, Stamping, Strategic Planning and Control, Total Vehicle Geometry, Total Vehicle Quality and Trim & Final. It was also a diversified group of people interviewed with various positions, e.g. managers, engineers in different areas and technical experts. In total, 22 persons were interviewed as listed in *APPENDIX, Interviewed persons*.

All of the interviews were scheduled for one hour, but varied between 40 minutes and one hour in length. The interviewees were not prepared in any way, except that they knew the topic of the meeting would be robustness. One of the interviewers asked all the questions while the other one was audio recording the interview. Both took notes during all interviews. Directly after the interview, all notes from both interviewers were written down in a document and more elaboration from the interview notes were done without the use of the audio record. To be able to do this, a gap of at least 30 minutes was scheduled before next interview. At a later point, the audio record was used to complement the already written document. For each interview a new document was made in order to make it easier to analyse.

The researchers also developed a new interface of the Robust Index Matrix during this study based on the collected data during interviews. In order to understand if this new interface could be helpful to the Manufacturing Engineering unit, the TVQ team and some heavy users of the tool were invited to test the new interface. Test persons tested the tool individually and the meeting started with a description of what had been changed in the interface. After this, the test person was offered to test the new interface him- or herself. When the test ended, feedback from the test person was collected.

In this study, analysis of documents inside the studied company has also been done, which is classified as a secondary method according to Marshall and Rossman (2006). However, it is still from a primary source with organisational documents that are only for internal use and these documents can be important to researchers doing a case study if also qualitative interviews and participating observations are made (Bryman and Bell 2011). In addition, documents and articles have been used together with books related to this subject. These documents would count as secondary sources and to retrieve them, Chalmers library's database has been used together with Google Scholar and Volvo library's database. Keywords like; *Robustness, engineering, index, measuring, robust design, robust index, robust matrix, indicators etc.* have been used alone or in different combinations to identify useful material.

Snowball sampling was also used to further expand the theoretical framework and according to Bryman and Bell (2011), this method is more suitable for qualitative than quantitative research. Snowball sampling is described as when one research subject leads to another subject and the theoretical framework grows like a snowball (Bryman and Bell 2011).

2.3 Data analysis

Qualitative research often generates a lot of data, which is one of the main difficulties with this research method. Unlike quantitative data analysis, the codification of qualitative data has no clear rules for how to interpret the data. What instead is provided are broad guidelines. The two most used strategies when analysing qualitative data are analytic induction and grounded theory according to Bryman and Bell (2011).

In analytic induction, the researchers are collecting data until no cases are inconsistent with a hypothetical explanation. Grounded theory on the other hand is defined as "*theory that was derived from data, systematically gathered and analysed through the research process. In this method, data collection, analysis, and eventual theory stand in close relationship to one another*" (Strauss and Corbin 1998, p. 12). The approach of grounded theory is that theory is developed out of data and the approach is iterative.

Systematic combining, by Dubois and Gadde (2002) says that the connection and interaction between empirical observations and theory are stressed more than in grounded theory. However, the systematic combining is similar to grounded theory because of the concern of generating new concepts and develop theoretical models rather than confirming existing theory.

In this study, the grounded theory concept has been combined with the systematic combining. The grounded theory has been used to have a guided way of how to do the data analysis. However, a too heavy focus should not be put on the grounded theory, since theory was used from the beginning to create research questions and there has been an iterative process between theory and results, which is connected to the systematic combining. The outline of the whole process of grounded theory can be seen in Figure 3 below (the right part of the figure). Since this study is based on systematic combining, equally important is the theoretical framework, which intertwine with the empirical studies as added on the left-hand side of Figure 3.

Coding is a key process where data are broken down into smaller parts and starts directly after the collection of data (Bryman and Bell 2011). Denscombe (2003) says that the first thing to do before analysing data would be to try to have all the data in the same format (for example A4). In this study, the primarily used format has been A4, but some other formats have also been used when the A4 has not been applicable. For example, also post-it's have been used together with a template that is in A1 format. Denscombe (2003) continues to say that coding is to break down data into units for analysis and then categorise them. The first thing should then be to decide the units and these can for example be specific words or particular ideas or events, which could be statements by interviewed persons or from internal documents. When doing the early coding it is not crucial what units are decided. In the analysis of this study, the first coding would be to see ideas of, for example, improvement suggestions and weaknesses of the tool today.

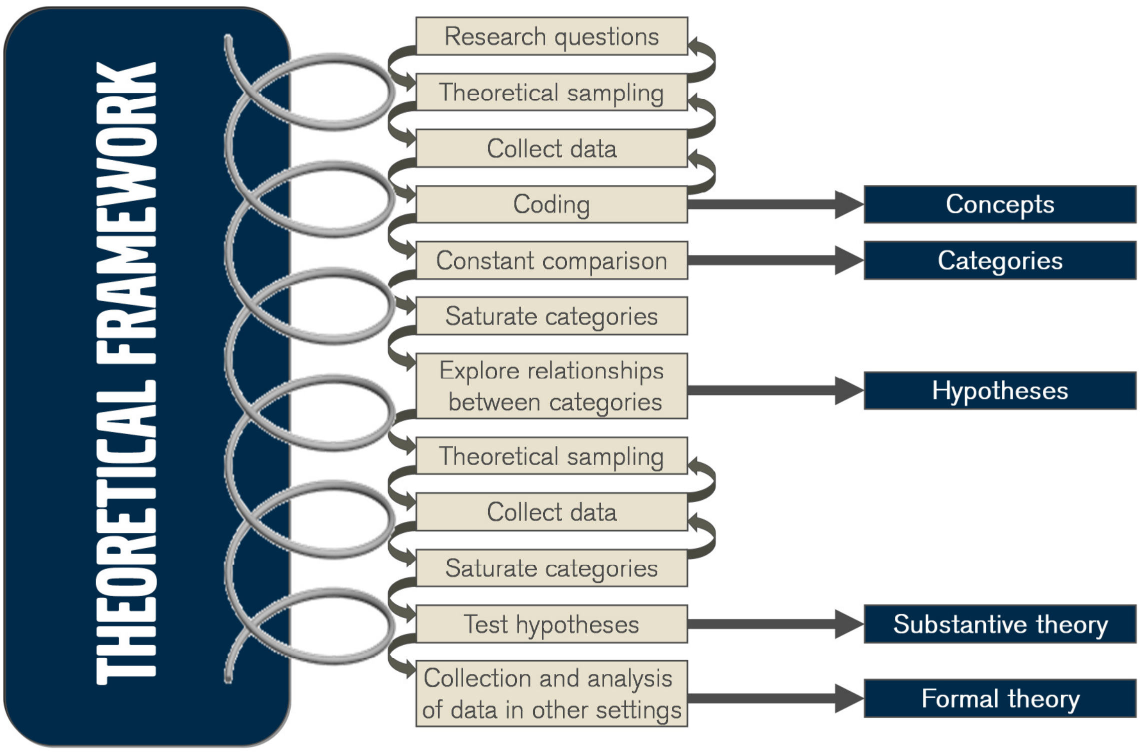

Figure 3, Processes and outcomes in grounded theory (adapted from Bryman and Bell 2011)

The coding should be done on for example field notes, documents etc. where comments and reflections are put in the margin. Coding of these different documents should also be done as soon as possible (Bryman and Bell 2011). The interviews and documents used in this study have been coded as soon as possible, but before the coding, general ideas have been written down in each document in order to have a good start when coding. When the coding started, the researcher took half of the interviews each and started coding. After both were finished, the coding was jointly discussed to see if something had been left out, or could be further elaborated on.

As the coding evolves, new insights, which leads to new units, may arise and be included in the data. It is also important to look for connections and relationships in the field notes and transcript or text (Denscombe 2003). Colour coding has been used in this study, where the different units and relationships have been marked in the documents with the help of different coloured pens together with notes in all documents (both interview documents and other documents). In the coding, it became clear that the questions asked to the interviewees could be grouped into ten clusters (*APPENDIX, Questions grouped into clusters*) in order to make it easier to continue the analysis.

Later, a whiteboard and an A1 template were used as a matrix to group the ideas by department and by type of engineers (core, commodity and resident engineers which is called phases in the template). This template was created in cooperation with staff from the TVQ team who also was present at occasions to help conducting the analysis. The employees from Volvo Cars were involved in the analysis in order to help the researchers understand the current situation. However, the researchers did all interpretations of the raw data.

With this first-level analysis, it would become obvious if there are big differences between the engineers inside each department and between different development phases (core, commodity and resident manufacturing engineers). Since it became ten clusters of questions, also ten different templates had to be used. Post-it's were used in this template where statements and ideas from the interviewed persons were written down on the post-it's and later placed in the template as in Figure 4 below which is showing one of the templates used.

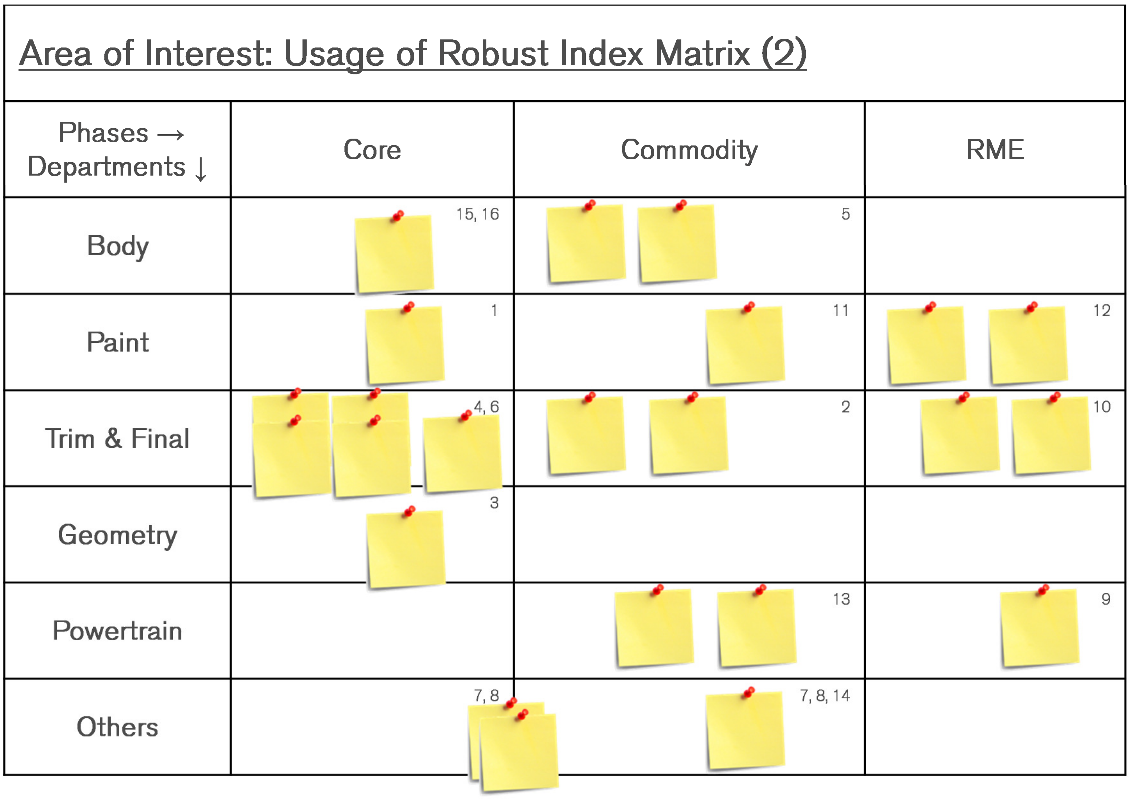

Figure 4, Example of template used for first level analysis

The results from the first level analysis were then used in the second level analysis. Focus here was to find similarities and differences between the departments and engineers in different phases of development. This in contrast to the first analysis were the differences inside each department and phase where analysed. In order to do this second level analysis, a second template had to be created, also in cooperation with staff from TVQ. Staff from TVQ also was present at occasions when this analysis was done. In this template, a separation between departments and phases has been done and what it looks like can be seen in Figure 5 below.

Departments		
Common	**Difference**	**Inference**
•	•	•

Phases		
Common	**Difference**	**Inference**
•	•	•

Figure 5, Template used for second level analysis

When the coding was completed, the statements could be turned into concepts. The frequency of a statement or idea tells if it will be useful to use that concept or not. An example of a concept could for example be an improvement suggestion that has been mentioned in many interviews.

Categories are concepts that have been elaborated. Many concepts can be found in the same category and therefore concepts are seen as a lower level of abstraction than categories. A category for this study could be improvements that can be done to the Robust Index. In this category, a number of concepts could be placed, so it will be easy to see all the improvements that can be done.

The two last things regarded as outcomes are hypotheses, which show the relationships between concepts, and theory, which according to Strauss and Corbin (1998, p. 22) are "*a set of well-developed categories*". They should explain a phenomenon with a theoretical framework that has been formed from systematically related categories.

2.4 Reliability and validity

The first word reliability is connected to if the results of a study can be repeated or not and it relates to if the measurements (motivation, effectiveness etc.) are consistent (Bryman and Bell 2011). Mostly reliability is connected to quantitative research but can be applied on qualitative research as well. Reliability can also be referred to dependability. External reliability refers to the degree a study can be replicated. It is of course hard to achieve the exact same social setting as when the research was conducted but in order to handle this the researcher that is replicating should adopt a similar role as the original researcher. To overcome this problem, all data gathered during the study should be saved (Bryman and Bell 2011). Field notes, transcripts of interviews, selection of research participants etc. should be available for auditing. During the study, peers should act as auditors to understand if the right procedures have been used or not. All data for this study have been saved, together with field notes. However, no auditing has been used to ensure the reliability. Instead, the researchers themselves have been trying to audit their own work, but external auditors would of course have been preferred.

To have a high internal reliability, the members of the research team should agree about what they see and hear (Bryman and Bell 2011). This criterion has been fulfilled according to the researchers. The researchers have agreed on almost everything they have seen in the company and when there have been differences of opinion, it has been often been related to misunderstandings.

Validity is the second word in the headline and relates to the integrity of the conclusions generated from the research. In qualitative research internal and external validity are most common according to Bryman and Bell (2011). They continue to say that internal validity explains if the theoretical ideas are equal to the researchers' observations. Dubois and Gadde (2002) talks about credibility (which parallels internal validity according to Bryman and Bell 2011) and have found three problems in the method of systematic combining. The first problem is if the study "*suggests that they are relying on some notion of statistical generalization"*, because a case study cannot build on statistical interference (Dubois and Gadde 2002, p. 554). Instead, they have to rely on analytical interference and this makes the sampling more demanding and is similar to theoretical sampling in grounded theory. Since the grounded theory approach also has been used as a guide in the sampling and collecting of data, the statistical interference should be minimised. This is also supported by Denscombe (2003), who says that the use of multiple methods would increase the validity.

In some case studies, researchers try to test the relationship and patterns in complex structures and this is the second problem (Dubois and Gadde 2002). In some cases, the theory generation and confirmation cannot be separated and then the credibility has to be checked in other ways. When analysing, a logical consistency has to be shown in order to prove the quality of the work. In business research, complete objectivity is impossible as well (Bryman and Bell 2011). Instead, the researchers have to show that they have acted in good faith and have not obviously allowed any personal values in the research. Using theory to manifest one standpoint and deriving findings from it is also something the researchers should be able to show has not happened in the study. Hopefully this study also fulfils these criteria, but as researchers it is hard to judge the own study, so this has to be done by others.

As a third problem Dubois and Gadde (2002) says that there is a risk that the researchers may end up with a lot of theory saying little about much. Instead, you should focus on being selective when choosing theory and be parsimonious. In systematic combining, there is a risk that you end up with theory that has helped you during the way of reaching your goal, but not adding something to the final findings. Therefore, some theory not adding to the final findings should not be presented in order to reach parsimony. In this report, more theory is presented than what have been used in the analysis. However, without the theory used earlier in the study, which is not directly contributing to the final findings, there could be gaps in this report and therefore it has been kept, even though it contradicts Dubois and Gadde's (2002) advice.

The research findings should also be shown to the persons that have been in some way involved in this study, to confirm that the researchers have understood everything correctly (Bryman and Bell 2011). Most persons involved in this study have been continuously updated with our understandings and every week there has been a meeting with our supervisor at the studied company. Some of these persons have also been involved when the analysis was performed, which also should strengthen the validity of this study.

The external validity can be a problem for qualitative researchers since they often do case studies and have small samples. The problem is then that the findings cannot be generalised for other settings and therefore the external validity will be low (Bryman and Bell 2011). This will probably be a problem also in this report since it is a case study at Volvo Cars and generalising this study even to other car manufacturers could be hard. However, the original researchers should take notes and be able to provide others with a description of the culture and environment. This could help the repeatability and let other researchers judge if it is possible or not to transfer the findings into other environments. In this study, a logbook has been written every week to reflect what the researchers have been doing during the study and what could be seen in the organisation. However, these notes have not been that comprehensive, but could still help others trying to repeat this study.

3 THEORETICAL FRAMEWORK

This chapter elucidates the theoretical background of this thesis work formulated with the framework. The chapter starts with a general view of quality management and continues with the robust design perspective. To get into the elements of the robust design, this study focus on the quality loss function, P-diagram and on-line & off-line quality control. Further to support the evaluation of how robustness can be measured, VMEA and performance indicators were referred. Finally, organisational learning and change helps in understanding how measuring robustness can be implemented and integrated in an organization.

3.1 Quality Management

Quality is a characteristic that gains its significance from a customer (Bergman and Klefsjö (2010). In the cornerstones of Total Quality Management (Figure 6) proposed by Bergman and Klefsjö (2010), the authors project the importance of *Focus on Customers* as the most important cornerstone in fulfilling any organisation's goals.

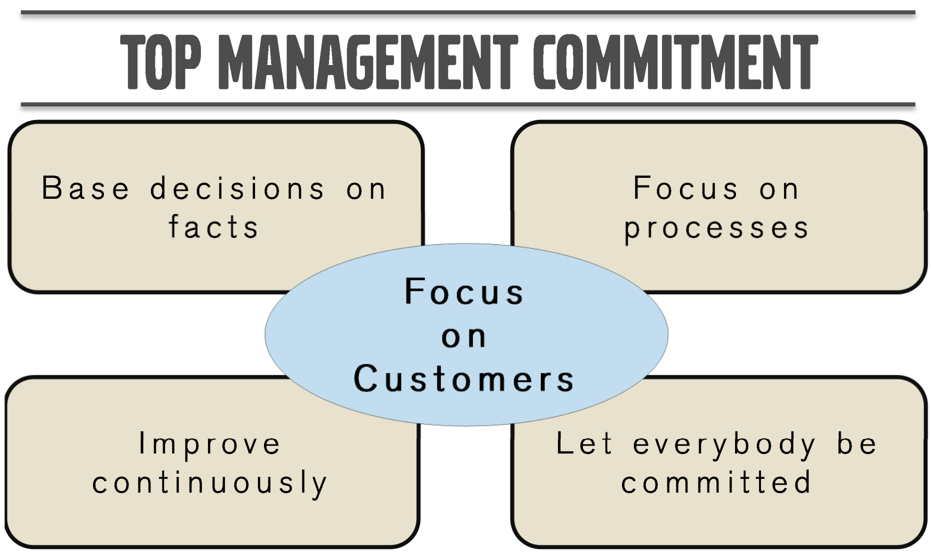

Figure 6, The cornerstones of Total Quality Management as presented by Bergman and Klefsjö (2010)

Similarly, Lengnick-Hall (1996) emphasises that, regardless of the specific tools and methods that an organisation adopts or follows, managing of quality and competitive advantage means that the organisation must become customer-oriented. Moreover, Ishikawa (1985, p. 80) insisted, *"Quality must be built into each design and each process"*.

