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P-VMEA

Variation Risk Management and Decision Making

P-VMEA: A New Developed Application Area of Variation Mode and Effect Analysis for Robust Process Design

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

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by

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ABSTRACT

Variations are always present in processes and depending on how organisations manage these variations, targets risk not to be reached. The performance of a modern company strictly depends on the ability of combining interfaces between different processes, increasing the value added to the customer and optimizing utilization of the assets and resources; reducing the variation affecting the process.

Variation Mode and Effect Analysis (VMEA) is a commonly known tool within product development for robust product design. The purpose of this study is to investigate if VMEA is applicable to processes in order to manage process variation and to build robust processes. The goal is to fulfil the purpose and to make generalizable conclusions.

This work rises after a successful Six Sigma project, where the authors applied the VMEA methodology to a process in an improvement project. With the intention to achieve the purpose, a qualitative research strategy was selected. Qualitative data were collected through semi-structured interviews and a Kano survey. The main research was done at Volvo Group Trucks Technology (Volvo GTT). Furthermore, for increasing the validity of the study, a benchmark was performed at Volvo Group Trucks Operations, Ericsson AB and Tetra Pak. In addition, VMEA researchers and experiences Six Sigma black belts supervised this thesis work. A case study was performed at Powertrain Engineering within Volvo GTT for analysing the In-Service Conformity test process.

The results of this thesis show that VMEA is applicable to processes. A new developed Process-VMEA (P-VMEA) framework is provided for identifying, assessing, mitigating and managing variations in a process. The deliveries of the framework are mainly directed towards decision makers and aim to strengthen fact based decisions. The reader is guided step by step in the P-VMEA methodology by using artificial organisation examples and real application cases. The P-VMEA framework is divided in four phases with review gates in the end of each phase to ensure that the goals are achieved.

Keywords: Process, Variation, Variation Risk Management, Variation Mode and Effect Analysis, Decision Making, Quality, Six Sigma, Key Process Characteristics, Improvement Project, Kano, Business Processes, Process Mapping Tool

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Gothenburg, January 2014

Isabelle Therese Andréasson

Gabriele Rosolino Catalano

Preface

This thesis is the final work at the master's degree program at Chalmers University of Technology in Sweden and was written in the last semester of 2013. The study was performed both in Sweden and in Italy at Università degli Studi di Palermo and is a result of a long and fruitful cooperation between the two universities. The thesis work corresponds to 30 credits and was in collaboration with Volvo Group Trucks Technology, Volvo Group Trucks Operations, Ericsson AB and Tetra Pak.

TABLE OF CONTENTS

Notations

LIST OF FIGURES

LIST OF TABLES

Abbreviations

ISC	In-Service Conformity
KPC	Key Performance Characteristics
NF	Noise Factor
P-VMEA	Process - Variation Mode and Effect Analysis
QFD	Quality Function Deployment
Sub-KPC	Sub-Key Performance Characteristics
TQM	Total Quality Management
VMEA	Variation Mode and Effect Analysis
VOC	Voice Of the Customer
Volvo GTO	Group Trucks Operations
Volvo GTT	Group Trucks Technology

Introduction

In this introductive chapter, the background, aim and goal of this thesis work will be presented. The research question and sub-research questions, developed in order to achieve the purpose of this thesis, will be presented. Finally, limitations and delimitations conclude the chapter.

1 INTRODUCTION

1.1 Introducing the Research Topic

Variation is constantly present in everyday life activities, impacting performance and increasing cost as well as causing targets not to be reached (Thornton, 2004). In a competitive environment, time and money are often limited. Therefore, tasks need to be prioritised and it is clearly impossible for managers to manage all activities and give allowance to all suggested improvement projects without any negative effects. In complex processes, variation cannot be handled by only looking at one single cause, managers must have a system perspective and processes need to be evaluated as a system.

Variation Risk Management (VRM) is proposed by Thornton (2004) as tool for identifying, assessing and mitigating variation. Today, companies have high potentialities to improve their business by taking advantage of the employees' knowledge, but this is often done to a minor extend. Even though there might not be any quantitative data present, people within organisations can have long experience and knowledge about processes, which should definitely not be either neglected or ignored (De Brujin et al., 2010). People can describe processes, give their judgements and provide highly valuable data for analysis in order to work with variation risk management. Making a wrong decision can cost a lot of time, money and also resources. To prevent this, experts can be involved in the decision making process. Consequently, the quality of the decision will be increased and the risk of misfit between the parties reduced.

Variation Mode and Effect Analysis, known as VMEA, is a method aiming to identify noise factors in a systematically way and to assess the effects of the noise factors on Key Product Characteristics (KPCs) (Chakhunashvili et al., 2004). In VMEA, the focus is on variation and the risks associated with them with respect to KPC. The main goal of the methodology is to identify and prioritize significantly contributing noise factors of the KPCs' variability

1.2 Thesis Background

This Master Thesis has some inputs from the previous Six Sigma project performed by the authors in the spring of 2013at Powertrain Engineering within Volvo GTT in Gothenburg. As the project was highly appreciated by the company it inspired to a continuous study within the field of process variations. The authors realized that by reducing variations there are high potentials to cost savings. In literature, there is a large opportunity to further investigate how companies can manage and create robust processes by transforming peoples' knowledge and experiences into quantitative figures useful for prioritize actions and making decisions. Therefore, it was interesting to investigate if a methodology commonly used for creating robust products could be applied in the similar way for creating robust processes.

1.3 Aim

To investigate if Variation Mode and Effects Analysis is applicable to processes in order to increase understanding of variation, enhance robust process design and support decision making procedures in accordance to the principles of Variation Risk Management.

1.4 Goal

The goal is to come to a conclusion if VMEA is applicable to processes, or not by theoretical and practical investigations. If applicable, the goal is to define the main characteristics that the methodology should include for meeting the users' needs, determine to what processes it is applicable for, and provide a Process-VMEA methodology. If VMEA is not applicable to processes, then a motivation of *why not* applicable, relying on an extensive analysis of possible scenarios will be provided. The goal is also to make generalizable conclusion.

1.5 Research questions

Given the background, purpose and goal the following main research question will be investigated and answered (see Figure 1): Can VMEA be applied to any processes and be used as an effective variation risk management tool to provide information for making decisions? This main research question is further broken down into three Sub-Research Questions. Furthermore, for each Sub-Research Question a second order Sub-Research Question has been developed.

The research questions to be answered in this study are illustrated in Figure 1 below.

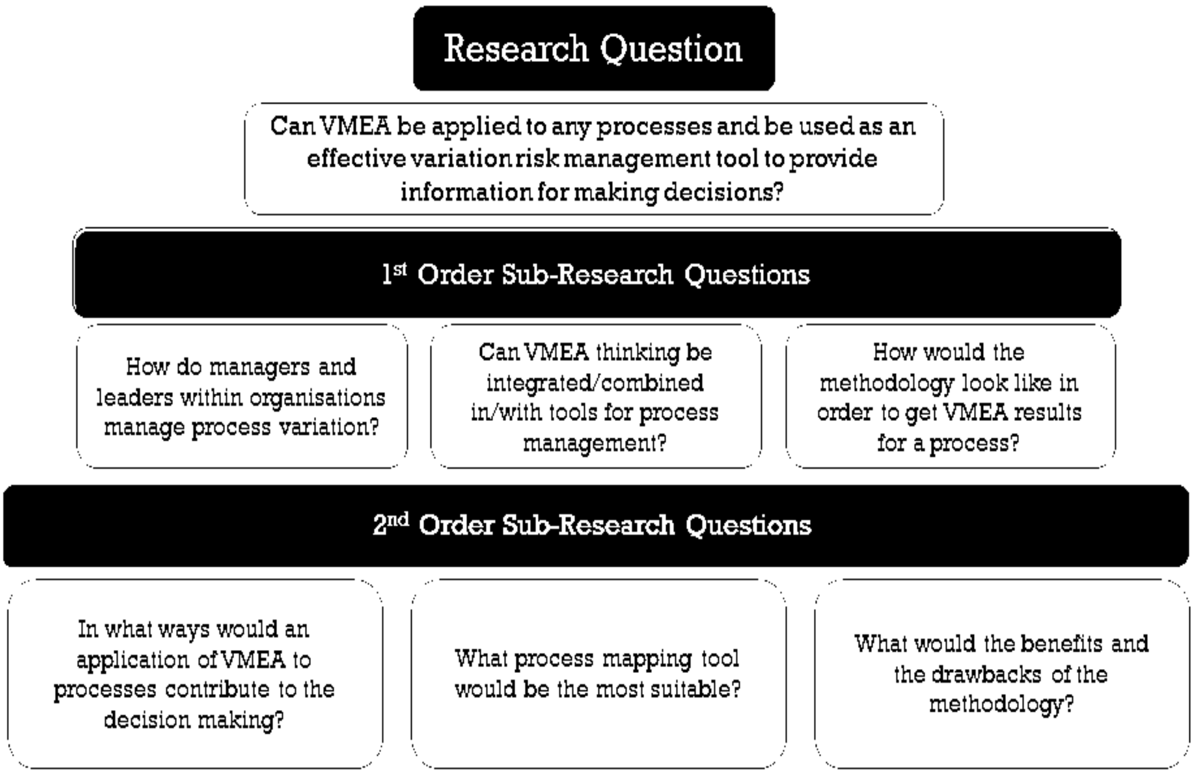

Figure 1: Research questions

The main research question is: Can VMEA be applied to any processes and be used as an effective variation risk management tool to provide information for making decisions? This research question is further broken down into three Sub-Research Questions, and each of them is supported by one Sub-Research Question each.

1.6 Limitations and delimitations

The master thesis is limited to investigate the application of VMEA to processes and not to products. Even though VMEA is a well-known tool for many organisations working with creating robust products, the aim is directed towards investigating VMEA and processes. Additionally, the main focus is on VMEA and the theoretical framework of Variation Risk Management (VRM) will not be criticized. The main principles of VRM framework will serve as a base for the Process-VMEA methodology development. The study will also focus on what information managers within large organisations generally need in order to make decisions. In the development of the Process-VMEA, a limited number of process mapping tools will be evaluated due to time restrictions. The time is limited to 20 weeks (see Appendix 1) and two master students, and the results of this thesis will need further validation. The final results are aimed to provide recommendations on how to proceed the further validation of the application, if possible, or suggestions on how to continue the investigation of VMEA.

Research Methodology

In this chapter, the research methodology will be presented for how to answer the research questions of this Master's thesis. The research strategy, research design and research process will be explained and illustrated, emphasizing on the data collection and analysis.

2 RESEARCH METHODOLOGY

2.1 Methodology introduction

Due to strong business competition among companies in the business world, it is of great importance to work continuously with process improvement and to focus on the customer in order to gain larger market shares. By researching, it helps the organization to identify the significant variables and different factors affecting the customer satisfaction and to increase customer loyalty. For the business environment, research is needed to take different factors into account. Factors are not always controllable by managers, but they can affect the company in different ways, for example, government legislation and social ideology. The process of making decisions can be complex since managers have a high amount of variables to consider, and it requires high knowledge and good level of information. Furthermore, research can be useful to develop new techniques that can increase the competitive advantage for a company, for example, creating a new company image, visualizing complex concepts and helping consumers to make better decisions. According to Sachdeva (2009), a good research requires that the scope and the limitations are clearly defined. It is important to have a high ethical standard and to clearly communicate the final results. (Sachdeva, 2009)

2.2 Research strategy

A qualitative, hermeneutic, research approach is selected for this study (Bryman and Bell, 2011). The research is of abductive character as some previous knowledge is necessary for developing the thesis and theory will be generated as a thesis outcome. The research follows a systematic combining strategy which is a back and forth approach among theory, empirical findings, case- and framework applications (see figure 2) (Dubois and Gadde, 2002).