According to Bergman and Klefsjö (2010), quality was initially associated with craftsmanship and later the desire to satisfy customers has been in existence for several centuries. The evolution of the quality movement started from craftsmanship and continued as follows:

- *Quality Inspection* – A defensive way of working where the products are inspected after they have been produced.
- *Quality Control* – An on-going inspection work during the production stage to identify the defective products and improve the process behind it.
- *Quality Assurance* – Once realising the impact of the cost of poor quality, a more pro-active way of working where the whole production process assessment was carried out before the production stage.
- *Total Quality Management* – By systematically determining the needs and requirements of the customer, by making well planned experiments and creating robust design solutions, it is possible to prevent the release of the poor-quality products to the market.

Moreno-Luzón and Peris (1998) state that the primary objective of TQM is customer satisfaction and it is regarded as a way of measuring quality. Walsh, Hughes and Maddox (2002) suggest that a continuous improvement culture can help an organization in satisfying the needs of its customers on an on-going basis. Bergman and Klefsjö (2010) insist on the creating a learning organisation in order to secure quality with a continuous improvement philosophy. Garvin (1993) defines a learning organisation to be an organisation that is skilled at creating, acquiring, and transferring knowledge, and at modifying its behaviour to reflect new knowledge and insights. However, if the execution of an improvement process rests on the culture, it is necessary that the top management is continuously and consistently committed to quality issues (Bergman and Klefsjö 2010).

However, continuous improvement requires both the management and the employees to receive sufficient training in not only the application of specific techniques, but also the need for understanding the underlying principles of this continuous improvement philosophy (Moreno-Luzón 1993). Deming (1994) presented his continuous improvement philosophy based on the Plan-Do-Study-Act (PDSA) or otherwise termed Plan-Do-Check-Act (PDCA) cycle and Juran (1988) promoted a ten-step quality planning process aiming at continuous improvement. In addition, He, Qi and Liu (2002) from the quality-engineering point of view suggest that in order to continuously improve the product/process quality, it is necessary to integrate all the quality tools as well as quality data and reduce the quality bottlenecks systematically.

Quality management is a complex phenomenon, which is practiced in many different ways in different organisations. Dahlgaard, Kristensen and Khanji (2002, p. 16) defines Total Quality Management as *"a corporate culture characterized by increased customer satisfaction through continuous improvements, in which all employees in the firm actively participate*". Hoyle (2009, p. 788) defines quality management system as "*The set of interacting processes used by the organization to achieve its quality objectives".* Pfeifer, Reissiger and Canales (2004) emphasise that the quality management systems help in enhancing the product quality and provides organisations with means to achieve higher quality processes. All of the above explanations clearly elucidate that a quality management system calls for a continuous improvement philosophy, which needs to be integrated in the daily operations as a natural learning process in an organisation.

Garvin (2000, p. 11) defines a learning organisation as "*an organization skilled at creating, acquiring, and transferring knowledge, and at modifying its behaviour to reflect new knowledge and insights".* In order to successfully work with continuous improvement practices, there must be tools that support this philosophy. Dean and Bowen (1994) emphasise that, total quality is not just a hodgepodge of slogans and tools; rather a set of mutually reinforcing principles, practices and techniques (presented in Table 1 below), which are ultimately based on fulfilling customers' needs.

Table 1, Principles, Practices and Techniques of Total Quality (Adapted from Dean and Bowen 1994)

PRINCIPLES, PRACTICES AND TECHNIQUES OF TOTAL QUALITY

	Customer Focus	Continuous Improvement	Teamwork
Principles	• Paramount importance of providing products and services that fulfill customer needs requires organization wide focus on customers	• Consistent customer satisfaction can be attained only through relentless improvement of processes that create products and services	• Customer focus and continuous improvement are best achieved by collaboration throughout an organization as well as with customers and suppliers
Practices	• Direct customer contact • Collecting information about customer needs • Using information in design and deliver products and services	• Process analysis • Re-engineering • Problem solving • Plan-Do-Check-Act	• Search for arrangements that benefit all units involved in a process • Formation of various types of teams • Group skills training
Techniques	• Customer surveys and focus groups • Quality Function Deployment	• Flowcharts • Pareto analysis • Statistical Process Control • Fishbone diagrams	• Organizational development methods such as the nominal group technique • Team-building methods (e.g., role clarification and group feedback)

Liker and Choi (2004) mention the importance of sharing the knowledge between the company and the supplier in terms of their best practices. This knowledge from the best practices could be contributed towards designing of products/processes.

3.2 Robust Design

Phadke (1989) emphasises that an ideal quality that a customer can expect in every product is the target performance that a product delivers during each time the product is used, under all intended operating conditions and throughout its intended life, with no harmful side effects. The International Organization for Standardization (ISO 8402, 1986) cited in Owlia and Aspinwall (1996 p. 162) defines quality as *"the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs"*. It seems that, any product that is not deviating from its intended performance and able to satisfy the intended needs and requirements of the customer is expected to gain a competitive advantage from the customers. Mashhadi (2010) states that, the customers appreciate a product that performs its functions independently of disturbances during its life cycle; thus unwanted variation decreases a product's value for the customers.

A robust product or process is a system that has a minimal tolerance of variation, which allows wider manufacturing tolerances (Phadke 1989). These sources of variation are referred to as noise factors and could in turn be due to manufacturing or user's environment or due to the aging of the product. This is addressed in Taguchi, Chowdhury and Taguchi's (2000 p. 4) definition on robustness, *"the state where the technology, product or process performance is minimally sensitive to factors causing variability (either in manufacturing or user's environment) and aging at the lowest manufacturing cost"*.

Hasenkamp, Arvidsson and Gremyr (2009) states that, the objective of RDM is to generate or identify design solutions that are insensitive to unwanted variation or noise factors such as environmental conditions, product deterioration or manufacturing imperfections. Robust design is further used to reduce the variation by improving the quality, which is done by striving to reach the performance targets, set by the organisation (Hu et al. 2004). Hasenkamp, Arvidsson and Gremyr (2009) further state that, these noise factors are typically difficult, impossible or too expensive to be controlled under operating conditions and therefore effort towards creating insensitivity to noise factors is required.

Phadke (1989) views robust design as a systematic method to keep the producers cost (operating, manufacturing and R&D) low while delivering a high-quality product and still keeping the operating cost low. Similarly, when considering the robust design of a system, it should be evaluated in terms of robustness at a system level, factory level and at a customer level. This is similar to the ideology of Davis (2006), where he recommends the analysis of the failure modes at three different levels - the vehicle, sub-system and the component.

Hasenkamp, Arvidsson and Gremyr (2009) present three central principles of robust design. These three principles are illustrated in Figure 7 below.

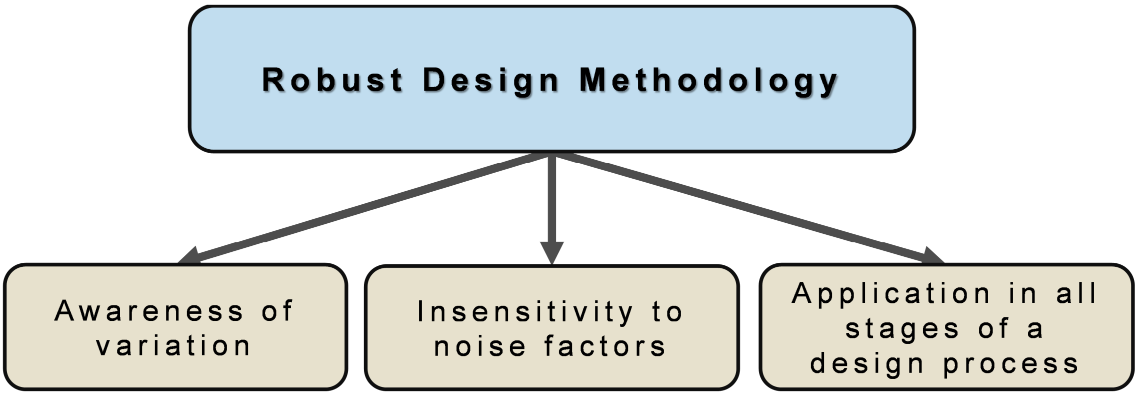

Figure 7, Three central principles of Robust Design Methodology (adapted from Hasenkamp, Arvidsson and Gremyr 2009)

The three central principles of Robust Design Methodology were summarised as a definition for RDM, which follows:

"Robust Design Methodology means systematic efforts to achieve insensitivity towards noise factors. These efforts are applied from concept generation to the production of a product", Arvidsson and Gremyr (2008, p. 31).

Numerous methods and methodologies were developed to support the designing of robust products and processes. Some of the methods and methodologies as cited in Arvidsson and Gremyr (2005) are Robust Concept Design, Variation Risk Management, Variation Mode and Effects Analysis (VMEA), and a semi-analytic approach based on the error transmission formula. Ford (1996) developed the robust concept design method carried out in the concept stages of development consisting of four different steps. The four steps include defining the robustness problem, deriving guiding principles, making a new concept synthesis and evaluating the alternative concepts. Thronton (2004) proposed a method called Variation Risk Management (VRM) supporting the reduction of variation from the system design to production. Chakhunashvili et al. (2004) developed a method called Variation Mode and Effects Analysis (VMEA), which is applicable for the concept selection phase as well as in the improvement of the existing designs. The VMEA method focuses on the identification of the noise factors that influence a design. Andersson (1996) suggest a semi-analytic approach based on the error transmission formula by comparing the different levels of noise factor sensitivity in different designs.

Phadke (1989) describes the costs incurred before the sale of product as unit manufacturing cost (umc) and the costs incurred after the sale of the product as quality loss. In addition, the loss function is a superior way to identify the quality loss and it can meaningfully approximate in most situations.

3.3 Quality loss function

Many different experts define quality in different terms. However, Taguchi (1986, p. 1) takes up an alternative statement to define quality as *"The losses a product causes to the society after being shipped, other than any losses caused by its intrinsic functions"*. Kackar (1989) interrogates the above definition of quality for ignoring the losses that are incurred just before the shipping of the product, which includes reworking, scrap etc. Lofthouse (1999) defines Taguchi's approach as a customer-centric approach explains the concept underlying the approach in two statements.

1. Quality should be measured in terms of the amount of deviation from the target value rather than conformance to the specification limits and

2. Quality should be an inherent property/characteristic build in the design of the product/process and cannot be ensured through inspection and rework.

Taguchi (1993, p. 4) states, *"Quality loss as the amount of functional variation of products plus all possible negative effects, such as environmental damages and operational costs"*. In order to measure this quality loss, Taguchi developed a quality loss function, which is shown in Figure 8 below.

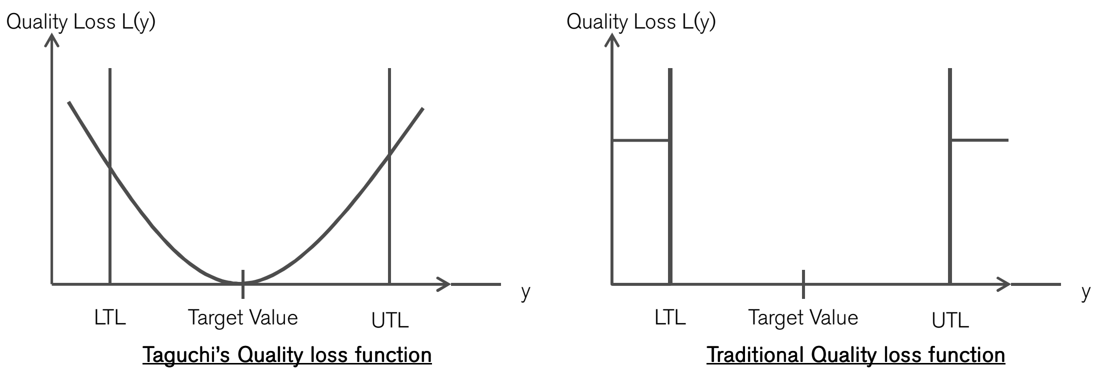

Figure 8, Two views of quality losses (Adapted from Phadke, 1986)

Taguchi's quality loss function in Figure 8 above is a continuous function, which explains that, any deviation from the ideal, or target value is considered a loss. Similarly, the traditional quality loss function (step function) in Figure 8 above describes that, the quality loss is zero when the deviation is within the tolerance limit. Similarly, Lofthouse (1999, p. 219) identifies that, *"the loss function establishes a financial measure of the user's dissatisfaction with a product's performance as it deviates from a target value".* Arvidsson and Gremyr (2008) refers to the criticism of the quadratic loss function of other authors and cites that, the quadratic loss function is a good conceptual model but not an exact model in owing to the difficulties of characterising and balancing economic losses.

Phadke (1989) describes that a number of parameters influence the quality characteristic or response of a product. Therefore, it would be easier to visualise them in a common picture, which would describe all the parameters that affects a product/process.

Harrington (1999) states that providing a product with a high quality is not more expensive than providing a low quality product. Cost can be reduced by solving quality problems and therefore quality work should be prioritised. He further states that managers often are shocked when they find out how big the cost of poor quality actually is, and that a system addressing cost of poor quality would be economically beneficial. Cost of poor quality is defined as the sum of; helping employees do the right things the first time, determining whether the output is acceptable and not meeting specifications and/or customer expectations (Harrington 1999). However, it is important to remember that, "*quality cost measurement and publication do not solve quality problems*" (Campanella 1999, p. XV). Traditional quality cost models can make companies only sub-optimizing their processes and in worst case, this will mean that quality improvements may reduce customer satisfaction (Moen 1998).

3.4 P-Diagram

Variation is expected rather than exceptional. Thereby, it is necessary to be robust enough to tackle variation. Bergman and Arvidsson (2009, p. 10) states that, *"The objective of Robust Design Methodology is to create insensitivity to existing sources of variation without the elimination of these sources".* In order to identify the potential insensitiveness, the product/process shall be visualised as a system with a defined input and output along with certain factors, which influence the system performance. This visualisation is referred to as the Parameter diagram or the P-Diagram. A simple P-diagram adapted from Phadke (1989) and Bergman and Arvidsson (2009) is illustrated below in Figure 9.

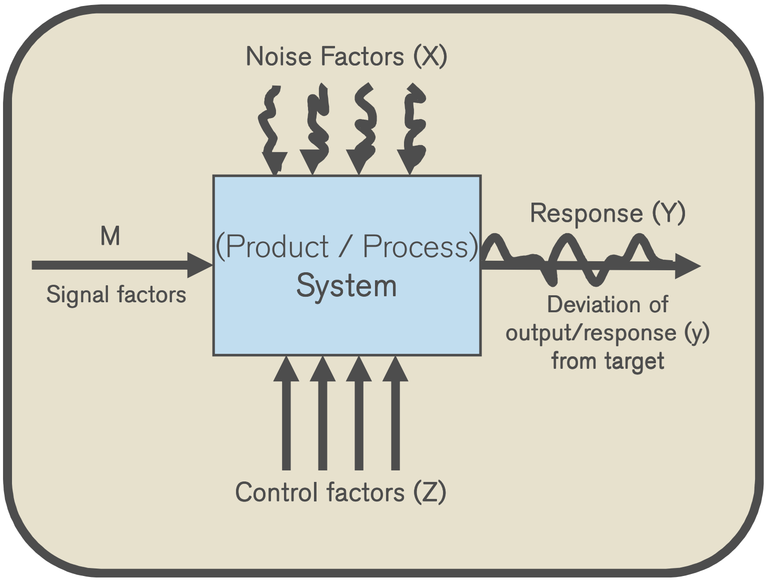

Figure 9, A simple P-diagram (Adapted from Phadke 1989 and Bergman and Arvidsson 2009)

As seen in Figure 9, there are four different variables that are linked to any product/process. The signal factors (M) are the input factors set by the user/operator in order to expect the desired output or response (Y). The noise factors (X) are certain parameters that cannot be controlled by a designer, as they are impossible or expensive to be controlled in the field. It is known that noise factors are difficult to control and therefore it is necessary that the products are robust against the noise factors. The last factor is the control factor (Z) which can be controlled by the designer to improve the product or process performance in order to make it insensitive to the variation. Thus, a P-diagram helps in understanding the various influences of a product/process by optimising the control factors and the input parameters in order minimise its sensitivity towards variation.

3.4.1 Variation and noise factors

Variation in the language of product variety is a characteristic of interest to customers when the variety of products delivered satisfies them. Unlike this case, unwanted variation in terms of the product characteristics should be avoided. Phadke (1989) states that a robust product or process is something that is insensitive to variation. Variation is the law of nature and in the real world; almost all products are exposed to different kinds of variation throughout their lifecycle (analogous signals in a medical equipment for instance). There will always be some deviation from the set target value. Similarly, no two customers utilise the product in the same way; no two environments in which a product is used are identical (Ross 1988, Watson & Watson 1994). Usually variation is perceived as the difference between the target value and the actual value. Juran and Godfrey (2000) visualise variation in this perspective and emphasise variability as the enemy of quality, which increases the unpredictability in the product performance. In addition, Hasenkamp, Arvidsson and Gremyr (2009) suggest awareness of variation, insensitivity to noise factors and continuous applicability as the three principles underlying Robust Design Methodology.

Improving quality in a product is often connected to reducing variation. However, in order to reduce variation awareness of variation must be created. Once the awareness is established, the next step is to try to create *"solutions that are insensitive to noise factors"* which is the goal of RDM (Hasenkamp, Arvidsson and Gremyr 2009, p. 650). Continuous applicability is the last principle, which means that RDM is not only applicable in early phases of a project, but rather in all phases of a project. Activities trying to stimulate the use in later phases are often not enough; efforts in early product development phases are also required.

Unwanted variation is caused by noise affecting the system. According to Clausing (1994), noise factors can be classified into three different categories: variations with respect to the conditions of the usage, variation in the production and variation due to deterioration. The first category of variation arises due to the customer's varied usage of the products in different environments. The second category of the variation is with respect to the factory where there can be a significant difference in the operating style between two operators. The last category of variation is due to the deterioration of the product characteristics over a period. Taguchi, Chowdhury and Wu (2005) have classified these noise factors as outer noise (for example temperature), inner noise (for example deterioration due to usage) and between-product noise (for example piece-to-piece variation between products). Phadke (1989) categorises the noise factors as external, unit to unit and deterioration. Davis (2006) sub-categorises noise factors as five different types under the main categories inner noise and outer noise. The sub-categories are:

- Variation of part characteristics due to production conditions → Piece to piece variation
- Variation of part characteristics over time in the field → Over time variation
- Customer duty cycles → Variation due to customer usage
- External environmental conditions induced by climate conditions and road inputs → Variation due to external environment
- Internal environmental conditions caused by complexity-induced interactions of neighbouring components → Variation due to interaction between systems

Clausing (1994) defines a failure as a variation from an ideal condition and operationalizes this via two modes of failure; they are soft failures (degradation of functional performance) and hard failures (complete ceasing of functioning). The variability or unwanted variation needs to be avoided or eliminated in order to sustain the robustness of a product/process. In order to overcome the problems of variability, Taguchi (1986) developed the on-line and off-line quality control methods; the design and production engineering department uses the off-line technique whereas, the production department uses the on-line technique.