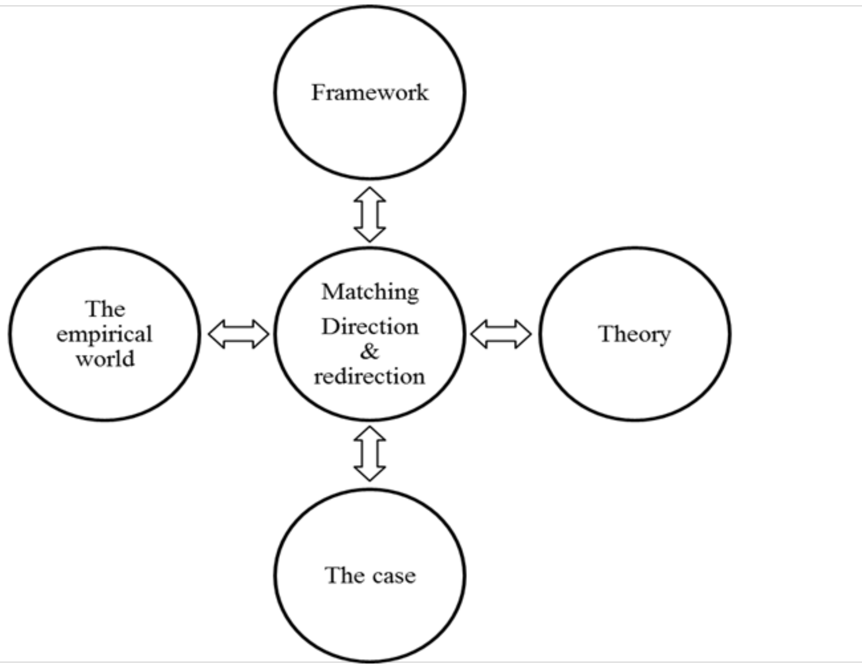

Figure 2: Systematic combining research strategy (Dubois and Gadde, 2002)

The strategy also involves the generation of generalizable conclusions (Bryman and Bell, 2011). The purpose of the selected research strategy is to build up understanding for the human research objects' experience, both implicitly and explicitly expressed. The research's epistemological orientation is interpretivism, meaning that the researchers will be "inside" the social circle in order to grasp different social subjective behaviours (Bryman, and Bell, 2011). The research's ontological orientation lies within constructionism as social actors are accomplishing social phenomena and their meanings. In constructionism, the researcher always interprets and presents the social reality in its own version, meaning it cannot be regarded as a definite version. The method will be exploratory in order to understand and interpret data.

2.3 Research design

According to Bryman and Bell (2011), the research design should be chosen carefully as it is the main framework for how the data collection and analysis are to be preceded. For this study, the previous Six Sigma project at Volvo GTT will be followed up by interviewing department responsible managers since the investigating method for this thesis, VMEA, was used in the previous project. Benchmarking at two external companies will be done via semi-structured interviews as well as internally within the main research company to obtain increased knowledge about how other companies manage process variation and discuss an application of VMEA to processes. Published written material around the research topic will be studied carefully and some interviews with VMEA researchers will be held to increase the researchers' knowledge and to discuss a broader tool application. The ISC process at Volvo GTT, Powertrain, in Gothenburg will be taken as a trial case.

2.4 Research method

How data are to be collected is also known as research method and there are different techniques for how to collect different types of data (Bryman and Bell, 2011). In this study, primary and secondary data will be collected. The qualitative data collection approach will consist of interviews, observations, analysing company documents, benchmarking at another large organization with project leaders, engineers, experienced six sigma drivers, and managers. Results from the previous six sigma project made by the authors in the spring of 2013 regarding VMEA, will be followed up. The research method is chosen in order to fulfil the aim of this thesis and draw generalizable conclusions and provide recommendations. The subject of emphasis will be how to manage variation and make decisions based on analysis of variations. Yin (2003) states that by having a detailed plan for data collection it will be easier to operate and enable replications. A more detailed data collection plan for this thesis is found in Figure 3, illustrating the research process and the expected deliverables for the data collection in this project.

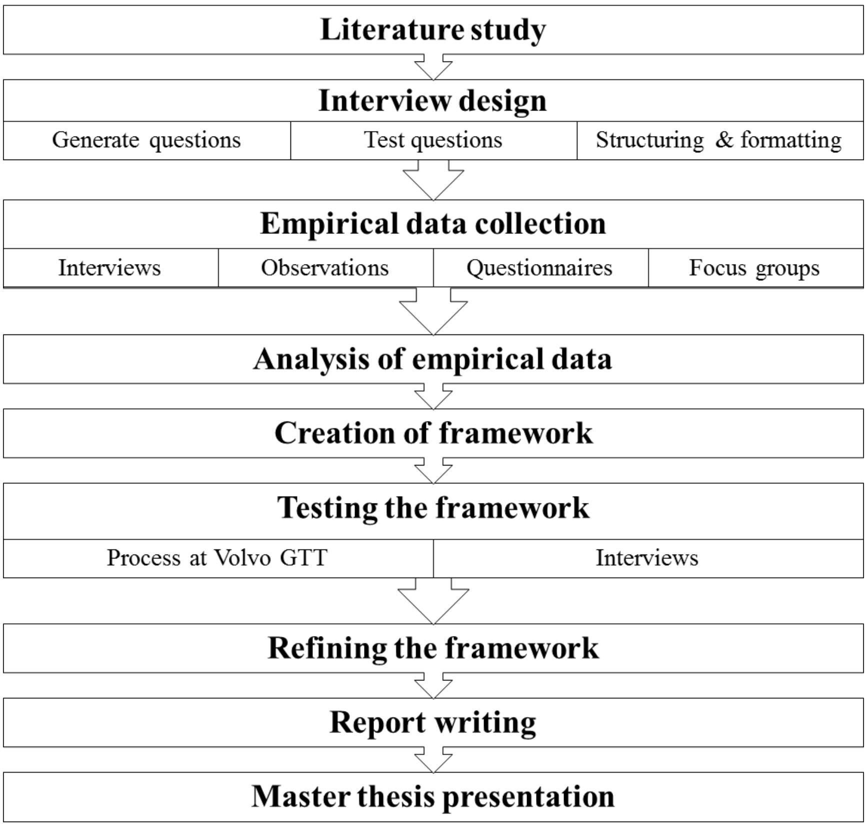

Figure 3: Research process

2.4.1 Data collection

The different research methods for collecting data are presented in the following sections.

2.4.1.1 Literature study

Literature has been studied before and during the thesis by taking part of previous research reading scientific articles, taking part of journals, written papers, books and lectures. Topics of main focus are: VRM, decision making regarding processes, VMEA, variation and roust process design and business process modeling. Previous six sigma project at Volvo GTT in 2013 has also been reviewed.

2.4.1.2 Observations

Observations will be used in order to catch the unspoken information during interviews and informal conversations. The body language will be studied to enhance understanding of the respondents' answers. The interviews are held with representatives from the following companies: Volvo GTT, Volvo GTO, Ericsson AB and Tetra Pak.

2.4.1.3 Interviews

Interviews can take place in different: forms, conditions and environments, involving varying types of people with different experiences and backgrounds. According to Rowley (2012), interviews are a verbal exchange of information done face-to-face where the interviewer tries to collect information from the respondent in order to gain an understanding. Interviews can also be held via telephone and online via internet where videoconferences are possible. Interviews were mainly held at Volvo GTT in Gothenburg and then also at Volvo GTO, Tetra Pak and Ericsson AB. For the development of the P-VMEA, interviews with managers were split into two sessions - one at the beginning of the investigation and one after that the methodology was developed (See Figure 3). The aim of the first section was to understand how process variation is visualized in the different companies today, and what managers are interested in while for the aim of the second session was to present to the respondent different examples of VMEA and process mapping integrations to get an evaluation of the proposed integration model. The aim of the second session was changed during the evolution of the thesis work.

2.4.1.4 Interview structure

The purpose of the interviews is to gain knowledge about the experience of people and to identify the needs and wants of the potential stakeholders. The structure was carefully selected since the nature of the data depends on the particular typology of the interviews that are conducted. The interviews can be classified according to the "level of structure" (Rowley, 2012). In particular, this study contains unstructured and semi-structured interviews that will provide us with qualitative data (Di Cicco-Bloom, 2006). The semi-structured interviews are a mix of well-prepared questions that the interviewer will submit to the respondent, like a structured interview but with a higher degree of flexibility in time for each question, the question order and the kind of answers, this structure was chosen for the first section of interviews. For this study unstructured interviews were opted for the second section of interviews since this structure leaves the participant free in the type of answer. During the interview the interviewer can tie the questions according to the interlocutor and to the flow of the discussion. The interview questions are designed in such that they will help answering the research questions (see Table 1).

Table 1: Interview questions design

Area	**Purpose**	**Sub-Research question**
1. Process variation management	To get a general view regarding how managers are managing business process variation.	Sub-Research question 1
2. Decision making	To understand how mangers take decisions today and what data or information they currently use and need. The results will be used as input for developing the P-VMEA methodology in order to enhance fact based	Sub-Research question 2 Sub-Research question 3

	and rapid decisions.	
3. P-VMEA as a managerial tool	To investigate the managers' needs regarding process information-and data presentation for collecting key tool characteristics by using the Kano-model.	Sub-Research question 1 Sub-Research question 2

2.4.1.5 Interview conducting

As a first step, the time for each interview was determined to 45 minutes, but the time frame was flexible according to the flow of the discussion and included the Kano analysis. Afterwards, the interview questions were selected. In order to choose the most suitable questions, a brainstorming session around the topic of the research was performed and before starting the real interviews, a pilot test was conducted. The pilot enhanced to understand if the selected questions were appropriate, understandable and useful for gaining knowledge. If not, the questions were re-formulated and re-tested.

2.4.1.6 Interview sample

The interview sample was selected in such way to include and represent different managers at different departments and at different hierarchy levels. A convenient sampling method was used in order to take advantage of the wide spread and valuable resources at Volvo GTT and Volvo GTO. The candidates were careful selected in order to involve managers, directors, vice presidents and senior vice presidents at Volvo GTT and Volvo GTO. Taking the opportunity of involving other organisations with experienced upper level managers from the field of Operational Excellence and Efficiency, benchmarking was used. The benchmark candidates were selected from two large companies: Ericsson AB in Sweden and Tetra Pak in Italy. The initial sample of candidates was expanded due to the participation of other candidates that were involved by previous interviewees; it became a snowball effect (Bryman and Bell, 2011).