3.5 On-line and Off-line quality control

Gremyr (2005a, p. 296) states that *"Noise factors are not always controllable or they might be too expensive to control".* Therefore, it would contribute towards improving the quality of the product, if the product/process could be made insensitive towards variation. According to Taguchi, Chowdhury and Taguchi (2000, p. 4), robustness is defined as *"the state where the technology, product, or process performance is* *minimally sensitive to factors causing variability either in the manufacturing or user's environment and aging at the lowest unit manufacturing cost".* In order to handle variation during product development and production, Taguchi, Chowdhury and Wu (2005) and Taguchi (1986) recommend two main ways of handling variation, classified as on-line quality control and off-line quality control activity. As stated in Gremyr (2005b), on-line activities refers to the countermeasures against the noise factors applied in production or manufacturing of products and off-line activities on the other hand refers to the efforts taken in during the design of the products and processes.

Table 2, Off-Line and On-Line Quality Control as countermeasures against noise (Taguchi, 1986) (Adapted from Arvidsson and Gremyr 2005)

Department Countermeasures			Types of Noise		
			External	Internal	Unit-to-Unit
Off-Line Quality Control	Research & Development	System Design	●	●	●
		Parameter Design	●	●	●
		Tolerance Design	O	●	●
	Production Engineering	System Design	X	X	●
		Parameter Design	X	X	●
		Tolerance Design	X	X	●
On-Line Quality Control	Production Engineering	System Design	X	X	●
		Parameter Design	X	X	●
		Tolerance Design	X	X	●
	Customer Relations	After-sales Service	X	X	X

● = Possible; o = Possible, but should be a last resort; x = Impossible

Arvidsson and Gremyr (2008) address that, these different approaches of quality control vary in their ability to create robustness against different categories of the noise factors. In Table 2 above, Taguchi (1986) proposed a three-step design procedure for the development of robust products where the primary objective is to reduce the effect of the noise factors. The three steps are system design, parameter design and tolerance design. Lönnqvist (2009) states that, off-line quality control techniques offers a way of thinking about the emergence of failures, provided an acceptable system design is available, as a result of the noise factor influence. Taguchi (1986) suggests that, the most important means of reducing the effects of noise factors is design and identifies design as an inherent aspect of off-line quality control. According to the description in Taguchi (1986),

- *System Design* is a high-level stage where the different concepts and technology are considered at different levels.

- *Parameter Design* aims at determining the appropriate level of the individual system parameters in order to reduce the effect of the noise factors on the output characteristics.

- *Tolerance Design* is the last step in the Taguchi's three-step procedure and emphasises the importance of close tolerance setting for noise factors having a great influence on the system.

It is apparent from the discussions above that unwanted variation contributes to higher costs and customer dissatisfaction. Therefore, it is necessary to control variation or somehow make the product robust against noise factor influence.

3.6 Variation Mode and Effect Analysis

Six Sigma methodology uses Statistical Process Control (SPC) to monitor the variation in production. Similarly, Robust Design Methodology (RDM) focuses on making the products insensitive to noise factors arising in production or during usage (Chakhunashvili et al. 2009). Engineers use FMEA to identify the potential failure modes and investigate their causes to determine their effects on the customer. However, the failure itself is often caused by variation.

The Variation Mode Effect Analysis (VMEA) is a method aimed at guiding engineers to find critical areas in terms of the effects of unwanted variation (Johannesson et al. 2012). The VMEA method starts with the identification of the critical/key product characteristics (KPC) where their variation affects the product function largely. Chakhunashvili et al. (2009) demonstrates the evaluation using the VMEA method in a general four-step procedure starting from,

- KPC causal breakdown – KPC broken down into sub-KPCs and Noise Factors (NFs) affecting the sub-KPCs.

- Sensitivity assessment – The sensitivity of the KPCs for the action of the sub-KPCs $(\boldsymbol{\alpha_i}^2)$ and the sensitivity of the sub-KPCs for the action of NFs $(\boldsymbol{\alpha_{ij}}^2)$ is assessed.

- Variation size assessment – The Noise Factors (NFs) are examined and their size of variation is assessed $(\boldsymbol{\sigma_{ij}}^2)$.

- Variation Risk Assessment and Prioritisation (VRPN) – The VRPN similar to that calculated in a FMEA (Risk Priority Number, RPN) is calculated for each noise factor based upon the above assessments.

The VRPN value is calculated using the formula,

$$VRPN_{NF} = (\boldsymbol{\alpha_i}^2) * (\boldsymbol{\alpha_{ij}}^2) * (\boldsymbol{\sigma_{ij}}^2)$$

If a sub-KPC is influenced by several noise factors, it is possible to calculate the VRPN relative to the sub-KPC in interest as a sum of the VRPNs for each NF acting on that sub-KPC.

$$VRPN_{\text{Sub-KPC}} = \sum VRPN_{NF}$$

A VMEA table is presented in Table 3 below for reference.

Table 3, An adapted VMEA table from Chakhunashvili et al. (2009)

KPC	Sub-KPC	KPC sensitivity to sub-KPC	Noise factor (NF)	Sub-KPC sensitivity to NF	NF variation size	VRPN (NF)	VRPN (sub-KPC)
Diagonal, Y	Length, X1	4	N11	5	8	25,600	25,600
	Width X2	3	N21	5	7	11,025	11,025

As can be seen, it is important to find the KPCs, but this is not always easy. In order to find them, it is vital to understand what the objective of the organisation is and what measurements are important.

3.7 Performance measurements

Today's business people are working towards less reliance on feelings and more on facts, thus there is often a focus on knowledge management (del-Rey-Chamorro et al. 2003). This adds a complexity to techniques like quality management that are already used by many organisations. Since knowledge is an intangible asset, it is hard to measure the performance of a knowledge management solution. Bohn (1994, p. 2) says that "*knowledge allows the making of predictions, casual associations, or prescriptive decisions about what to do*" and he continues to say that better performance can be achieved if better knowledge of key variables are collected.

Hence, there is a need of performance measurements to get a stronger focus on goals and performance and allocate appropriate resources to reach the predefined goals (Franceschini, Galetto and Maisano 2007). Nevertheless, it will also improve communication between both internal and external stakeholders and helps when it comes to justify changes because of the good visualisation with performance measurements (Franceschini, Galetto and Maisano 2007, Fortuin 1988).

Muckler and Seven (1992, p. 441) reminds that, "*All the measurements in science and technology is necessarily filled with subjective elements, whether in selecting measures or in collecting, analysing, or interpreting data*". In addition, in order to measure something subjective, an organisation cannot always aim for perfect measures (Walsh 2005). Walsh (2005) has found six constraints that make it hard to find the perfect measures. First of all, collecting data for a survey will take a lot of time and organisations have to be careful using surveys because of this, even though they can be good instruments for performance measuring. Data can sometimes also be infrequent, yearly for example, and managers cannot wait to make decisions once a year, which is the second constraint. Thirdly, big investments in developing a tool for evaluation can sometimes be a problem when measuring intangible assets. The fourth constraint is that organisations sometimes do not want to record data, because unwanted events can have occurred such as frauds or fines. As a fifth constraint, Walsh (2005) has presented an example where he says that if sales are not meeting their targets because the company is trying to sell a not so good product, how much should Research and Development (R&D) and Manufacturing be blamed for this problem? The last constraint presented is when data has to be gathered manually, it can become a big obstacle just to create a report, which will probably result in a need of simplification of the measurements. Performance measurements are often divided into different indicators that will be explained further down. Indicators help to summarise data that a company is collecting (Franceschini, Galetto and Maisano 2007). The difference between a measurement and an indicator is that measurements are a sub-set of indicators, which means that a measurement is always an indicator while an indicator does not have to be a measurement.

3.7.1 Performance indicators

To make an organisation perform as desired, performance indicators (PI) is a great help (Parmenter 2007). The performance indicators are also useful in organisations that strive to have a "total quality control" (Fortuin 1988). Franceschini, Galetto and Maisano (2007) states that an indicator should make it possible to perform evaluations and comparisons by making a situation tangible. In order to do so, the PIs should be user-friendly which in this case means that they should be presented in a suitable way to show the information quickly (Fortuin 1988).

For a team to focus on their daily activities, performance indicators are good, but they do only complement key performance indicators (KPI), which are crucial for the business to work according to Parmenter (2007). Popova and Sharpanskykh (2010) agree on this and say that not all the performance indicators can be monitored because of the large amount of PIs, but rather only KPIs can be monitored. The KPIs should be a subset of indicators that represent all the PIs. Parmenter (2007) continues to say that for an organisation, around 10 KPIs and 80 PIs would be adequate and explains that the difference between the PIs and KPIs are that the former "tells you what to do", while the latter "tells you what to do to increase performance dramatically" (Parmenter 2007, p. 9). Fortuin (1988, p. 2) says, "*A Performance Indicator is a variable indicating the effectiveness and/or efficiency of a part or whole of the process or system against a given norm/target plan*". The PIs are also helping an organisation to innovate faster, because of helping in "doing things right the first time" (Fortuin 1988).

When an organisation is going to choose KPIs, they have to be careful, because the KPIs must represent both the PIs and the company goals (Popova and Sharpanskykh 2010). Key result indicators (KRI) are also used in most organisations and "tells you how you have done in a perspective" and these three measures are grouped as Performance Measurements (Parmenter 2007, p. 9). The relationships between KRIs, PIs and KPIs are described in Figure 10 below.

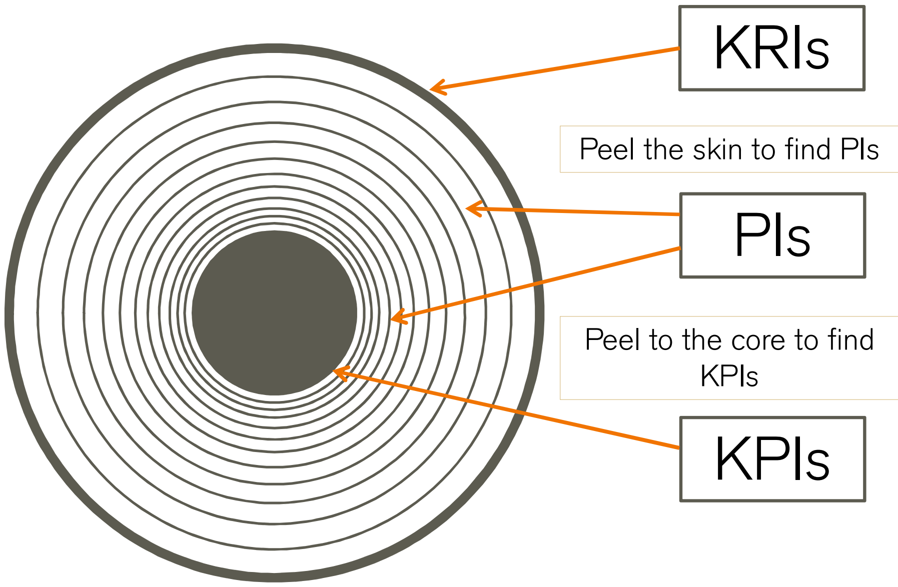

Figure 10, Three types of performance measurements (adapted from Parmenter 2007)

The UNI 11097 Standard suggests that indicators should be divided into three types, namely initial, intermediate and final indicators (Franceschini, Galetto and Maisano 2007). The initial indicators are measuring what the processes are capable of doing while the intermediate indicators are measuring the differences between the specifications and results. This in turn gives valuable information regarding the manufacturing compliance. Final indicators measure the final results from the process and could for example be customer satisfaction.

Indicators, independently of which type they are, can be classified in four ways (Franceschini, Galetto and Maisano 2007). Objective indicators are the first class and they should show the same result without depending on who has done it, for example how many units that have been produced during a specific time. Subjective indicators would be dependent on personal beliefs and an example is when trying to measure the design of a car. Direct observations are used for the third type of indicators, the basic indicators. The last type of indicators according to Franceschini, Galetto and

Maisano (2007) are the derived indicators that are a combination of different sources of information.

One more classification mentioned by Veleva and Ellenbecker (2001) is to divide indicators into core indicators and supplemental indicators. The core indicators can be used at any department or facility while the supplemental indicators vary between departments or facilities. However, standardised measurements should be strived for and used as much as possible instead of having supplemental indicators. This could also help the organisation to have better performance measurements (Veleva and Ellenbecker 2001).

Not always are the indicators used in an organisation equally important though (Franceschini, Galetto and Maisano 2007). In such a case, weights could be adopted to the different indicators. However, these weights cannot be found by calculating, instead they have to be set by people with knowledge of the indicators, which means that the weights used are set subjectively. The indicators could also be ranked by having a scale and three scales mentioned are 1-3-9, 1-3-5 and 1-5-9 (Franceschini, Galetto and Maisano 2007). Four different types of scales could be used, namely nominal, ordinal, interval and ratio scales (Pavan and Todeschini 2008). Nominal scales are only using numbers to separate the measurements while ordinal scales use the numbers to decide greater, less or equal. Interval scale also takes into consideration the size of the interval between the numbers used in the measurement. The last scale is the ratio scale, which is used when the ratio between two measurements also needs to be taken into consideration. However, the only difference between the interval and ratio scale are that the number zero is natural in a ratio scale (as in a Kelvin scale) while the zero is decided in an interval scale. Non-parametric methods usually use nominal or ordinal scales and parametric methods usually use interval or ratio scales (Pavan and Todeschini 2008).

When the performance measurements have been set, they should also be tested. One method, developed at the University of California in 1998, is the SMART test and another is the three criteria test, developed by Performance-Based Management Special Interest Group in 2001. The SMART test uses five criteria, which are (Franceschini, Galetto and Maisano 2007):

- S (Specific): The measurement should be easy to interpret and have a focus to avoid misinterpretations.

- M (Measurable): The indicators should be available to use for statistical analysis and be comparable.

- A (Attainable): Is it possible to reach the goal of the measurement and is it a reliable measurement?

- R (Realistic): Are the indicators measuring the limitations of the company?

- T (Timely): Do the measurements take too much time to complete?

The Three criteria test starts with strategic criteria, which checks if the measurements are aligned with the strategic work of the organisation and if the measurements help prioritise what is the most critical problem at any time (Artley and Stroh 2001). Quantitative criteria is the second test and tells you if the measurements help in finding gaps between what the process outcomes really look like and what was the intention of the process. Thirdly, the qualitative criteria assesses if the people using the measurements perceive them as useful.

Performance measurement systems must be continuously checked so that they are in line with the organisational goals and if possible, the system should be improved (Franceschini, Galetto and Maisano 2007). Some of the main components in a performance measurement system are the stakeholder needs, changes in the organisational context and new standards and regulations. However, it is often easier said than done to do changes when they are needed, therefore it is of great importance to understand what changes demand in terms of organisation learning. Franceschini, Galetto and Maisano (2007) and Parmenter (2007) also say that in order to have a well-functioning performance measurement system, it is important to be clear who should collect data for the system and to whom the data should be delivered. It should also be clear who is the owner of the performance measurement (Kuwaiti, 2004). In past literature, it has been mentioned that information technology, human resources, financial managers or the user should be the owner, but Kuwaiti (2004) has found that a performance measurement should be owned by a new post.

When a performance measurement system is set up in an organisation, it is also important to have a database where all data regarding the performance indicators are stored (Parmenter 2007). In this database it should be stated where data should be gathered from and who is responsible of gathering this data. In addition, how often the indicators should be measured and how the indicators should be calculated, should also be stated in the database (Parmenter 2007).

3.8 Organisational Learning and Change

During the last 20 years, the number of significant changes in organisations has grown immensely (Kotter 1996, By 2005). Organisations will be more and more pushed to do changes in reducing cost and improving quality while they at the same time have to improve productivity (Kotter 1996). Changes made in organisations are often triggered by a discussion where the problem is that people have not done their jobs right in the first place (Weick and Quinn 1999). For some organisations, these changes have helped them to be able to handle upcoming and future difficulties, but this is not the case for everyone. Many changes end up in a disaster with frustrated, scared or even burned-out employees because of disappointing improvements, which means wasted resources (Kotter 1996).

Two different types of changes common in organisations are; episodic changes and continuous changes (Weick and Quinn 1999). The episodic changes on one hand are characterised by its distinct time periods when the change is supposed to be done. An episodic change is an interruption from the ordinary state of the organisation and is infrequent. It is also often driven externally. The continuous changes on the other hand are changes that never stop to evolve or are always on going. It is a change with endless modifications and is driven by the organisation itself.

Weick and Quinn (1999) state that even though Lewin's three stages of change was made public in 1951, it is still a model that works in general for organisational development and is used by many other researchers. The first stage is to unfreeze the current state, which actually means that a motivation to change has to be created. In the second stage, the actual change is taking part. In this stage, information is used to decide how the change should be performed and what the outcome of the change should be in order to know in what direction to head. When the change is made, the third and last stage, refreezing has to be done. This is to stabilise and integrate the changes (Burke, Lake and Paine 2008).

Nadler and Tushman (1997) have a similar model, also with three steps. They start to say that an organisation is found in a current state A at any time. However, in order to do a change in the best way possible, the organisation must have a good idea about what they want to achieve in the future state B. Between the current state and the future state, the company will be in a transition state (C). When comparing Lewin's model with Nadler and Tushman's model, both seem to cover the same aspects of changes.

When implementing organisational changes, organisations could face some problems. The failure rate of organisational changes is as high as 70 % (By 2005). The two most basic issues are what the changes should be and how these changes should be implemented (Nadler and Tushman 1997). Nadler and Tushman (1997) continue to say that whenever a major change is made in an organisation, three problems will occur.

The first problem is the problem of power, which is related to if the balance of power in some way could be disrupted between formal or informal groups or parties (Nadler and Tushman 1997). The problem of anxiety is the second problem that is faced (Nadler and Tushman 1997). This since whenever a change is made the situation is going from a situation that is known to a situation that is unknown. Anxiety and stress could of course be created out of the changes since no one really knows what is behind the corner. At last is the problem of organisational control (Nadler and Tushman 1997). When a change is made, the management will often have control before and after the change since they are steady states, but during the change, there will be a lack of management control. This is because management systems are not made to be used during transitions (Nadler and Tushman 1997).

Another problem presented by Sirkin, Keenan and Jackson (2005) and Waddell and Sohal (1998) is the problem of resistance. People are not against changes *per se*; rather the resistance is connected to the outcome of the change (Waddell and Sohal 1998). Sirkin, Keenan and Jackson (2005) even say that middle managers are willing to ignore the problem of anxiety and take on extra work, trying to help in the changing. However, the middle managers can be resistant against changes because no sufficient ways of communicating the change initiative to their employees exists.