2.4.1.7 Interviews using the Kano model

The interview session 1, Area 3 (see Table 1) is, in comparison to Area 1 and Area 2, based on the Kano model (see Section 3.3). Keeping in mind the research questions (see Figure 1), a literature research was conducted on "How to write a good report" (Armstrong 2011; Forsyth 2010; Hering and Hering 2010) with the purpose to collect different attributes. This was done via a brainstorming session where the different associations to Variation Risk Management, Variation and report were generated and written on post-its. The goal was to obtain a fair number of questions, no too low but neither too high for not losing the candidates' attention. Thus, the generated items were organised and grouped according to their correlation in order to have at the end one item for each macro area. After this first screening other items were eliminated if they were not strongly related with the research field. Before submitting the survey, the selected Items for the Kano analysis were put in a Pilot that was discussed with the researcher and Volvo GTT manager, Per Johansson, and pre-tested.

2.5 Data Analysis

Data must be collected in a strategic way to be faster analysed. The interviewer can record the candidates to be able to analyse the results afterward and to use the documents and files produced during the interview (Hannabuss, 1996).

In order to divide and organise the data into categories that can be easily coded and processed, Hannabuss (1996) suggests the interview answers to be collected by using an interview schedule. This form was constructed in order to gather not only the Explicit Verbal communication but also, where it was possible, the Explicit Manifest communication, what was clearly understood during the conversation and the Implicit Latent communication, what was indirectly understood during the flow of the discussion (see Appendix 2).

2.6 Research Quality

In this thesis, a quality criterion for the researchers is to achieve a high research quality by collecting real and natural situations data and not artificial data. Bryman and Bell (2011) introduce four criteria for evaluating the quality of a qualitative research, those are: confirmability, dependability, transferability and credibility (see Figure 4).

Confirmability
Confirmability regards to how large extent personal values and theoretical inclinations have been avoided and if the researcher has acted in a good faith (Bryman and Bell, 2011). Achieving a complete objectivity in qualitative studies is impossible but the degree of objectivity between researchers can vary. In this study, even though the researchers are a part of an inner relation to the research objects, there will not be any evident reason for imply subjectivity of the research in the analysis. During interviews, leading questions will be avoided in order to not lead the respondents in any particular direction.

Dependability
Dependability is often referred to trustworthiness and entails ensuring the research consistency throughout the work in, for example, interview transcripts, fieldwork notes, interviewing the same people and decisions for data analysis. What can be of a challenge in a qualitative research is the high amount of data sets and auditing all data. Therefore, auditing has not been so popular since it takes extremely much time which might be a main reason for why the method has not become an approach for research validation. (Bryman and Bell (2011)

The study will to some extent achieve high dependability. The procedure of developing P-VMEA can be followed by studying the methodology, theoretical and empirical sections. Fieldnotes have been kept in the same structure and have been stored directly into the computer in same way for all interviews in order to keep track of all interview information. What can be of a challenge is gathering the exactly same data with the same people and their present minds and since the people involved in this study now are more aware about variation risk management and P-VMEA.

Transferability

Qualitative studies often entails intensive studies of individuals or a small group and goes into depth instead of the breadth which is often a preoccupation in this context (Bryman and Bell, 2011). Transferability concerns the degree of which the research study hold in other context than the context of the research study. In this study, several organisations and people from different working fields will be involved for testing if the study can hold in other contexts than only engineering. Generalizable conclusions will be drawn and different examples of cases in the study will be provided.

Credibility

Research credibility involves ensuring that the research has been carried out in a good practice and that the findings of the research are submitted to the social world members as the members want to get confirmed that the researcher has understood the social world correctly (Bryman and Bell, 2011). To obtain as much information as possible interviews must be held with different employees and managers. According to Bryman and Bell (2011), data collection via interviews should be done when the information is not observable, for example an action in the past. However, this will be a challenge in this thesis work.