3.8.1 Common mistakes

Kotter (1996) continues to say that eight common mistakes are done repeatedly by organisations that are failing with changes and that if organisations are aware of these mistakes they are avoidable. The first and biggest mistake is to allow too much complacency and this is a fatal mistake. If too much complacency is allowed, transformations always fail to reach the goals.

Next mistake is failing to create a sufficiently powerful guiding coalition with people that are dedicated in implementing the change. Kotter (1996) says that it is about not only having a CEO (Chief Executive Officer) or head of the organisation that is an active supporter, but in successful transformations, people on lower levels like department heads, division managers are also actively supporting the transformation. Fortuin (1988) is content with only saying that top management is important when implementing performance indicators. Alänge and Steiber (2009) say that the time for organisational change is often longer than the time top managers stay in the company. There is a great risk that the changes that have started with one CEO fail to be implemented in case of a new CEO in the middle of the process.

Argyris (1999) argues that in order to make everyone involved in the change, not only do the people in the company have to understand what is wrong in the organisation, but they also have to understand what is wrong with their own situation. Deming (2000) in his 14 points for management mention that, many problems arise because the people are ignorant of what is right. If it is not clear what the focus should be on, and what the outcome will be of it, it is harder to avoid making mistakes. Deming (2000) suggests that, the management should identify the need for education and training for employees to support their development. In addition, Wetlaufer (1999) suggest that in order to change the fundamental way of working, the DNA of the company needs to be changed and the best way to do that is through education and training. In addition, Deming (2000) among his 14 points for management insists the importance of breaking down the barriers between the departments, which is necessary to have a better communication between the different departments thus supporting a change.

The third and fourth mistake presented by Kotter (1996) is underestimating the power of vision and undercommunicating the vision. Without a vision, it is hard for the employees to see the direction, where they are supposed to go with the change. It has to be clear for the employees what the change is leading to, otherwise it does not matter how many goals, milestones and methods are presented.

In addition, without a good communication, and a lot of communication, it will be hard to capture all employees (Kotter 1996). Communication is not only about words and presentations; it is rather actions, which is a more powerful form. In addition, Nadler and Tushman (1997) say that communication is of importance to reach all employees with the change ideas and the communication should be made through several different channels of communication.

Mistake five in Kotter's (1996) list is permitting obstacles to block the new vision. The obstacle could be the organisational structure where for example compensational systems could force the employees to choose between their self-interests and the new vision.

The sixth mistake is when failing to create short-term wins and this is since transformations always take time and there is a risk of losing momentum if no short-term goals are met, which gives a chance to celebrate for the moment (Kotter 1996). People can also be tempted to declare victory too soon, which is the seventh mistake. While a temporary celebration is allowed, it is not allowed to relax and not continue to contribute in the transformation. It can take between three to ten years before changes are rooted in the culture of the company (Kotter 1996).

Mistake number eight, neglecting to anchor changes firmly in the corporate culture relates to the final step of the transformation process (Kotter 1996). When everybody sees the change as "the way we do things around here", the transformation process is done (Kotter 1996, p. 14). It is vital to show people how this change has improved performance and that management personify this change and the change is well incorporated with the rest of the company.

4 RESULTS

This chapter presents the findings from the interviews and internal documents. The interviews and internal documents have been a source when understanding the history of the Robust Index tool. When understanding the evolution of the robustness evaluation at Volvo Cars, interviews were the main source of information. The views of the interviewees were analysed in three categories: Perception, practice and the tool.

4.1 History of Robust Index

The Manufacturing Operations Review (MOR) is a meeting headed by the top management at Volvo Car Corporation where decisions are made on key issues (issues that are critical to solve). During the year 2005/2006, there were many delivery issues of complete cars in the factory. This was due to the variations of the incoming material and lack of predetermined prerequisites and procedures to measure the products and processes. In every product and production process project, dilemmas related to un-robust designs existed and could vary from a-pillar panels that were sensitive to dirt, to paints that were easy to scratch. This un-robustness created problems in all the phases of the car project ending up in launch problems and finally resulted in customer concerns. After this, a debate started in production regarding the variations and led to the introduction of the term "Robustness" in the company.[1]

In 2006, the initiative to start working with robustness began to speed up. The Quality Core Manager at TVQ became responsible for this issue after a decision on VCC level to become more robust in the future. After this decision, it was a big pressure from the CEO to deliver a process, which could improve the results. However, robustness was a new term for the employees at VCC. Before introducing a new process/procedure to measure robustness, a change of mind-set was necessary to become upstream and proactive regarding the development of robustness of the product and production process, and the verification of it across the projects. This

[1] Anders Ortmon, Interview, 2012-02-27

created a necessity to develop a visual mapping of the system in order to understand the areas of insensitivity and increase the cross-functional way of working.[1]

4.1.1 Timeline of robust index

The first version of the robust index matrix released in 2007, was basic and based on a cause and effect matrix. The evaluation in the matrix was carried out to measure the product/process with respect to three different aspects, which are:

i. *Voice of the System (VOS)* – VOS refers to the design of the system or more of a theoretical evaluation measured out of experience along four different criteria. They are material, machine, method and milieu. These four criteria together referred as the 4M(s). In simple terms, VOS measures the actual product/process against the specifications set earlier.

ii. *Voice of the Factory (VOF)* – VOF refers to the measurement of the product/process at the factory level such as measuring the quality, cost and delivery aspects with respect to the factory target settings. Some of the errors measured in production would include extra inspection/repair work, speed loss at the assembly line. They utilise data both from running production and as well as from the audit findings.

iii. *Voice of the Customer (VOC)* – VOC refers to the evaluation of the customer's opinions and issues. The VOC is measured with respect to environment, safety, perceived quality, convenience, driving experience etc. Some of the errors that would be accounted include audit findings, warranty costs and sales losses. The Voice of the Customer is measured to understand the customers' problems and opinions.

In each of these aspects an ideal function along with error states are established. To measure if the product has an ideal function or an error state, the product is assessed with respect to certain criteria and requirements that are used in the RIM. The requirements were developed with the help of a P-diagram and an example of a requirement in the method criterion would be, *K1: The parts must be guided to correct position first time, self-setting by design. No fixtures allowed to reach final position. (PLUG-IN).*

In Figure 11 below, VCCs robust design process is shown, which is a broad view of VCCs way of working with robust design (Ortmon 2007).

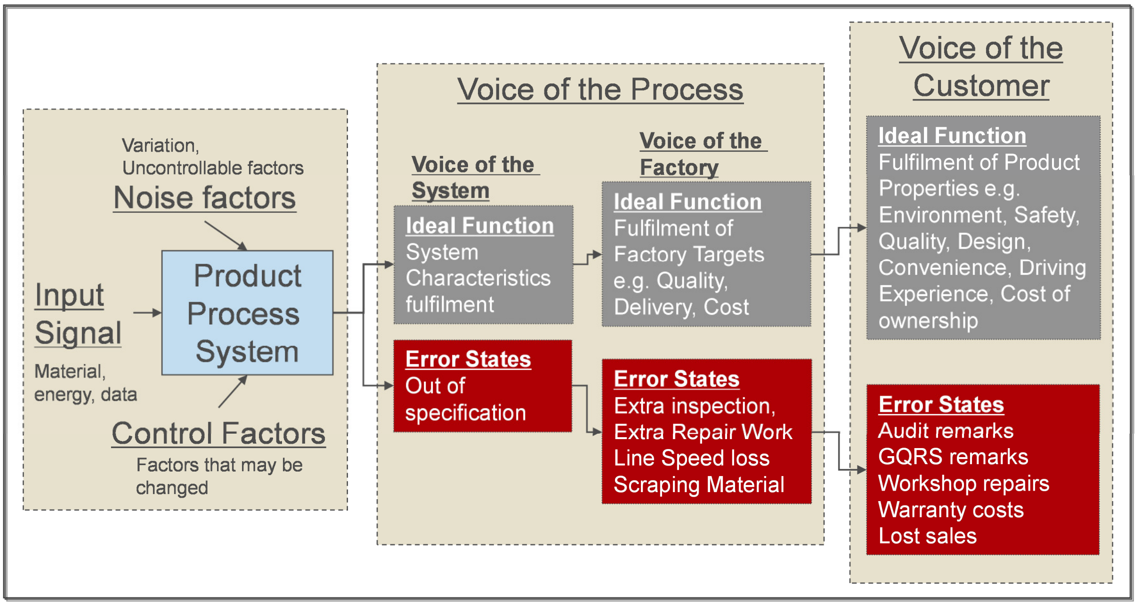

Figure 11, The robust design process in Volvo Cars (Ortmon 2007)

One discussion about the first model was the scale of measurement part of the matrix. In the matrix, a scale between 0-9 was used where 0 meant totally robust and 9 meant very un-robust. The original scale also limited the steps to 0, 1, 3 and 9. The higher the numbers are, the more non-conformances found on that part. Instead of using this scale only in Voice of the System, as is done today, the first matrix had similar numbers on Voice of the Factory and Voice of the Customer, even though it was not applicable. This since it would become subjective to put a number like 3 or 9 on for example the number of cars that did not pass a station FTT (First Time Through), instead of using the actual number of cars that did not pass at this station.

In autumn 2009, the matrix was updated and instead of the earlier scale of measurement for Voice of the Factory and Voice of the Customer, numbers of defects per million opportunities (DPMO) directly from the factory and number of warranty claims for a specific part could be used. This was because of the much better flow of information from the factory to VCME where ATACQ (Answers To All

Car Questions) and audit numbers could be found easily. At this time, there was also a change of name of the tool from un-robust index to robust index.[1]

When the Robust Index was introduced, quality engineers were both owners of the tool and responsible of filling in the number in the RIM. Today, only the method itself is still owned by the TVQ department. Instead, core engineers in each of the different departments (Paint, Trim & Final, Body, etc.) are responsible to fill in the numbers in the RIM and to call for meetings regarding robustness issues. To make it easy for all engineers to find the RIM, it is placed in the Business Management System (BMS), used inside Volvo Cars. All tools and systems used in Volvo Cars should be placed in the BMS with descriptions of each tool and system. Together with the core engineers, quality engineers, commodity engineers and resident manufacturing engineers are the ones that are working with robust index. Core engineers are responsible for the concept phase, commodity engineers are responsible for the development phase and resident manufacturing engineers are working with the running production. In all of the different departments, core-, commodity- and resident manufacturing engineers are present. The RI values for each car model in the RIM should be updated annually in order to monitor changes in robustness over years. For future models, the RIM is also used and benchmarked against previous comparable models.[1]

To understand how the tool was developed from the initial level until it was ready to be used is illustrated in Figure 12 below. The figure illustrates the road map of the creation and implementation of robust metrics, cost of poor quality etc. As can be seen in the figure, the creation of robust metrics should have been done in 2007 together with robust evaluations of current models at that time, which were done. In the same year, TVQ wanted to start collecting the Voice of the Factory and the Voice of the Customers, but not until now, in 2012, TVQ started to collect data for Voice of the Factory and only as a pilot project. During this time, there has been an extensive work with robustness and it has been implemented in the VCC cycle plan, which is the road map for all new car models. The criteria used in the RIM have also evolved during this time and the current version of RIM is the third version. A similar road map as Figure 12 below exists through 2015 as well (Ortmon 2007).

[1] Anders Ortmon, Interview, 2012-02-27

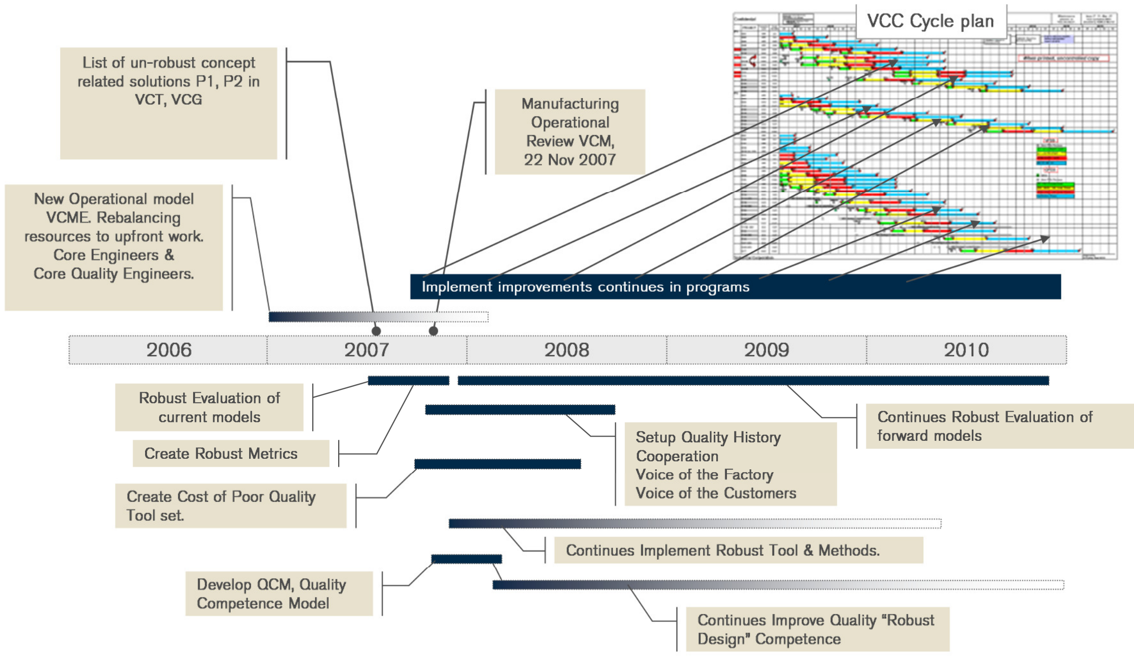

Figure 12, Quality road map; progress and highlights 2006-2010 (Ortmon 2007)

4.2 Explanation of the Robust Index Matrix

Ideally, the time between the creations of the failure mode and adoption of the suggested countermeasure should be as short as possible, as illustrated in Figure 13 below (FMC documents cited in Ortmon 2007). This is required in order to reduce the cost and number of people involved in developing counter-measures. If the failure mode is discovered late, it will cause many changes or counter-measures. If some of the counter-measures do not work, there is a big risk that some failure-modes will not be fixed before launch of the product and escape into the field. Moreover, it is harder to fix failure-modes in the later stages of the engineering phases and efforts are put into a design that is not as good as it could have been. Instead, more time could be placed on other projects if the counter-measures are implemented early, which will create a positive chain reaction, since the counter-measures could be implemented earlier in the other projects as well (FMC documents cited in Ortmon 2007).

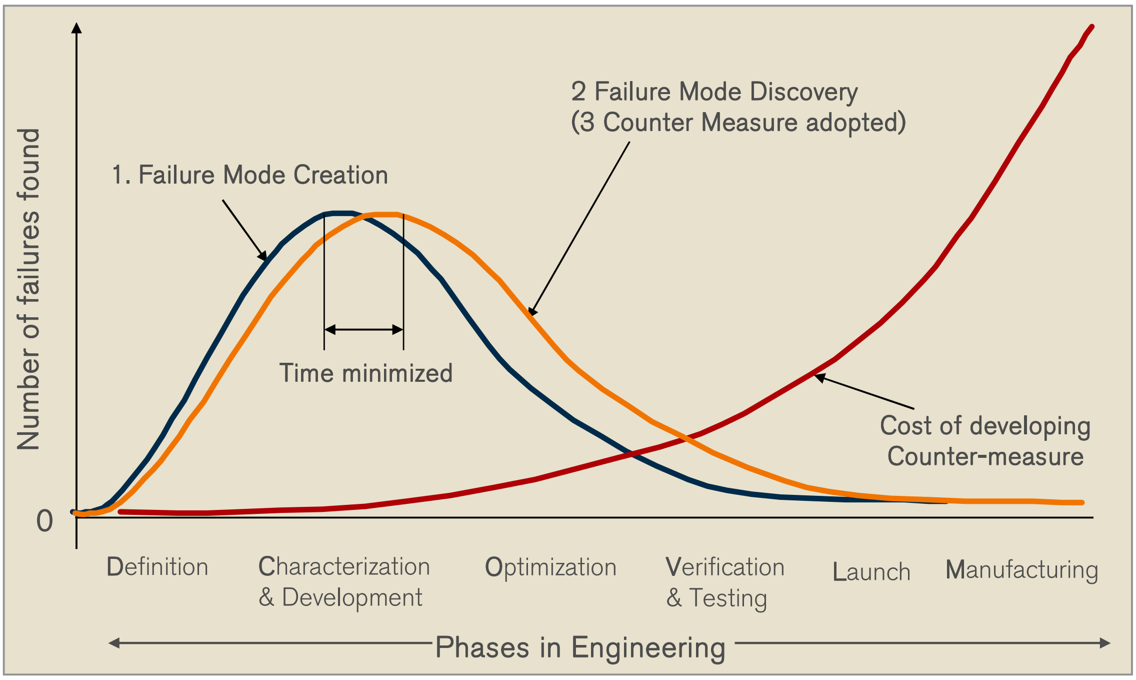

Figure 13, Ideal state of engineering activity (adapted from internal FMC document, cited in Ortmon 2007)

Volvo Cars' goal is to reach this ideal engineering activity and as one way to achieve that, the Robust Index was created back in 2007 (Ortmon 2011). The RIM is a tool focusing on identifying the sensitivity of a system against pre-defined variations. The sensitivity varies from being a fully robust system to being an extensively un-robust system. The purpose of this tool was to evaluate the fulfilment of the product/process systems characteristics towards the manufacturing 4M, the fulfilment of factory targets such as Quality, Cost, Delivery etc. and fulfilment against the customer in terms of design, safety, environment etc.