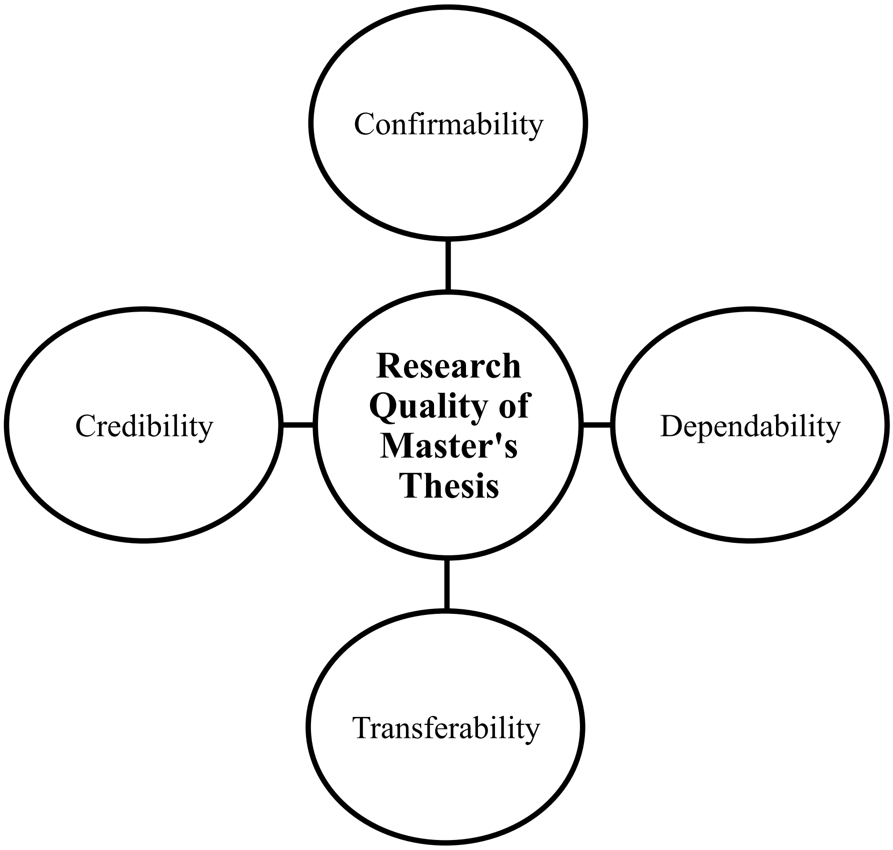

Figure 4: Dimensions of research quality of the Master's Thesis

2.7 Research Ethics & Anonymity

Bryman and Bell (2011) stresses the importance of taking research ethics into considerations as researchers otherwise can create harm to participants. The interviewees can feel a lack of informed consent, that their privacy is invaded or that they are experiencing deception. To avoid this, informing the interviewees before the interview starts about what the purpose of the research is, how their results will be used and giving them alternatives to review the written work regarding interview results before any publishing. All the respondents will be kept anonym and be referred to as "interviewee", "candidate" or perhaps the job title.

2.7.1 Trustworthiness

To obtain research trustworthiness four areas are considered: credibility, transferability, dependability and conformability. To ensure high credibility, data triangulation will be used to largest possible extent, meaning that several sources will be used for collecting data. In this thesis literature study will be combined with interviews and taking part of internal company documents. By describing the research procedures and the method thoroughly, transferability will to some extent be achieved. During the interviews some observations will be made and attention will be paid to the interviewee to avoid misinterpretation and questions will be clarified as much as possible to achieve dependability. Also, a white book will be used to keep track of information, actions and working progress to ensure that no information is missed or forgotten. The investigators will try to stay as objective as possible to achieve high conformability. However, the reader should be aware that this is a qualitative study and to some extent objectivity is unavoidable. (Bryman and Bell, 2011)

Theoretical Framework

In this chapter, the theory base of this thesis will be presented with the aim to provide the reader with a theoretical background for the forthcoming chapters. The concept of Quality and Variation will be explained, followed by an introduction to Variation Risk Management. The basic concepts regarding how to make decisions concerning processes in organisations are presented followed by the theory behind the Kano model for investigating customer needs. A description of the Variation Mode and Effect Analysis and the Business Process theory will conclude this chapter.

3 THEORETICAL FRAMEWORK

3.1 Quality and variation

3.1.1 What is quality?

Law (2009) defines quality as:

"The totality of the features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs".

In other words, companies today needs to meet customer needs by providing them a product/ service that can meet or even exceed their expectations. This is achieved by choosing the right product/service attributes and characteristics which can be tangible, for example speed or durability, or intangible like taste, smell and colour variants. These can be either objectively measured or be evaluated according to the consumer's perception. Law (2009)

According to Griffin and Hauser (1993) a customer need is a "description" of the product or service and the benefits it will provide, described in the words of the customer itself.

Nowadays quality is the engine of the new economy, more and more consumers seek for companies that are able to provide them a combination of high quality products at a reasonable price (Law, 2009). Quality of a product or a service satisfies a customer need on different levels (see Section 3.5). Thus in a competitive environment, understanding the Voice of the Customer (VOC) is crucial.

3.1.2 Voice of the Customer (VOC)

Griffin and Hauser (1993) stress the essence of knowing the customer needs, knowing how to structure and prioritise the needs in order for companies to know where to put the right focus. This philosophy is a part of the Total Quality Management (TQM) theory with the focus on Quality Function Deployment (QFD). TQM and QFD will not be further explained in this thesis but can be found in Griffin and Hauser (1993).

3.1.2.1 Strategic and operational decisions based on VOC

Griffin and Hauser (1993) address the "Voice of the Customer" (VOC) as a customer input to companies when both operational and strategic decisions should be made. VOC provides organisations with customer needs in a hierarchical order, giving important information about what customer needs that are must be met or the customer might be dissatisfied. This is done via customer needs prioritizations.

3.1.2.2 Why is the VOC important?

Developing products or services in accordance with customer needs will more likely lead to more satisfied customers (Matzler, 1996). In TQM, basing decisions on the VOC is a key criterion. In the Baldrige Award, VOC is an important concept since "Quality is based on customer" is the first criterium (Griffin and Hauser (1993), NIST p.2 (1991), Juran (1989)). Then, if a developed product or service is not satisfying the basic needs, the customer will be dissatisfied. However, organisations should not be restricted and take the customer needs as a solution but rather use them as guidelines. Otherwise, the organisation risks killing or limiting the creativity of the developers.

3.1.3 What is variation?

Brue and Howes (2006) state that variation is the fluctuations present in the output of a process. Everyday variation plays an important role in our life and affects us differently, for example, the tram that often deviates from the scheduled time although the way is always the same and it is marked by tramlines causing destination arrival time to be later than expected. Today, there are more and more awareness that two products or two services cannot be exactly identical. Sometimes the variation is small and acceptable, but sometimes it is not acceptable, for example if we need to rush for the tram that is obviously leaving earlier. In conclusion, variation can make a stakeholder satisfied or dissatisfied depending on the circumstances and it can decide the future or the continuity of a company in the market. According to Barone and Lo Franco (2012) there are two sources of variation: Natural-cause and Special-cause of variations. Natural-causes of variation are variations that are known and usually assessable in the process. With special-causes of variation, variations are not always possible to predict or detect and is usually not even measurable. A natural-source of variation is represented by a noise factor in the system whereas a special-cause of variation can be usually fixed by operating on the process. The variation is measured in standard deviations (σ) that represent the deviation from the mean (μ).