The first version of the Robust Index Matrix was an Excel based tool that can be seen in Figure 14 below, where the calculations for how the Robust Index value for each car model and component are shown (Carlen 2008). The Robust Index value is set for each of the 4M's based on how many requirements that are fulfilled in each of the 4M. These requirements are set in advance and in the first template, the same requirements were used for all departments. Depending on how many of the requirements that are not fulfilled, it will generate a number of how robust the product or process is. In the first template, the generated number was 0 or 1 or 3 or 9. The number that came out of the 4M's were then calculated together as a sum, but the 4Ms were not equally weighted, for example, Method was four times as important as the environmental aspect. What the weight figures should be was decided at a meeting with managers before the tool was launched. Among the four criteria discussed during the meetings, the Method was considered the most important criterion. These discussions ended up in proposing the weight figures that are still used today.[1]

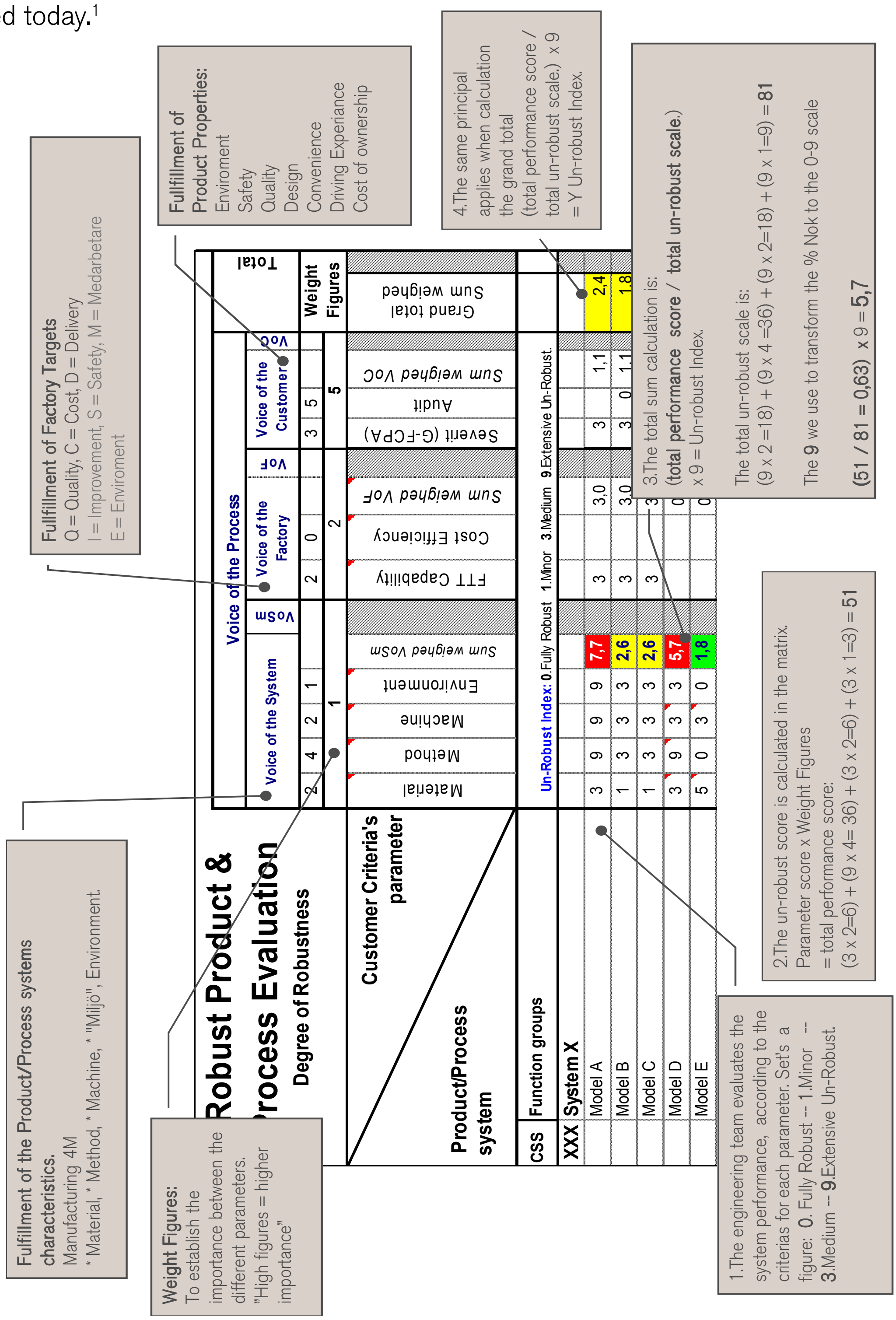

Figure 14, First version of Robust Index Matrix (Carlen 2008)

[1] Anders Ortmon, Interview, 2012-02-27

The robust index number were in the first template also set for Voice of the Factory and Voice of the Customer as can be seen above in Figure 14. One problem with this was that even though the robust index numbers had been specified in advance corresponding to a specific interval of cars that did not make it through the FTT station as an example, it could be interpreted in different ways by different people. For some persons a number 3 could be seen as a good number, but remember that 3 is the second highest number that could be scored in the first version of RIM, which meant medium in un-robustness. In addition, the RI numbers in Voice of the Customer were chosen in the same way as in Voice of the Factory. The sum from the Voice of the System, Factory and Customer was then calculated together, which gave a grand total sum of robustness for one product or process.

The persons doing the evaluation of the components in the RIM must bring papers with the requirements for each of the 4Ms and a paper on how to calculate the robust index number depending on how many requirements that are not fulfilled. Alternatively, they can check this in the template, but it would be tedious, especially if many persons are watching the same template. In addition, the persons doing the evaluation also have to keep track of how many requirements that are not fulfilled.

In the on-going pilot project at Volvo Cars, a new template has been created but is still an Excel-based tool. The 4M's are calculated in the same way as before, but the scale is now 0, 1, 3, 5 and 9. These numbers are once again calculated into a sum, but when looking at the Voice of the Factory and – Customer, the robustness numbers have been replaced. Instead, numbers that can be collected manually directly from each of the different measurement systems, for example ATACQ, are used as can be seen below in Figure 15. However, there are discussions about using the scale also in Voice of the Factory and Voice of the Customer, as in the first version seen in Figure 14 above, but no decisions are taken regarding what arrangement to use. If the scale would be used, it would be with strict intervals that should correspond to a specific RI number, which should not allow the user to take any decisions on what RI number should be used.

Robust Product & Process Evaluation Manufacturing (Producibility) Degree of Robustness			Voice of the Process																VCME Manufacturing Engineering 81000 Area: Review date. Responsible name:
			Voice of the System					Voice of the Factory						Voice of the Customer					
			Base car					MY12						MY12					
		Customer Criteria's parameter	Material	Method	Machine	Environment	*Sum weighed VoSm*	Atacq (R/1000)	Audit running (R/1000)	Audit (baseline) (R/1000)	TPKI (in-line)	Concept adjustments	Scrap	ECB					
XX	System X	Average	6,8	1,3	3,9	0	3,0												
		A					0,0												
		B					0,0												
		C					0,0												
		D	9	3	5	0	4,4												
		E	5	0	3	0	1,8												
		F	5	0	3	0	1,8												
		G	5	0	3	0	1,8												
		H	5	0	3	0	1,8	25	13	0	0	0		2					
		I	9	3	5	0	4,4	27	0	0	1	0		0					
		J	9	3	5	0	4,4	30	8	0	1	0		5					
		K	9	3	5	0	4,4	31	5	0	1	0		0					
		L	5	0	3	0	1,8	40	28	456	0	0		2					
		M					0,0												

Figure 15, Latest template of Robust Index Matrix (internal document)

4.3 View of Robust Index tool

To understand the current situation of the Robust Index tool, semi-structured interviews with 22 people in the Manufacturing Engineering unit were conducted. In order to get a better understanding and identify the interviewees' opinions, the results of the interviews were clustered into ten different elements. Based on a thematic analysis of the data collected the elements were then categorised into three categories: perception, practice and tool. The structure used in this study is shown below in Figure 16.

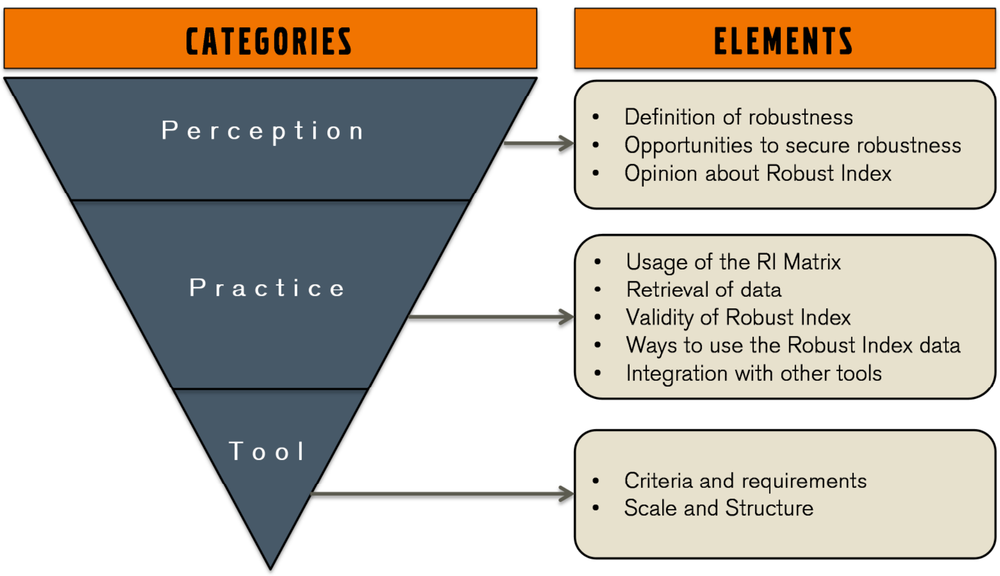

Figure 16, Structure of findings based on a clustering of the results

4.3.1 Perception

The interviewees were asked about their definition of robustness and more general questions of the robust index tool, such as their opinion about the robust index and how robustness can be secured in the manufacturing.

Definition of robustness

In order to understand if robustness is a rooted term in the organisation, it was vital to ask the interviewees what their definition of robustness was. What could be interpreted from the interviews was that practically all of the interviewees gave the same definition. Even though the definition differed slightly between the interviewees, the main words were that robustness means that a product or process is insensitive to variations. This was by some people not only meant to regard the manufacturing and process itself, but also that the product should withstand variations when customers place it in tough conditions. Some even further extended the above definition by stating that, the variations are permissible but can be restricted within their tolerance zone. However, in order to understand how to reduce variation, robustness should help in understanding the noise factors and how these can be controlled according to some interviewees.

Robustness was by many interviewees also seen as an instruction or guideline that does not allow any mistakes and some connected robustness with Design For Assembly (DFA). The interviewees saw robustness as a tool that can help the product or process not to deviate from the set conditions. One interviewee said that robustness is,

"A fool-proof procedure that makes it impossible to assemble wrongly"

Another interviewee put forward that robustness was perceived as linked to the Six Sigma framework, as both Six Sigma and Robust Design Methodology deal with reduction of variation. The interviewee related the thinking with Six Sigma methodology and stated that robustness is *"something that is connected with Six Sigma in the course of reducing variations"*. Six Sigma and other quality tools such as FMEA and Control Plans are all connected to robustness in some way, which was shown when the interviewees were asked how robustness could be secured in the organisation.

Opportunities to secure robustness

Not only Robust Index is used for securing the robustness of the products and processes in Volvo Cars. In addition, quality tools such as FMEA, Six Sigma and Control Plans are used to secure robustness, especially in the departments where Robust Index is used at a minimum or not at all. Teamcenter, which is a software used at Volvo Cars, is also used for securing robustness. In this software, requirements can be set for different projects. FMEA together with the Teamcenter requirements have functioned as basis to secure robustness. One interviewee said,

"We have not been using Robust Index, instead FMEA have been used to secure robustness"

In addition, knowledge from earlier programs is important and should be collected in what Volvo Cars call Lessons Learned. In Lessons Learned, lessons from old projects are collected to make it easy to see what can be improved in the next projects. One interviewee said that it is important to use Lessons Learned, but it is not working perfectly and it has to be even further improved. Another possibility according to the same interviewee is to learn from Volvo Cars' suppliers and see in what ways they are working and the suppliers can show what is possible in terms of measurement etc.

A better communication has been said earlier to be good for the robustness work in general, but there are improvements that can be made. The cross-functional way of working should be improved according to some people. For example, one suggestion from one interviewee was that managers should attend meetings regarding robustness more than they are doing today. The problem now, according to the interviewee, is that managers are just looking into the Robust Index Matrix and the data inside, without having the knowledge about why the numbers look like they do.

More job rotation was also a suggestion by another interviewee, so people do not stay too long in the same working position. This would help the engineers thinking in the same way. Some interviewees have expressed that there is a big difference in the way of using Robust Index between core and commodity engineers. An example mentioned by one interviewee was that a core engineer could benefit from becoming a commodity engineer for some time and vice versa.

Some interviewees also mention continuous improvements as a way of securing robustness and a connection to this is the possibility of updating the data in the Robust Index Matrix. In one department, the Robust Index Matrix numbers are updated whenever an issue arises according to one interviewee. These kinds of issues could for example be when a concept turns out to not be useful and another concept has to be used instead, which has not been evaluated with the RIM earlier. Since the securing of robustness differs between the departments, the next step is to understand the opinion of Robust Index.

Opinion about Robust Index

The opinions about the tool were broad in the sense that almost all interviewees had their own opinion about the Robust Index. Nevertheless, some common opinions could be found when the interviews were compared. For example, almost all said that the RIM as it is right now is very time consuming and that it takes a lot of administration just to use the tool One interviewee mentioned that only one component of a car model in the RIM could take up to ten minutes to fill in. The same interviewee also showed that there could be around 500 rows to fill in for one department, which makes this a prolonged process. Instead, the tool has to be easier to fill in and less time-consuming. Another opinion from the interviewees was that the RIM is a good tool for communication purposes. For example, it has become easier for manufacturing engineers to present un-robust solutions, which also was confirmed by one interviewee that said,

"It is a good tool with graphs to communicate with R&D"

It has been mentioned several times that the RIM is especially good to use when manufacturing engineers want to influence R&D to do changes to create a more robust solution. Similarly, another interviewee mentioned that, *"It is a good way of measuring robustness and lifting up the parameter may show results in a good way"*. The numbers from the RIM are also given early in the projects, which is seen as positive by many interviewees.

A need to have a standardised tool was also mentioned by several interviewees, in order to have everybody using Robust Index in the same way. What they meant with these comments was that the template and requirements should be as similar as possible between the departments. This would also make it easier to understand what a department has done in their RIM. Some interviewees also mentioned that there is a necessity of having some prior knowledge and training before starting to work with the tool. This since each person would see things in different ways and evaluate with their own understandings, since no training regarding RI exist today.

In addition, one of the interviewees mentioned that, *"It is necessary to update the reference values regularly in order to secure validity of the measurement. It is necessary to check the base values at least".* This should be done since some interviewees mentioned that when a new project starts, it will always be a reference model and the numbers in the RIM of the reference model could be several years old sometimes. Since changes of the model can have taken place during these years, the RIM numbers could be wrong if the numbers of the latest model year are not in the RIM. Therefore, it is necessary to update the reference values regularly.

4.3.2 Practice

Upon understanding the interviewees perception about robustness, it was more interesting to know how the Robust Index tool is been practiced at VCME. Some of the areas focused in the interviews are summarised below.

Usage of Robust Index Matrix

When inquired about the usage of the Robust Index Matrix, not everyone was using it. Rather, only some of them were using it and the rest supported the tool with their inputs for evaluation. It was identified in the interviews that the Robust Index Matrix is being used only until the PTCC milestone (Program Target Compatibility Checkpoint), a stage in GPDS (Global Product Development System; *APPENDIX, Picture of GPDS*) which is a milestone in a project meant to confirm that the requirements from the manufacturing are confirmed. Further, when asked about the interviewees' opinion about the possibility of using RIM after the PTCC stage; even though few of them opposed its usage after PTCC, many of the interviewees suggested that it could be used after PTCC also. One interviewee suggested that, *"A good idea to maximise the usage of RIM could be to have milestones also in Final Data Judgment (FDJ) and after Verification Prototype (VP) and also between Tooling Trial (TT) and Pilot Production (PP) build in the Global Product Development System (GPDS)".*

Final Data Judgment (FDJ) is when all the engineering designs are completed and the data is ready to start with the Verification Prototype (VP), which is validation of the complete car as a prototype. Tooling Trial (TT) is the phase where the design is approved and the tools are ready representing the readiness to start with the Pilot Production (PP) phase.

It was evident that, there exists some problem in the usage of the Robust Index tool after PTCC. One possible reason identified was that there seem to be a missing loop with feedback data from the existing cars. It also appeared that, not everyone has used the RI tool and some interviewees do not feel that they are being benefitted by working with the RI. This was mentioned when one of the interviewee stated that,

"The Robust Index tool is used only when having issues"

Another interviewee also added that they do not use the data themselves rather fill in the robust numbers in the tool only because they are asked to do it. The interviewee continued to say that they only use the RI tool as a reporting tool.

Retrieval of data

During the interviews, it became evident that there are no common ways of retrieving information or data that can be used for the Robust Index Matrix. Some of the interviewees thought it was easy to find the data needed while others said the exact opposite. One statement was that,

"*People do not know where to look for data"*

The meaning of this statement was that it is not hard to find data, people just do not look at the right place, but this could also be seen in another context. Almost none of the departments were using the same systems for retrieving data. The body department stated that FTT is used while Geometry is using a software called CM4D. Trim & Final are using the Early Claims Binning (ECB) together with the ATACQ system while Paint is using Kvalitetssystem (KVAST) in Torslanda and ATACQ in Gent. This was shortened down in a good way by one of the interviewees,

"It is totally different worlds in the A, B and C shops"

To elaborate this, A shop is the body shop, B shop is the paint shop while the C shop is the final assembly. A suggestion from one of the interviewees regarding all the different systems and the differences between the different shops was that,

"There is a need for a system from plant with measures that can be easily retrieved"

To summarise the retrieval of data, the communication structure between the departments and engineering phases could be improved. An interviewee commented that communication is the biggest part to work with when it comes to RDM work. A good communication between the different departments and phases is regarded necessary to have an opportunity to strengthen the validity of the data retrieved.

Validity of Robust Index

A common understanding when it comes to the validity of the Robust Index is that it is too subjective. The way the Robust Index Matrix has evolved over the years, it is clear that Volvo Cars have strived to make the tool less subjective. Still there are people that think there can be problems with the repeatability when two different persons are using the Robust Index. Even though almost all interviewees think that it is subjective, one person said that it could be used as it is, but only as a rough tool. This means that the tool should be seen as something used for a start of an analysis, and not to be used when wanting to dig deep in problems.

In order to increase the validity of Robust Index, the interviewees mentioned some suggestions. For example, the templates should be standardised between the departments as much as it can. Of course, there has to be some differences in the template between the different departments, since they cannot have the exact same criteria, but irrespective of that, the template should be the same for everybody. In one of the interviews, it was mentioned that the tool itself should not be changed too often. This since every time a change is made in the template or there is a change to a new tool, the old data will become almost useless and not comparable.

One person also said that it could increase the sense of validity if it is shown that another company is also measuring robustness. It would be better to see how other companies are securing robustness and try to adopt some best practices. This would be good when the engineers in the Manufacturing Engineering unit are showing the robust index numbers to R&D, to prove that others also are measuring robustness. Some suggestions were also that the quality department should be responsible of driving the Robust Index, since then it will be an even more common way of working with robustness inside the departments. Some other suggestions said the opposite and meant that the departments cannot sit and wait for TVQ to start working with the Robust Index numbers. Instead, it should be kept, as it is today, with core engineers responsible. One concluding suggestion from a Powertrain engineer was that,

"If the tool should reach full potential, everybody has to think in the same way"

Upon understanding the different opinions of the interviewees regarding the practice of the Robust Index tool, additional questions were focused on understanding the tool itself.

Ways to use Robust Index data

The most common way of using the Robust Index data is for something called SDA-M (System Decision Approval – Manufacturing) and CBP (Commodity Business Plan). The SDA-M is used to choose what concept to continue within the project while the CBP is containing the strategy for each system regarding R&D and purchasing. In the SDA-M, the RI data is used for comparing different concepts and to decide which concept is the best, while it in the CBP is used for target setting. For example, when a new model is going to be introduced, the previous best achievement in terms of robustness has to be improved with a certain percentage. Since the Robust Index data are graphically easy to understand, it is also a good reporting tool and therefore used as an input tool to R&D as well. Some people only use the Robust Index as a reporting tool and only fill it in because some other department needs the numbers. The requirements in the Robust Index tool is also used for requirements setting in a software program called Teamcenter.

Some of the interviewees also mention that it could be used for strategy work and benchmarking activities. In some cases, the data has also been used in Six Sigma cases, and several departments see the possibility of using Robust Index as an add-on tool for Six Sigma. However, views on how it should be used in Six Sigma differ quite a lot between different interviewees. While one person thinks it could be used in the measuring phase of the DMAIC-cycle, another person says that it should only be used to identify problems suitable for a Six Sigma project.

Data from the Robust Index could also be used in FMEA and Control Plans according to some of the interviewees. This also brings the question if Robust Index could be integrated with other tools.

Integration with other tools

When it comes to if the Robust Index should be integrated with another tool or used as a stand-alone tool, it became obvious that there are two main understandings. On the one hand, people that want it as a stand-alone tool and only use the data in other tools, on the other hand some interviewees want it to be incorporated with FMEA and Control Plans. The main reason why it should be merged with another tool is that it would make one less tool to use, while the reason why it should be kept as stand-alone is because it could be too complex to merge the tools. In addition, it could be connected to Lessons Learned according to some interviewees. A comment from one of the interviewees were,

"Integration can be good, but do we have a need of an integration?"

Some also stated that the Robust Index works well today as a stand-alone tool but that does not exclude the possibility of integrating it with another tool. However, regardless of if it should be used as a stand-alone tool or integrated with another tool, what should be considered is a better red thread with all the tools. A suggestion was that it could start with Robust Index, which is connected to FMEA, which in turn is connected to Control Plans and continues to Lessons Learned.

4.3.3 The tool

Understanding the tool itself would give a better insight about how the users feel about the different parts of the tool such as criteria, scale & structure and other prospective usages of the Robust Index tool.

Criteria & requirements

There are four criteria (4M – Material, Method, Machine and Milieu) along with requirements for each of them used in the Robust Index evaluation. In addition, there are certain set of conditions for evaluation, which would help the user to evaluate the RI depending upon the nonfulfillment of the requirements in each of the criteria. Since these criteria and conditions for evaluation represent the base of this tool, it was necessary to identify the interviewees' opinion about them.

The majority of the interviewees were satisfied with the existing 4Ms and they think that the 4Ms are useful when evaluating concepts in terms of robustness. However, one of the interviewees suggested, *"Only some of the requirements in the criteria are applicable for us".*

The interviewee felt that there were certain requirements in the criteria that were not applicable for them. Another interviewee continued on the same topic and mentioned *"Milieu is often squeezed out, just to have".*

The interviewee explained that the milieu criteria that is present in the 4Ms now is not being used efficiently and that it is necessary to see if improvements can be done to the criteria and requirements. Nevertheless, not only problems were revealed during the interviews, also suggestions on what kinds of criteria that could be useful in RI were mentioned. One interviewee thought it could be interesting to introduce management as a fifth M in the RIM and explained further that it should measure how good the managing of the projects are. Another interview suggested having *'Deviations reporting'* as another criterion. In addition, People and Measurement were mentioned as criteria that could be used since both could cause variation. People could affect the parts in different ways like deforming them and measurements could be differing if different tools are used for measurement as an example. However, one suggestion stood out from the rest. Many interviewees thought that a cost aspect in the evaluation could be useful in order to know how much money can be used for different projects.

Not all interviewees were fond of the idea of including a cost aspect in the RIM though. The RI was seen as rough measurement tool of robustness and that the criteria used now are enough. One interviewee was more specific and said that the RI should be used only to reduce variation. Therefore, the cost should not hinder the creation of robust solutions and stated that,

"I see robustness as a way to evaluate quality. If a solution is costing more than another, I think that is another issue."

Many departments also saw the requirements for the 4Ms as not fully adapted to their area. Therefore, suggestions were that these requirements should be updated as soon as possible. One department said that almost none of the requirements could be used in their work and that it could be hard to adapt the criteria to their way of working. Even though there are many different opinions of what should be included in the RI, one statement made during an interview summarises what the other interviewees said in a good way,

"There seem to be a missing 'X – Factor' which accommodates the special causes in the four criteria and therefore it is necessary to fulfil that too".

Scale & Structure

The scale represents the measurement scale used in the Robust Index Matrix and the structure represents the level of evaluation. It was identified from the interviews that, there are two main types of structures prevailing, namely the Program System Structure (PSS) and the Bill of Process (BOP). The PSS structure was the most commonly used of the two, but some departments also used BOP. The difference between the two different structures is that the PSS structure contains different sub-systems in the cars, for example, an AC-system or an A-pillar panel while the BOP structure contains the different process steps instead.

One department that was using the BOP structure had plans to change to the PSS structure soon. The main advantage of using PSS instead of BOP is that R&Ds work is divided into the PSS structure and therefore it would become easier to give input to R&D if the RI data are made in the PSS structure. During the interviews, it was mentioned that the BOP structure also would be more time consuming than using a PSS structure. In addition, one department explained that it would not be suitable to use the BOP structure in their work, since process changes occur, which would increase the work load of using RI. This since the RIM would have to be updated whenever a process change has occurred.

When the scale was discussed with the interviewees, it was clear that not all are using the same scale. Some of the departments are using the newest scale with 0-1-3-5-9, but some departments were still using the old scale, which only includes 0-1-3-9. However, all of the departments that were using the old scale saw no problems in starting to use the new scale instead. One of the interviewees mentioned that, *"Maybe we could use the same scale as in FMEA"*, which is a scale from 1-10. In contrast, some interviewees suggested that it would be too complicated to have too many numbers and were comfortable using the existing scale. In addition, a suggestion in one interview was that a scale with only three steps could be used. Another suggestion was also that the current scale should be inverted, because *"In other quality tools a higher number means a higher quality"*.

A common belief in all the interviews though was that both the scale and structure should be standardised and easy to understand. According to the interviewees, this could increase validity since the way of working would be easier to understand between the departments and therefore make it easier to see if the RI is used in the right way.

5 ANALYSIS

When performing the analysis, it became evident that Volvo Cars have achieved their goals in some sense, but still have space for improvements in others. However, it is important to remember that the interviews have been conducted focusing on a specific tool, which measures robustness with respect to different aspects. Thus, it is likely that the results are more detailed and specific, whereas the theoretical framework is more generic in nature.

Ever since the first version of the Robust Index Matrix was released back in 2007 at Volvo Cars, it has been divided into three different aspects, Voice of the System, Voice of the Factory and Voice of the Customer. These three aspects try to cover what happens in terms of robustness when producing a car, from the concept phase until it is delivered to the customer. The UNI 11097 Standard also divides indicators into three different areas namely, initial, intermediate and final indicators (Franceschini, Galetto and Maisano 2007). Initial indicators are measuring what the processes are capable of doing, which is similar to when Volvo Cars is measuring the Voice of the System. This since the VOS is a theoretical evaluation that has the requirements set according to what the process should be capable of doing. However, the initial indicators propose to involve facilities, human resources, technological and monetary assets and so on. For example, the monetary aspect is not considered in the VOS.

The Voice of the Factory is also similar to the intermediate indicators since the intermediate indicators are measuring the difference between the specification and the result. This is what the VOF is measuring also, since the sensitivity of the part should be set earlier, this could be compared against the actual outcome of the products or processes. Customer satisfaction is measured in the final indicators as a measure of the final results of the products. The Voice of the Customer is in this sense similar, since that is also trying to measure the customers' opinions and issues with the products. However, what the process outcomes are and how well the process meets the purpose should also be measured in the final indicators (Franceschini, Galetto and Maisano 2007).

From the above, it seems that the RIM has a good basis to measure robustness, but there is still some scope for improvements. For example, Bohn (1994) says that better knowledge about key variables can help improving the performance in the area where the variables are used and Franceschini, Galetto and Maisano (2007) continues to say that performance indicators will give a stronger focus on goals. In this way, the RIM has probably helped Volvo Cars during the last five years to have a bigger focus on robustness issues. Fortuin (1998) also says that performance measurements will help the company to do the right things the first time, which is one of the purposes of introducing the RIM.

Further, Franceschini, Galetto and Maisano (2007) divide the indicators into four different types, namely objective, subjective, basic and derived indicators. So far, both objective and subjective indicators have been used in the RIM. However, objective indicators cannot only be used when measuring in science or technology but also subjective indicators are needed (Muckler and Seven 1992). Objective indicators seem to have more reliability than subjective indicators (Muckler and Seven 1992, Franceschini, Galetto and Maisano 2007). However, work has already started to make the RIM more objective than earlier as can be seen in the evolving of the RIM. This could for example be seen in the increased usage of data from the factory in order to reduce the influence of personal opinions in the RIM. Basic and derived indicators have also been used. For example, FTT is a basic indicator, since it is a direct observation and consists of raw data that can be used directly in the tool, while e.g. the Method criterion is a derived indicator, which is a combination of different sources of information since it is based on many different requirements. However, both basic and derived indicators can be subjective or objective indicators, depending on what is measured.

As presented earlier, the RIM has evolved during the years, trying to improve the measurements. It is good that the tool has been evaluated on a continuous basis; otherwise, there is a risk that the tool will no longer meet the predefined goals, which in this case is measuring robustness (Franceschini, Galetto and Maisano 2007). Nevertheless, focus has been only on the criteria and the scale when updating the RIM and has made the requirements in the 4Ms outdated, which in turn has made the requirements not applicable for all the departments that are using RIM. This since the requirements from the beginning were set according to how the work is done in the final assembly. Since more and more departments have started to use the RIM this could in some cases mean that the requirements are not contributing towards measuring robustness at all in some departments. However, during this study a work with intention to update the requirements and have different requirements in different departments has started.

The 4Ms used in the RIM have so far been weighted differently with weight figures. This was decided in meetings with managers before the RIM was launched and in those meetings, it was decided what the different weights should be for all the different criteria. Before the launch of RI in 2007, it was apparent in meetings that the Method criterion (one of the 4Ms) was the most critical criterion and therefore it has the highest weight figure. Franceschini, Galetto and Maisano (2007) say that weights are commonly used to reflect different importance between indicators. It must be remembered though that this is a subjective method, and the subjectivity of the tool was criticised during the interviews. However, Muckler and Seven (1992) says that subjective measurements will be needed when measuring science and technology. It cannot be forgotten though that the same weights decided to be used in 2007, are still used in the RIM, even though other elements of the RIM have been updated. Since processes and car models have changed since the tool was launched, there is a possibility that the weight numbers could be out-of-date.

When looking at the VOF and VOC, the scale (0-1-3-9) should have been used when the RIM was launched, according to the interviews, but was taken away during the development of the tool. Instead, the numbers from each measurement system were used. However, plans are to introduce the robust numbers again, mainly to make it easier to compare the numbers between the different voices. When introducing the numbers again, it could be possible to see what scale is best fitted for using in the VOF and VOC. Four scales mentioned are, nominal, ordinal, interval and ratio scales (Pavan and Todeschini 2008). Usually an interval scale is chosen for parametric methods while an ordinal or nominal scale is used for a non-parametric method. However, introducing the scale again would mean the interval of numbers in the different measurements has to correspond to a specific robust number and these intervals have to be carefully chosen. An example would be if the interval 10-25 cars in the FTT measurement correlates to a RI value of 3. Nevertheless, in order to understand that exactly this interval corresponds to a RI value of 3, further investigations have to be done. Otherwise, there is a risk that the comparison will not be valid.

In Volvo Cars internal document (Ortmon 2007), it was mentioned that the time should be minimised between a failure mode creation and until the failure mode is discovered. This since the cost of developing a counter measure will be kept at a minimum in this way. These failure modes could be caused by noise factors that are not under control. Therefore, Taguchi, Chowdhury and Wu's (2005) on-line and off-line quality control could be used to handle the variation caused by the noise factors. The on-line quality control activity is referring to the countermeasures that can be applied in the production, while the off-line quality control activity refers to countermeasures that can be applied in the designing of the products or processes. Depending on when the failure mode is found, either off-line or on-line quality control activities have to be used.

The RIM could help Volvo Cars in achieving this "ideal engineering activity" since it is a tool that is meant to be deployed early in the projects. This means that the RIM could be seen as an off-line quality control activity, which could make the design less sensitive to variation. Taguchi (1986) further says that off-line quality control activities should be the most important activities to reduce the influence of noise factors. However, in some cases the RIM has not been helpful. This is not because of the tool itself, but rather the people that are using it, or not using it. Because if the tool is not used, it does not matter how good the tool itself is. The RIM will not show any robustness issues early in the projects, if it is not used as an off-line quality control activity. If the evaluation with the RIM is started too late, it will only function as an on-line quality control activity, which means that the design will not be as insensitive against noise factors as it could have been. This also means that the time from when the failure mode is created until a solution is found will be unnecessarily long. In addition, if the RIM is evaluated with numbers in an incorrect way (e.g. if a user puts a value 5 in the RIM because of miscalculations, when it actually should have been a value 3), it will still not find any issues, which also puts a pressure on the users to use the tool in the right way.

5.1 Perception

The initiative to use Robust Index has continued throughout the years, even though there have been several different CEOs since the RI was launched. Even though the CEOs have not been directly involved in the RI, an initiative was to deliver a process to become more robust and the initiative to work more and more with quality has continued, which points at a strong guiding coalition (Kotter 1996, Alänge and Steiber 2009). This quality work has also been helpful when Volvo Cars has tried to integrate the RI tool in the Manufacturing Engineering unit's way of working since it would be easier to convince employees to implement a new quality tool when focus is to improve the quality of the products. Lewin's three-stage model with unfreezing of the organisation, implementing the changes and then refreezing, as said by Burke, Lake and Paine (2008) is also talking about how to integrate changes in the third step (refreeze). Kotter (1996, p. 14) also says that a change is done when the change is seen as "*the way we do things around here*" This was also evident in the interviews, where the definition of robustness was almost the same between all the interviewees. This definition seems to have been clearly communicated throughout the Manufacturing Engineering unit, which is also connected to how well the change has been rooted in the Manufacturing Engineering unit.

Robustness according to almost all the interviewees means a process or product that is insensitive to variations, which is similar to Arvidsson and Gremyr's (2008) definition of the meaning of robustness. Taguchi (2000) also says that the product or process should be insensitive not only in manufacturing environments, but also in a user environment, which also were mentioned by some interviewees. All this points towards a good communication of the fundamentals of RDM since robustness was introduced as a new concept at Volvo Cars in 2007.

However, even though the definition of robustness seems to have been communicated clearly in the organisation, the Robust Index tool has not been communicated that well. Some of the interviewees had not been using the tool at all and some had only general understandings about the tool. Instead, other tools such as FMEA and Control Plans have been used to secure the robustness of the products and processes, and acted as an alternative to the RI in late phases. In the early phases, FMEA and Control Plans have not been used as alternatives. Lengnick-

Hall (1996) says that the focus should be on the customer and not what system is used in the organisation and the initiative in 2007 was to make the products more robust for the customer. In that sense, there is not a failure that the RI is not used in all departments. However, there was also an intention to deliver a process that should make the robustness issues visual and increase the cross-functional way of working and this has not been as successfully implemented as the definition of robustness. Of course, RI can be used together with other tools to secure the robustness and Hoyle (2009) says that in order to achieve the organisation's quality objectives, many different processes should be used in a quality management system. He, Qi, Liu (2002) also say that all quality tools should be integrated together with the quality data in order to continuously improve the quality. Nevertheless, FMEA and Control Plans should work more as a complement to the RI and not as an alternative because RI can help the manufacturing engineers in deciding what concepts are most suitable for a new project.

Continuous improvements

A quality management system should be used in a continuous improvements philosophy (Pfeifer, Reissiger and Canales 2004). This was also mentioned as one way of securing robustness by some interviewees, who wanted the continuous improvements philosophy to be used more. However, in order to have continuous improvements, the tools used must support this philosophy (Garvin 2000). FMEAs and Control Plans are living documents that are updated and used throughout design phases and manufacturing phases. If the RI could be classified as a tool that can be used iteratively is not easy to answer. However, some departments have shown that it is possible to use the RI during later phases of the product development and update it annually, so it should not be impossible to use the RI for continuous improvements. Hasenkamp, Arvidsson and Gremyr (2009) states three principles by which Robust Design Methodology can be applied for a product or process. These three principles are insensitivity to noise factors, awareness of variation and continuous applicability where the third principle regards continuous improvements. Besides this, several authors are pointing at the importance of working with robust design early in projects (Hasenkamp, Arvidsson and Gremyr 2009). However, robustness should be a part of the whole project and not only the beginning of the project (Hasenkamp, Arvidsson and Gremyr 2009). This is what Volvo Cars is trying to do when they are measuring robustness not only in the design phase, but also in the industrialization phase and when the product has reached the customer

However, in order to include efforts towards achieving robustness throughout projects, the most vital facet is how robust design methodology is implemented in the organisation and how it is controlled (Hasenkamp, Arvidsson and Gremyr 2009). Bergman and Klefsjö (2010) continue to say that, in order to make continuous improvement a natural feature of an organisation, a learning organisation should be shaped. Garvin (1993, p. 80) define a learning organisation to be, *"… an organization skilled at creating, acquiring, and transferring knowledge, and at modifying its behaviour to reflect new knowledge and insights".* Therefore, it is important to start with training of the employees using the RI tool in order to make the tool better implemented than today. In addition, the communication should be improved in order to be better at transferring knowledge between engineers in different phases and between engineers in different departments.

Communication

Argyris (1999) says that it is important to understand what is wrong in your own situation in order to understand the changes that are needed for the organisation. With more job rotation, which was a suggestion by one interviewee, it would be easier for the employees to understand the working situation in other departments or even in other parts of their own department. This could then help the employees to understand what is wrong with their own situation compared to the situation of other employees. In turn, this could make it easier for people to understand why a change is needed. However, too much job rotation has a risk of destroying functional expertise, so it will be a balancing act of what is too much and too little job rotation

One interviewee said that managers should attend the RI meetings more than today in order to understand more about why there are robustness issues. However, this could rather be a feeling from the interviewee that there is a lack of communication of what the data in the RI are used for. Kotter (1996) says that it is more powerful to use actions rather than presentations and words to communicate anything to others, and this could be lacking in this case. Even if the employees have been told what the

RIM data are used for later, it can still be hard to understand the purpose of using the tool. In order to convince everyone, the best way of showing the advantages of RI could have been to have managers attending a meeting where a RIM was first filled out and later show how the data are used in for example CBP or SDA-M.

An improved communication between both departments and the different types of engineers (core, commodity and resident manufacturing engineers) would also make it easier to use the lessons learned. This since, with a better information flow inside the manufacturing engineering unit, it can be easier to find problems in the different projects, because it seems that not everyone knows where to find information. In addition, with better communication not only inside the manufacturing engineering unit, but also with suppliers, it could be easier to understand how the suppliers are working (Liker and Choi 2004). Especially since an improvement suggestion by an interviewee was to better understand how suppliers are working and improving their quality. For example, the RI tool used by Volvo Cars could also be used by suppliers, which should improve the communication according to Franceschini, Galetto and Maisano (2007).