3.2 Variation Risk Management and Decision Making

Variation Risk Management (VRM) is a way to work with managing risks, focusing, as by the name, especially on variations (Thornton, 2004). Wall (2009) defines a risk as the probability of an outcome to be either unwanted or unacceptable. Making decisions can therefore be highly complex as the variation is constantly present (Benítes et al., 2012)

3.2.1 VRM

When talking about risks within organisations, risk is often related to negative matters of not knowing what to expect from the future outcome of a product/service or from any process activity. According to Park (2010), the risk management philosophy strives to maximize the positive impacts and minimize the negative consequences in the process of new product development. Ahmed et al. (2007) stresses the importance of making the weaknesses in the process more visible in order to manage them to prevent possible negative impacts. Thornton (2004) presents VRM in three phases: Identification, Assessment and Mitigation (see Figure 5).

Figure 5: Variation Risk Management model (after Thornton, 2004)

Identification
Risk identification sets the foundation for the risk assessment and mitigation steps (Tchankova, 2002). If organizations do not succeed in identifying the correct risks, the risks can become non-manageable and lead to process ineffectiveness. Thus, the risks need to be identified in order to avoid unexpected consequences and to select suitable management actions (Greene and Trieschmann, 1984). The identification step starts with identifying the VRM scope and after the system requirements, which could be either customer, regulatory or corporate requirements. To identify the VOC the QFD methodology and the Kano model can be used (see Sections 3.1.2 and 3.5). Instead, regulatory and corporate requirements are usually already pre-defined. Thereafter, all requirements are ranked with respect to the level of importance.

According to Thornton (2004), there are two main outputs of the identification phase:

1. Critical system requirements must be identified
2. A flowdown of the variation must be created

Finding the critical system requirements and narrowing the scope of investigation are important for reducing the complexity of the identification phase as well as keeping the right customer-focus from the beginning. The flowdown of variation consists of a breakdown of the main Key Product Characteristics (KPCs) in as many sub-KPC levels as the variation is understood at a satisfactory level. Using the variation flowdown, the sources of variation affecting the Key Product Characteristics (KPCs) (see Section3.4.1) are investigated.

Assessment
Assessing variation is done to provide a data driven approach to the VRM work. This phase consist in prioritizing among and within the selected areas of improvement. Moreover, the assessment phase with its holistic approach shows the impact of variation on the organisation

and allows displaying the associated costs. According to Thornton (2004), two main outputs of the assessment stage are:

1. A risk prioritisation, where the associated variation risks are identified and graded
2. A quantification of how the variation on all system levels are transferred to the KPC

Without an assessment of the findings in the identification stage, applying different mitigation strategies to reduce the impact of variations on the KPC will be difficult since it is impossible to mitigate all variations at once. A prioritization is therefore a must. (Thornton, 2004)

Mitigation

The selection of an appropriate strategy approach for mitigating the risks as cost-effective as possible can be done in different ways. Organisations can mitigate risks by changing the process design, changing the process, driving process improvements initiatives as well as using monitoring actions or inspection. The purpose of mitigation is to take actions based upon the previous information gathered during the identification and assessment steps. According to Thornton (2004), mitigation seeks to either reduce the source of variation and their impact on the selected KPC. There are different mitigation strategies depending on what necessary actions will be taken, for example process changes, process improvements or process monitoring.

The three main outputs of the Mitigation stage are:

1. Reduced risk
2. Reduced cost
3. Improved quality

Mitigation strategies will not be further described in this thesis but can be found in Thornton (2004). What is important to consider are the costs and the benefits of each strategy approach which is an organisational trade-off situation. Also, it is very important that the project progressions and improvements are recorded for future learnings. (Thornton, 2004)

3.2.2 Decision making

Making decision is becoming more complex due to an increasing numbers of possible alternatives and conflicting goals (Benítes et al. 2012). Therefore, powerful systems for making decisions are needed which can look very different from organisation to organisation. Decision making can involve peoples' different ways of interpreting a problem, their views on how goals should be formed and the combining of information that lead to solutions (Patrick et al. 2013). The way people make decisions varies as they seek various types and amounts of information. This can be due to several factors such as age, personal experience, knowledge, social context and environment, affective context and the decision domain. According to Patrick et al. (2013), the strongest predictor of decision outcome are both the intermediate and basic cognitive skills that people have developed in terms of working memory and processing speed.

3.2.2.1 Risks in decision making

From a substantive perspective, there are two risks that are important to consider.

Risk 1: Process Displaces Substance – Negotiated nonsense rather than negotiated knowledge

Risk 2: Insufficient Use of New – Lack of innovative insights

With Risk 1, it means that the parties involved in the decision making process have such an interest that the interest itself becomes dominant. This means that the parties are willing to accept an outcome of the process that is, for them, appealing and does not have to include a scientific backup. In fact, the parties can by themselves formulate the problem and come up with, for them, a suitable solution. Any views of experts or correction by substantive insights are most probably not accepted by the parties. If the problem is of unstructured character, the ideal step for the parties would, according to De Brujin et al. (2010), be to seek negotiated knowledge. A negotiated knowledge, so called substantive knowledge, is characterized by its acceptance among the stakeholders and the scientific criticism. Risk 2 concerns that the decision making might lack innovation for the selected process and does not include so much of new insights. Participating people, having managerial positions in the process, could be unaware of this. Another theory is that the participating experts are simply not disclosing all information that could be relevant or available, this can be due to the fear that the idea is judged as no good, or that someone can steal it or moreover to lose their dominant role within the organisation (De Brujin et al. 2010)

3.2.2.2 Four strategy approaches

When making decisions about processes, experts working in or close to the actual process can be involved (De Brujin et al., 2010). However, expert opinions are not always accepted by the process stakeholders. De Brujin et al. (2010) claims that there are several reasons and explanations for the ignorance of the experts and the reasons for this (see Table 2). Different strategy approaches and remedy are needed depending on *why* the expert opinions are not accepted. The strategic approach also needs to consider the relationship between the substance in the process and the process itself.