When looking deeper into the RIM, many interviewees said that the tool is good for communication purposes, much because of the good visualisation of robustness issues offered by the RIM. Performance measurement can often be helpful when justifying changes, much because of the good visualisation offered (Franceschini, Galetto and Maisano 2007). For Volvo Cars this seems to have come in handy especially when trying to justify changes to the R&D department, but also inside the VCME department. With a good visualisation, it becomes easy to show the robustness issues to people without having deep knowledge about how the RIM works.

Testing

However, the tool takes a lot of time and administration according to many interviewees. Only one cell in the RIM could take up to ten minutes to fill in according to one interviewee and in some departments it has been as much as 500 rows to fill in, which make this a prolonged process. This could also be understood when looking at how the robust numbers are being calculated in the RIM today. Hence, there seems to be a scope for improvements from Volvo Cars side, since the measurement is not fulfilling the SMART test (Franceschini, Galetto and Maisano 2007). The last criterion in the SMART test is a question if the measurement is taking too much time to complete, which in this case is obvious it does take too much time. In addition, Walsh (2005) says that when data has to be gathered manually (which it has to be done in the RIM), there will be a need for a simplification of the measurement.

When looking at the rest of the SMART test criteria it is harder to judge if Volvo Cars have fulfilled the criteria. The measurements are in some cases easy to interpret, but some of the measurements could easily be misinterpreted as well. Measurable is the second criterion in the SMART test and the measurements are not consistent here either. The numbers can be compared to each other when looking at concepts regarding the same component of the car, but it can be difficult to compare different components against each other. This is mainly because the different requirements that have been used between the departments and because the same template has not been used either. However, a standardised template was asked for by the interviewees and even though this could not make all components comparable, it would at least make it feasible to compare some components and of course easier to understand the tool. In addition, since the numbers in the RIM sometimes can be outdated, it is not meaningful of doing a statistical analysis, which is also a part of the Measurable criterion. The same goes for the attainable criterion, which tells if the measurements are reliable or not. If outdated numbers are used, they cannot be said to be reliable. Necessity of updating the values was also mentioned during one interview; thereby it is clearly a need of a better updating procedure. Walsh (2005) also sees the lack of updating values as a constraint against finding the perfect measures. However, it seems that it is not impossible to fulfil all the requirements set in the RIM when looking into the Attainable test since the requirements seem reasonable.

If the measurements are realistic or not is the last criterion in the SMART test and in this criterion, it seems to be space for improvements. Since there has only been one set of requirements (mainly useful for the final assembly factory) it would be fair to say that the measurements have been measuring the limitations in some part of the company, but for some departments, the measurements have not been useful at all.

However, during this study it was apparent that the company is doing a study on its own to make the measurements more suitable for each department.

The three criteria test is another method for testing criteria (Artley and Stroh 2001). The method starts with testing if the criteria used are strategic criteria. This means that the criteria should help to take the actions required to achieve goals and strategies. In the RI tool, the criteria is not really helping drive deployment of actions, rather it is a tool useful to find what areas the actions must be taken in and therefore not fulfilling the first criterion. The second test is if the criteria can be so called quantitative criteria, which questions if the criteria can identify gaps between the current status and the desired status. This can be referred to the answer of the first question and since the tool has set requirements used to define the desired state, the criteria in the tool are fulfilling the second test. Finally is the qualitative criteria test, which should test if the organisation and people involved with the measures perceive the measures as valuable. It seems like this test is fulfilled somewhat, since many interviewees sees the tool as valuable. However, not all interviewees see the tool as useful in their work and therefore some improvements can be done to improve the qualitative criteria test.

5.2 Practice

Among the interviewees, the most common opinion was to not restrict the usage of the tool at the PTCC milestone, which is a milestone when the concept has been selected. Rather should the tool be used later on in the projects as well. Hasenkamp, Arvidsson and Gremyr (2009) also say that robustness should be improved in phases after the design phase. All opportunities to create a more robust product or process should be used (Hasenkamp, Arvidsson and Gremyr 2009). However, there needs to be a clear line of responsibility as to who is going to update the tool and how frequently it should be updated. This is important since the core engineers are responsible of filling in the numbers of the RIM, but if the tool is going to be used also later in the projects, commodity and resident engineers will also be involved. Then it has to be stated who is responsible of doing the update and when it should be done (Parmenter 2007). Several different suggestions regarding when to do the updates were also mentioned in the interviews. However, if the tool should be updated more often than today, choosing when to do the update will probably also affect who will be involved in doing this task, so this has to be chosen carefully.

Data

When analysing the results for the question about the retrieval of data, it was identified that, there is a real absence of guidelines regarding what data should be used and where the data should be retrieved. Different systems are used between the departments and sometimes even different systems inside a department are used, depending on what factory the data is collected in. Franceschini, Galetto and Maisano (2007) say that it is important to clarify who should collect the data for a performance measurement system and to whom the data should be reported.

This calls for a system or database to retrieve input information or at least it should be an attempt to make the collecting more standardised than today and state what systems to use for collecting data for each department. A common database or system of input information would enhance the validity of the Robust Index evaluation. A need of a database for the performance measurements are also mentioned by Parmenter (2007). Walsh (2005) also supports this when he says that collecting data manually can be a constraint when trying to find perfect measures. With improved measures, it would probably also increase the validity of the measures. Moreover, a common system would support the users to communicate using a common language during and after evaluation of the Robust Index.

In addition, some interviewees felt that it was tedious to retrieve input data from the factories while others replied that it was an easy task to retrieve this information. What could be seen was that resident engineers seemed to have much easier to retrieve the information than the core engineers. This can partially be explained by the fact that resident engineers are placed closer to the factory and can easily talk to the persons who discovered the problem. However, when data becomes personalised instead of codified, there is a risk that the knowledge will not be as widespread in the organisation as it could have been (Hansen, Nohria and Tierney 1999). This could make useful information difficult to reach the employees who really need the information.

One of the interviewees felt that the communication between departments and between different kinds of engineers is the fundamental aspect for the retrieval of data. Deming (2000) among his 14 points for Management insists resolving this by breaking down the barriers between departments. Nadler and Tushman (1997) also mention that communication is an important way to reach all the employees to share the gained knowledge and ideas. However, the key here is to provide the users with knowledge of the RI through training and development. For example, computer-based learning programs (so called e-learning) have been used at Volvo Cars and it could be used when training employees in the RI tool as well. Also having workshops regarding the RI tool could be helpful when trying to educate employees in the way the RI tool is used and why it is used. Training is also needed according to Wetlaufer (1999) in order to change the fundamental way of working. This could also be connected to the suggestion by one interviewee who said that managers should be more attending in RI meetings, where the managers could work as a helping hand towards the users of RI.

Validity

Additionally, in order to increase the validity of the robust index data, the interviewees mentioned that there is a lack of reproducibility in the evaluation since it is a subjective measurement and they wanted measures that are more objective. However, subjective measurements would not have to be an issue. Muckler and Seven (1992) for example says that subjective elements are necessary for measurements in science or technology. The validity could be improved by providing training for the users on how to use the Robust Index Matrix, since this could reduce the difference in the evaluation between different users. Deming (2000) also supports training for the users. In addition, a steering responsibility for the tool with proper vision and motivation would provide a better support for the users of the tool. Who should collect the data and where the data should be collected from are part of the steering responsibility (Franceschini, Galetto and Maisano 2007). In addition, what templates to use for different departments and how frequently the tool should be used and in what phases it should be used should be steered by the owner of the tool. However, who should be the owner of this tool can be discussed. Kuwaiti (2004) says that a new post separate from the user of the tool should be the owner of the tool and in that sense, it is good that the quality department is the owner of the method. However, the ownership could also include for example the calling for meetings instead of having core engineers to do this work.

A red thread

Regarding the ways to use the evaluated Robust Index data, most interviewees said that the data are used for the System Decision Approval-Manufacturing (SDA-M) and in the strategy for each concept (CBP). SDA-M is only used in the Manufacturing Engineering unit but are contributing to the SDA used by R&D, which is more general than the SDA-M. R&D and Purchasing also uses CBP, which makes the Robust Index data not only used in the Manufacturing Engineering unit. However, the data could also be used in other tools as well. These other tools could be for example FMEA, Control Plan and Lessons Learned. Of course, the data from these tools could also be used in the RI tool. Upon analysing the interviewees' opinions and suggestions, there seem to be a need for a red thread between the Robust Index tool and the other tools. This could make it easier to use the other tools, since the numbers from the RIM could be re-used in some way in the other tools. The VMEA tool could be useful in this sense, since some of the ideas in VMEA could be useful if trying to integrate the RI with the FMEA. This since the VMEA tool is used in a similar way to the FMEA but instead of finding potential failures, it is used to find the underlying variation that is causing the failures (Chakhunashvili et al. 2009). To illustrate a possible connection between the tools, a visual map is presented below in Figure 17. Improvements of the tools should be a continuous process in each of the stages in Figure 17 below.

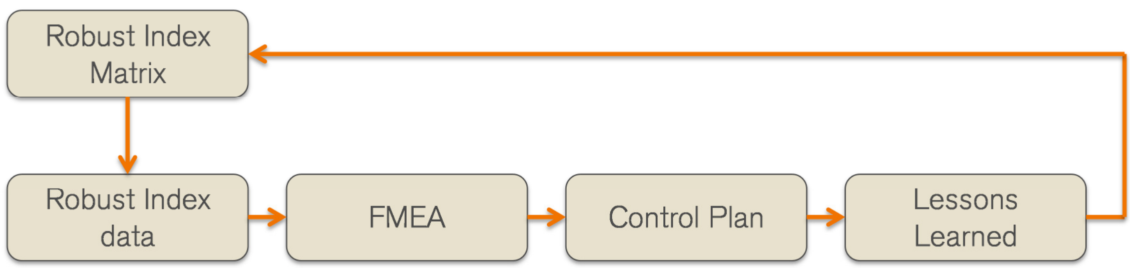

Figure 17, Visualizing a red thread between the Robust Index tool and the other tools

Some interviewees' opinions were that the RIM number could also be used in the Six Sigma framework. In order to understand how it could be used together with Six

Sigma, it is necessary to understand whether the tool itself could be used as an analysis tool in the DMAIC cycle or if it should be used to find problems that can be solved with Six Sigma methodology.

This also leads into the question on how the RI could be integrated with other tools. From the interviews, it was identified that there was quite a diverse opinion regarding the integration of the robust index tool with the other existing tools at the Manufacturing Engineering unit. It was obvious that no one was certain about the efficiency if integrating RI with the other tools. However, as mentioned before, it is not a contradiction regarding the usage; rather the possibility of integrations has to be discussed among the users of the different tools. He, Qi and Liu (2002) from a quality engineering point of view suggest that in order to continuously improve product/process quality, it is necessary to integrate all the quality tools as well as quality data and reduce the quality bottlenecks systematically. They also propose certain advantages with integration such as maintaining data integrity, implementing continuous improvement techniques, involving cross-functional designing, achieving process optimisation with different tools, keeping track of the process changes and easiness in training new engineers. This describes the necessity for a red thread between the RI tool and the other tools, which is visualised in Figure 17 above.

5.3 The tool

The Robust Index tool, launched in 2007, is used for measuring robustness at Volvo Car Corporation and it has been received well by almost all of the interviewees. However, there were some aspects of the tool where opinions differed between the interviewees. To delve into the details of it, there were certain elements in the interviews dealing with the tool itself. The elements include the criteria and requirements during the evaluation and the scale and structure used in the tool.

Cost criterion

Even though a majority of interviewees stated that they are satisfied with the 4M criteria (Material, Method, Machine and Milieu), some of them felt that there were some missing criteria. Two examples of missing criteria could be cost and project management. Among the suggested missing criteria, cost was the one mentioned by most interviewees. Cost has also been viewed as a measure connected to quality since decades. Phadke (1989) interprets the impact of the quality loss of a product before and after sale in terms of a cost. Similarly, Taguchi (1993) view quality losses with an eye of cost and assert that any deviation from the target value is considered a quality loss, which in turn would incur cost or cost of poor quality as mentioned by Harrington (1999). In addition, Lofthouse (1999) views Taguchi's loss function as a financial measure of users' dissatisfaction. However, there is also a risk in including cost. A cost criterion could make systems sub-optimized (Moen 1998). This could also happen in the RIM tool. One interviewee also mentioned this risk when saying that the RIM should only be used for measuring robustness and that cost could interfere with that purpose. Campanella (1999) who says that cost measures will not solve quality problems shares the interviewees' view.

Level of standardisation

Apart from the above discussion, some interviewees also felt that some of the criteria and requirements were not applicable for them. For example, one interviewee criticised the milieu criterion and another interviewee said that the interviewees department could not use the existing requirements. This could lead to a problem if all the different departments would decide on their own criteria and requirements to use since that could end up in a difficult situation to manage, with so many different tools. Instead, the tool should be standardised as much as possible regarding both requirements and criteria. However, some differentiation has to be allowed between the departments since they have different processes in the different factories. Veleva and Ellenbecker (2001) also mention this when saying that indicators should be divided into core and supplemental indicators. In addition, they say that organisations should strive for a standardisation of the indicators. All organisations should strive for as many core indicators as possible, since these are standardised, while supplemental indicators are differentiated between e.g. departments.

The SMART test (Franceschini, Galetto and Maisano 2007) together with the three criteria test (Artley and Stroh 2001) are good ways to evaluate the performance measurements and test them, as mentioned earlier. The authors also suggest that the performance measurement system need to be regularly checked and updated in order to keep it in line with the predefined goals. Similarly, the criteria for the Robust

Index tool should also be monitored for its fulfilment of the purpose of evaluating robustness. In addition, any changes carried out in the tool should be spread to the users (in for example the Business Management System, BMS). Thus, this could help to avoid the usage of different versions of the RIM tool between departments.

From the interviews, it was identified that there are two different types of structures of the tool that has been used in the Manufacturing Engineering unit. In addition, there seems to be an absence of proper guidelines or direction from the tool owner regarding what scale to use in the tool. Even though everyone interviewed agrees that the 0-1-3-5-9 scale would be suitable, some of the interviewees still use the old scale, which is the 0-1-3-9. Franceschini, Galetto and Maisano (2007) mention three different scales, namely 1-3-9, 1-3-5 and 1-5-9 scales. In this sense, the scale used in the RIM is similar to the ones mentioned, but seems to be a combination of them However, Pavan and Todeschini (2008) says that scales are divided into nominal, ordinal, interval and ratio scales. Which one of these scales that are the most suitable for the RIM have to be investigated further. However, a standardisation and simplification of the scale and structure for the RIM would probably make the tool easier to use and understand, which Veleva and Ellenbecker (2001) support. In addition, it is vital that the scale and structure that are decided upon can be used far into the future, since whenever the scale or structure is changed; it will make comparisons with older data harder.

6 DISCUSSION

This chapter is discussing the empirical findings at Volvo Cars Manufacturing Engineering in a broader context than the previous analysis. Finally, this discussion will lead us into the conclusions of this study in the next chapter.

The purpose of this study is to investigate how robustness can be measured, in what ways the measuring can be improved, and to understand how indicators contribute towards securing robustness. In addition, this study is believed to contribute in the field of RDM with new insights on how robustness can be measured with indicators. From our literature survey, we identified that there is a lack of a tool to measure robustness. VMEA is the only other tool found, which has been used by Volvo Group to measure robustness. The RIM developed by Volvo Cars captures the robustness of the evaluated system through measuring the sensitivity of the system with respect to the pre-defined variations, i.e. the requirements under the 4Ms. The delimitation of the RIM is that the measurement relies on the pre-defined requirements. Therefore, the requirements under the criteria play a vital part in the reliability of the robustness evaluation. The basic difference perceived between VMEA and RIM is illustrated in Table 4 below.

Table 4, Comparison between VMEA and RIM

VMEA	RIM
• VMEA is a method aimed at guiding engineers to find critical area in terms if the effects of unwanted variation, Johannesson et al. (2012).	• RIM is a tool focusing on identifying the sensitivity of a system against pre-defined variations. The sensitivity varies from being a fully robust system to being a extensively un-robust system.
• Different models for the concept phase, detailed design phase and the industrialization phase	• One matrix for all the stages of PD

This study is meant to provide Volvo Car Corporation with a holistic view of the users' opinions about the Robust Index Matrix and how it could be improved. This study is also believed to be a good resource to other companies interested in measuring robustness of its products or processes.

The Robust Index tool studied in this report is a tool developed by Volvo Cars in order to identify un-robust systems. Robustness according to Taguchi, Chowdhury and Taguchi (2000) is a state where the performance of the product, process or technology is minimally sensitive to the factors causing variation. Corresponding to this, the Robust Index Matrix evaluates the voice of the system with criteria on Material, Method, Machine and Milieu (4Ms) and identifies the sensitivity of the systems towards the factors causing the variability. The objective of the tool is to identify un-robust systems and improve them in order to reduce the systems' sensitivity against variation, which is in line with the objective of Robust Design Methodology as elucidated by Hasenkamp, Arvidsson and Gremyr (2009).

From the analysis of the interviews, it was found that the Robust Index tool is a good way of measuring robustness and that it has been accepted by most of the interviewees. It helps in measuring the sensitivity of the products against variation with respect to 4M criteria as mentioned earlier. We believe that this tool also could benefit other companies having the need to measure the robustness of its products or processes. However, the product or process whose Robust Index value is being evaluated should be assessed with respect to the predefined criteria and requirements. Of course, these criteria and requirements need to be tailored with respect to the companies employing the tool.

The perception about robustness among the members at Volvo Cars Manufacturing Engineering seems to be well rooted in the organization. Nevertheless, there seems to be a lack of direction from the management regarding the steering of the Robust Index Matrix. From the interviews, it was identified that not all interviewees had used the tool before. When inquired about the reason for it, it was found that they are not sure about how to use the tool. Kotter (1996) says that it is not only important with a lot of communication, but also it is better to use actions than words to create interest in the implementation of the change for the employees. In this implementation, both actions and communications could have been lacking.

Not all of the interviewees had knowledge about the Robust Index tool and some other interviewees wanted managers to be more attending to meetings in order to help them with the Robust Index Matrix. The participation of managers could also help in overcoming the problem that it is hard for some interviewees to retrieve input data for the Robust Index evaluation together with more job rotation. If it were a better communication between the engineers in the different phases of engineering as well as between departments, information would probably be easier to find. Since Volvo Cars is a large company with many tools to monitor quality, the information seems to be fragmented as there are several systems that are in use and there is no clear information of what information to use in the RI evaluation.

With well-structured information handling, Volvo Cars could increase the reliability and validity of the RI evaluation. A set of guidelines and instructions regarding what data to use and from where the data should be retrieved (Parmenter 2007) could be a good start. In addition, searching and retrieving of relevant information could be faster and easier if a database for the Robust Index would be used. Parmenter (2007) also supports usage of a database for a tool using indicators   Moreover, this could support the users with a common language of communication during and after the Robust Index evaluation. A common language of understanding in a company would reduce the level of misconception between the employees in different departments.

Similar to FMEA and Control plan, the possibility to make the RIM as a living document should be identified. Even though there was a diverse opinion among the interviewees in the integration of the other tools with RIM, they see an opportunity to connect the Robust Index data with the other quality tools as a means of securing robustness. Connecting the RI tools with other quality tools in Manufacturing Engineering would possibly contribute in increasing the usage of the RI tool. The organisation could also be benefitted by integrating the RIM with other quality tools in order to drive improvements.

The Robust Index tool should be updated regularly for reference values (Franceschini. Galetto and Maisano 2007), which could increase the reliability of the tool since updates are made too seldom today. Along with the reference values, the weight figures allotted for each of the criteria could be updated from time to time in order to have a more updated tool. However, this is a balancing act of how much to upgrade the tool. Updating too seldom will make the tool not weighting what is most important in a proper way and updating too often will make the old RI numbers hard to use for comparisons.

The performance indicators in this tool would be the 4Ms and cost appears to be an interesting aspect of measure. The theoretical framework shows that a cost criterion could be used together with quality. One example of a cost connected to quality would be the cost of poor quality as mentioned by Harrington (1999). We recommend any company using the Robust Index tool to identify the possibility to include cost as a criterion in the evaluation. Another recommendation is to evaluate the indicators (set by each company) with the SMART test proposed by Franceschini, Galetto and Maisano (2007), which is an effective way for companies to evaluate their performance indicators.

In order to improve the usage of the RI Matrix, standardisation was one of the most discussed issues since no one is aware of which template, scale and structure to use in the evaluation of the RI. However, the departments have their own needs and requirements. Therefore, it is essential to decide the right level of standardisation and delineate as to which template, scale and structure should be used in the RI evaluation in the future (Veleva and Ellenbecker 2001). This is of course not only important for Volvo Cars, but for all companies measuring robustness with this tool. Therefore, there should be clear guidelines stating which template should be used and how often the evaluation should be updated. When it comes to standardising of the scale and structure, it should also be clearly specified in the guidelines. In Volvo Cars case, this should be stated in the Business Management System (BMS).

Among the issues with the usage of the RIM, one common and the most important opinion from the interviewees was that the RIM takes a lot of time in the evaluation of the RI. We believe that the RIM should be more user-friendly to use. A new interface was developed for evaluating the RI, which could reduce the time and resources required extensively. Compared to the existing template, the new template with the application interface helps the user in three different ways. One benefit is that any person could be operating the tool in the meetings. The person who operates the meeting can open the tool in his/her computer and all the attendees see the criteria and requirements in a common screen. Another benefit would be the elimination of manual calculation in the evaluation. Manual calculation is a tedious job and it is tiresome since a tool would contain about 200-500 rows to fill in. The third benefit is a poka-yoke feature, which prevents the user from making an error by clicking the wrong cell and the wrong criteria button. All this benefits would together reduce a lot of time and errors.

To conclude this discussion, it was identified that many factors were influencing the usage of the Robust Index Matrix at Manufacturing Engineering. It was also found that the tool needs to be robust with the right level of standardisation and need to be regularly updated. The new user-friendly interface is believed to reduce a lot of time and error. A standard training and clear guidelines should be formulated along with an information sharing strategy, which could reduce the problems related to data retrieval and usage of the RIM.

7 CONCLUSION

In this chapter, answers to the research questions will be given together with future research that has been found in this study.

The purpose of this study is to investigate how robustness can be measured, in what ways the measuring can be improved, and to understand how indicators contribute towards securing robustness.

This research was based on understanding the Robust Index tool, which is being used by Volvo Car Corporation. In order to understand how robustness can be measured in terms of a value, it was crucial to understand the perception of the Robust Index Matrix, how it was practiced and the tool itself. There were many insights from the interviews by which it was understood that, even though the tool is interesting to work with, there are certain underlying principles that are necessary to be optimised.

The first research question of the study was to understand how robustness is measured today and how the measurement can be improved. We can conclude that the measurement of robustness is based on predefined requirements and criteria. The criteria help in identifying the different means by which a product could be affected by noise factors. In each criterion, there are certain predefined requirements that take the responsibility of covering the possible variations, which could affect the system.

When it comes to how the measuring of robustness could be improved, we suggest that the measurement of robustness should be a continuous cycle rather than being restricted within any stages of product development process. Robustness evaluation should be a basic function throughout the development of the product. Any deviation from the nominal value would contribute to a quality loss. Therefore, it is necessary to constantly monitor the robustness of the system for any variations.

The second research question of the study was to understand the contribution of the indicators towards securing robustness. From the study, we identify that the criteria and requirements help in making comparisons between systems and this helps to identify the system with the highest robustness. This is also clarified since the Robust

Index Matrix helps in visualizing which system has the highest robustness from the evaluation. However, some benefits from integrating the Robust Index tool with other quality tools, e.g. FMEA were also identified. The usefulness of the Robust Index tool could be improved if integrated with other quality tools in order to drive improvements.

7.1 Future research

During this study, certain areas have shown to be interesting for further research on the topic of measuring robustness with indicators. The first suggestion should be to study if, and if so how, a cost criterion could be included in the RI tool. Opinions by the interviewees contradicted each other, where most of the interviewees suggested studying the possibility of including cost in the tool and where others said, cost should not be included.

Since there have also been so many interviewees saying they want a standardized tool, a future research could be to study the criteria and requirements more deeply. An interesting view of this would be to see what criteria and requirements can be standardized between different departments and which criteria and requirements that cannot be standardized. In a bigger context, this could be studied not only in the automotive industry, but also in other manufacturing industries.

This tool is still in its development phase and still many improvements can be done. A suggestion for future research could be to study what scale is best to use in a tool that measures robustness. From this study, it could be shown that the opinions differ between interviewees. The scale suggestions were scales only containing three numbers, up to scales with ten numbers (similar to the FMEA scale), and all scales in between. There is also a possibility that the VMEA tool could contribute in deciding the rating scale. Therefore, it could be interesting to make deeper research on what the best scale should be in a tool measuring robustness.

The possibility to measure robustness in the same way at both suppliers and customers could be interesting to investigate further. This could contribute towards a common understanding between the supplier and the customer in terms of understanding robustness issues. In addition, this could contribute towards comparing the robustness of similar products supplied by different suppliers.

Since the Robust Index tool has taken so much time and administration at the Manufacturing Engineering unit, an interesting future research would be to investigate if the tool is necessary to use for all systems. Perhaps the tool should only be used on some manufacturing related critical systems in order to reduce the time and administration even more and this could be interesting for other companies as well, when trying to adopt the RI tool.

Last, but not least, the communication have said to be improved between the Manufacturing Engineering unit and R&D with the help of the RI tool. However, in this study, these statements were only from interviewees' in the Manufacturing Engineering unit. Therefore, it could be interesting to understand also from the R&D perspective if the communication really has been improved. This is also interesting for other companies, since then it could be proved that measuring robustness with the RI tool would enhance communication regarding robustness issues between the two units.

8 MANAGERIAL IMPLICATIONS

This chapter addresses the researchers beliefs of how the tool and everything connected to this tool could be improved at the studied company Volvo Cars.

This study assesses the Robust Index Matrix, which is proved a useful tool in measuring robustness. However, from systematically combining the theoretical framework with the results obtained, many issues were identified and analysed. Volvo Cars have developed an interesting tool to measure robustness. However, they might have missed to make the tool insensitive to variations among the users. Improvements of the tool are better late than never and before the next version of the tool is released, changes can be done. Some of the recommendations that would benefit Volvo Cars in improving the tool are presented below and the recommendations have been divided into groups depending on which recommendations we think Volvo should prioritize first, second and so on.

First priority

Evaluate the criteria and possibility to include Cost criterion

Even though the criteria seem to suit many, there is no justification stating whether the RIM takes into account all the factors that can cause variation. Thereby, we would recommend Volvo Cars to take the possibility to evaluate the existing criteria with the help of the SMART test and three criteria test. In addition, the requirements could be individually evaluated within departments in order to understand their distinct contributions in fulfilling the purpose of evaluating robustness. When evaluating the criteria, the possibility to include cost as a criterion should be investigated. This since many interviewees were interested in having a cost aspect in the RI evaluation. One example of a cost criterion that could be used in the RIM would be the cost of poor quality. However, some interviewees were not in favour of introducing cost in the RIM because it should only measure robustness and nothing else.

Standardize the scale and structure

The scale and structure should be standardised. Even though some of them are using different scales and structures, it was understood from the interviews that the 0-1-3-5-9 scale and the PSS structure are good to adopt. However, it could also be investigated further if another scale would fit the RIM better. The scale and structure should be standardised regardless of what scale is used in order to make the evaluations easily comparable.

Make the tool user-friendly

One important reason for the poor usage of the RIM is that, the users feel the RI evaluation to be very time-consuming and not user-friendly. This is because; the user needs to get back and forth with the requirements in the criteria during evaluation of the RI. In addition, there is a need for concentration and manual calculation involved in the evaluation. This could be overcome by the proposed new interface, which helps the user during evaluation. It also eliminates the need for manual calculation since the interface is already programmed with the evaluation criteria.

The RIM with the new interface was demonstrated to and tested by the members of the TVQ and some heavy users of the tool. The tool was appreciated with minor suggestions on how to improve the tool even further. The possibility to introduce the new interface in the other sections (VOF and VOC) was also discussed. The new user-friendly interface design was perceived to be interesting and less time consuming to work with among the people who tested it. The new template with the user-friendly interface is presented in Figure 18 below.

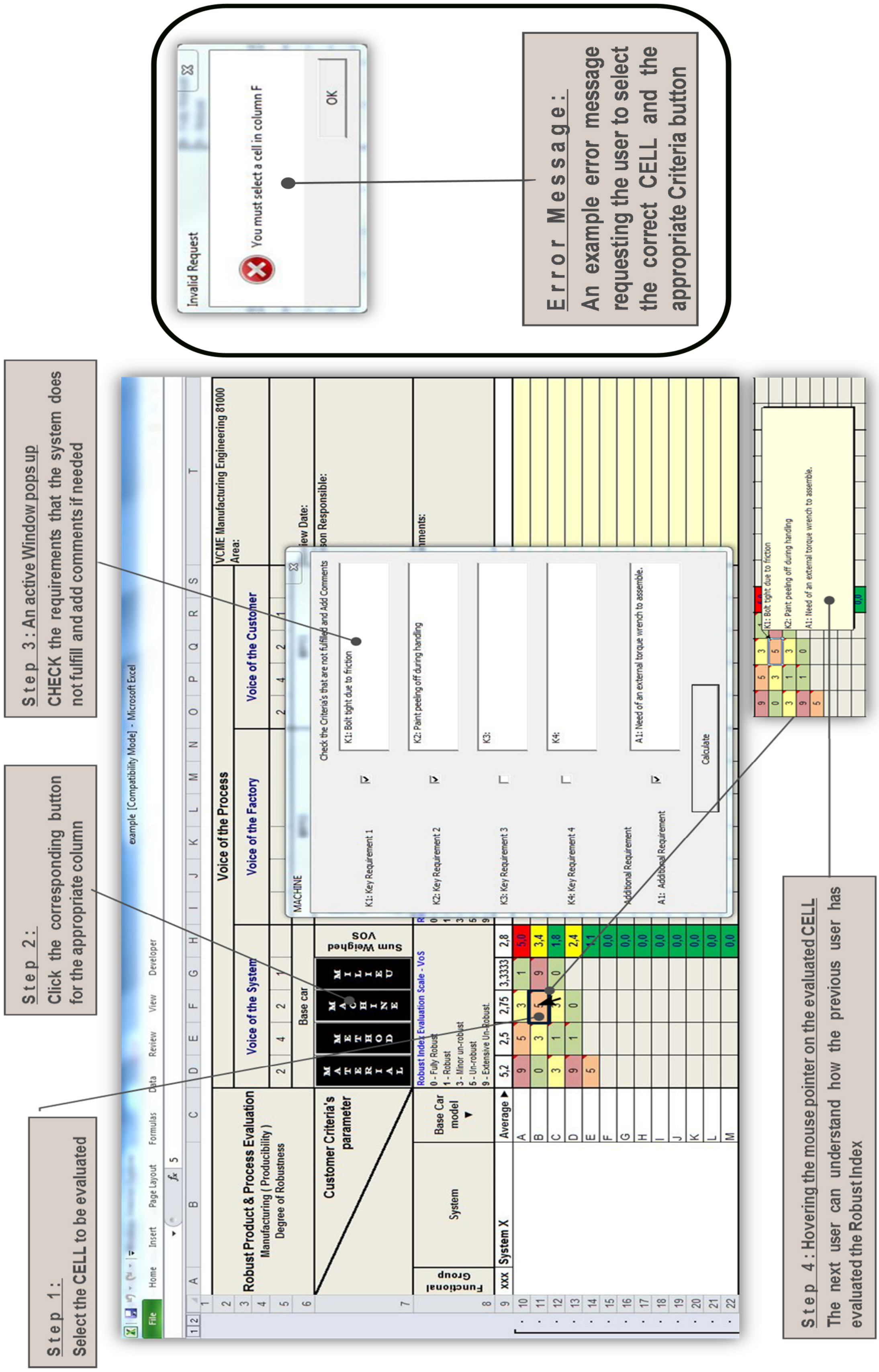

Figure 18, Proposed new interface for the Robust Index Matrix

Second priority

Have a structured information handling

Since there are no clear rules stating which information to use for evaluation of the RI, the departments choose to go with their own interests. There needs to be a structured information handling strategy, which helps the user to use the right information for evaluation. In addition, the data should be saved and be retrieved easily. A common database can be created by which the users can store and retrieve the necessary information from the factories. This would increase the reliability of the data and the evaluation.

Continuous improvements

The tool should be continuously updated for reference values. There is no point in evaluating with old values, which could be no longer valid. The weightage of the 4M criteria should be evaluated regularly in order to see their relevance to the current evaluation. There should be clear guidelines stating the frequency of updating the reference values and the responsibility for updating the RIM. It is recommended to test the tool with some heavy users in order to avoid frequent releases of a new template.

Many interviewees have expressed their interest of using the RIM after PTCC as well and it has also been used by some departments in later phases than PTCC. However, there are no clear opinions of when to use it in the later phases and further investigation is needed at what milestones/gates an update of the evaluation can be done.

Provide guidelines

It is recommended to have a link in BMS to contain all the necessary information regarding the Robust Index Matrix. The page should contain information regarding the latest template to be used along with the frequency of updating the evaluation values. In addition, an e-learning application focused towards educating the user on how to use the tool and the benefits of using the tool. It should clearly mention the owner of the tool and contain a section to post comments regarding the tool.

Define ownership for the tool

As of now, there is no clear information stating who has the steering responsibility or the owner of the RIM. What is meant with this steering responsibility is, who should own the tool, who should call for meetings and who will make sure that all the guidelines set up for RI is followed. This steering responsibility for the tool with proper vision and motivation would provide better support to the tool. A steering person should focus on a continuous improvement philosophy and see the possibility of using the RIM throughout the product development process. The possibility to make the RIM to be used in all phases of engineering should be considered.

Third priority

Create a common understanding

Even though the definition of robustness seems to have been communicated clearly, there are still some people who have not used the tool and some who have only general understandings about the tool. There needs to be a clear indication of the purposes of the different tools. Therefore, it is advisable to arrange for an e-learning training, which could help people at Manufacturing Engineering unit in understanding the usage of the RIM. In addition, managers at VCME as well as people that are provided with data from the RIM, e.g. R&D, should be benefitted by this training. The tool should become a natural way of working.

Communicate effectively

The communication could improve the usage of the RIM. It is better to have a cross-functional communication during the evaluation of the RI between all the phases of engineering and between different departments. For example, it seems to be easier for RME employees to retrieve data, which could be useful in the RI evaluation, than for the core engineers. An improved communication between the departments and between the engineers in different phases would contribute to the continuous improvement of the RIM largely. As mentioned before, a common system or database would contribute towards communicating a common language not only during evaluation but also after the evaluation of the Robust Index.

Fourth priority

Red thread

Another possibility to improve the usage of the RIM data is to investigate the possibility to have a red thread between the RIM and the other quality tools, FMEA, Control Plans and Lessons Learned. VMEA is also a tool that could contribute towards improving the evaluation of the RI. For instance, VMEA could help in identifying more noise factors (requirements in the 4M) that could be missing in the current evaluation of RI.

Fifth priority

Other possibilities

To make the robustness evaluation even more widespread, an idea could be to introduce and use the RI at suppliers. It could help to understand where suppliers have possible un-robust systems. Making suppliers use the RI evaluation could also help comparing the robustness of similar products supplied by different suppliers.

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10 APPENDIX

10.1 Interviewed persons

1. Lars Nilsson	Project Leader, Paint
2. Ulf Selhammer	Manager Commodity, Exterior Trim & Final
3. Henrik Börjesson	DPL2, Geometry
4. Liselott Erixon	DPL2 Core, Trim & Final
5. Birger Lindblom	Commodity Engineer, Body
6. Thomas Hermansson	Technical Expert, Core Trim & Final
7. Stig Bigseth	Engineer, New Model Program
8. Lenny Stoltz	Project Manager, New Model Program
9. Sanna Rydberg	RME, Powertrain
10. Robert Krickic	Manager, Manufacturing Engineering Int. & Ext.
11. Helene Ahlenius	Project Manager, Paint
12. Henrietta Johansson	Manager, RME Paint
13. Anna Zederfeldt	Quality Engineer, Powertrain, Skövde
14. Sten Gedda	Manager, Strategic Planning & Control
15. Tore Launing	Project Manager, Concept and Program Management
16. Torbjörn Appelros	Senior Manager Core, Stamping, Olofström
17. Anna Bergelin	Quality Engineer, TVQ
18. Roy Börjeson	Quality Engineer, TVQ
19. Christer Carlsson	Quality Engineer, TVQ
20. Liselotte Johansson	Quality Engineer, TVQ
21. Alejandro Vega Galvez	Quality Engineer, TVQ
22. Anders Ortmon	Quality Core Manager, TVQ

10.2 Interview guide

1. What is your definition of robustness?
2. How often do you use RIM?
3. What influences you to use RIM in a natural way in the initial phases of engineering?
4. What do you like/dislike about the RIM?
5. What kind of tasks do you use the RI evaluations/results for?
6. What do you think are the weaknesses and the strengths of the RIM?
7. What is your perception of RI today and how can the RI as a measurement be improved?
8. Do the criteria (4M) fulfil your requirements for robustness evaluation? (evaluation in Annual and robustness assurance in Forward Models- Project phases)
9. What do you think Voice of the Factory and Voice of the Customer could add to this matrix?
10. What other criteria do you think could add value to this evaluation?
11. What do you think about the scale (1-9) today used in RIM?
12. What do you think of the validity of RI as a measurement for robustness?
13. In what phases is the RI used today?
14. In what phases do you think the RI should be used?
15. How often should the numbers in the RIM be updated?
16. How often is the RIM updated today and what does that process look like?
17. In what other tools can the data from the RIM be used?
18. How should this tool be used, as a stand-alone tool or integrated with some other tools?
19. What are other opportunities to secure robustness in Volvo Cars systems? From annual to running production.

10.3 Questions grouped into clusters

- Definition of robustness
- Usage of Robust Index Matrix
- Opinion about Robust Index
- Criteria, requirements and 4M
- Scale & structure
- Retrieval of data
- Validity of Robust Index
- Ways to use Robust Index data
- Integration with other tools
- Opportunities to secure robustness

10.4 Picture of GPDS