Table 2: Four strategy approaches involving experts in the decision making process (After De Brujin et al., 2010)

	Why expert opinions are not accepted	**Remedy - Improvement areas in need of actions**	**Relationship substance – process**
Strategy 1	Insufficient quality of the analysis	The analysis	Sequential: first the substantive analysis, then the decision-making process
Strategy 2	Stakeholders does not understand the analysis	The communication about the analysis	Sequential: first the substantive analysis, then the decision-making process

Strategy 3	Stakeholders does not commit to the way in which the analysis has been performed and do not commit to the results either	The interaction between experts and stakeholders about the design and implementation of the analysis, allowing the parties to commit	Sequential: first the substantive analysis, then the decision-making process
Strategy 4	Mismatch between the analysis and the dynamics of the decision making process	The interaction between experts and stakeholders with focus on the moments of interactions	Analysis and decision making largely proceed in parallel

The first strategy concerns the insufficient authority of the expert's analysis and is the most classical strategy. Here, the focus of the improvement is the quality of the analysis. For example, sensitivity analysis of other types of data or boundaries of the system can be performed in order to strengthen the authority of the conclusion. For the second strategy, communication is the main core. Communication is a unilateral activity. The stakeholders make a decision that is based on the facts presented by the experts, but the facts might not always be self-evident. How the facts and results are communicated is important, especially in terms of language. The language of a scientists or an expert could differ from the language of the decision maker(s), therefore the risks of misinterpretations or not understanding at all, are present. The language should be adapted so that is it understood by the stakeholders and fit into their frame of reference. This is a well discussed area within risk where analysts produce reports that are difficult for other people to interpret and thereby, the desired impact is not reached. The third strategy mainly focuses on interaction, which is, in comparison to communication, a bilateral activity where stakeholders are involved in the analysis instead of getting the analysis explained to them. The key idea of the third strategy is to get stakeholders and experts to share the same view about the method of the analysis. This strategy is based upon peoples' assumptions and allows to critically questioning each other in an opener way, this leads to increase the acceptance of the results. The fourth strategy approach involves the following of the process dynamics where the expert is a part of the decision making process. If experts follow the dynamics of the process they can, to some extends, do the analysis parallel with the decision making. By doing this, the sequential analysis and the decision making phase become more synchronized in time. Involving the expert opinion in the decision making stage increases the quality of the decision and reduces the risk of misfit between the parties. Furthermore, decision makers are kept informed during the analysis, which increases their degree of commitment. (De Brujin et al., 2010)

3.3 The Kano Model

As discussed in Section 3.1, delighted customers are important for the success of the company. Today, companies need to anticipate the next generation of needs and try to build products that can meet the new customers' expectations and thus, that can increase the quality of the products. According to Matzler (1996) the Kano model is a methodology that determines what effect the attributes of products/services have on the satisfaction of the customer. The Kano model is based on the assumption that quality is a multidimensional concept and thereby a product can be of high quality in some attributes and of low quality in others (Löfgren, 2005). Therefore, the purpose of the Kano analysis is to select the main attributes that are able to increase customer satisfaction.

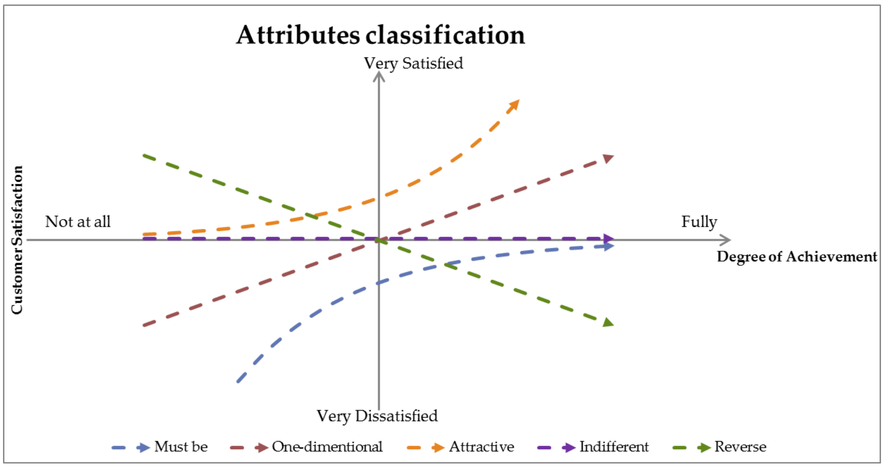

Figure 6: The Kano model categories

To select the right attributes, the attributes are categorised into six different categories: Must-be, One-dimensional, Attractive, Indifferent, Reverse and Questionable (Chaudha, 2011).

Must-be (M)

These are the basic attributes for the customers, thus if they are not satisfied the customer will be dissatisfied but if they are fulfilled they do not represent a reason of satisfaction for the customer. These attributes are not always expressed, spoken, by the customer.

One-dimensional (O)

These attributes proportionally make the customers satisfied when they are fulfilled and dissatisfied when not. One-dimensional attributes are often spoken and they are the foundation of the competition among companies.

Attractive (A)

These attributes are often unexpected by the customers but when these are fulfilled they are able to make the customer very satisfied. If a company can understand these attributes in advance, for instance by using the Kano model, it can make a significant difference in profit and customer loyalty can be easier built.

Indifferent (I)

The customer is completely indifferent to these attributes in the meaning that if these increase or decrease in quality the customer satisfaction is not affected

Reverse (R)

These attributes have an opposite impact on the customer satisfaction, the more these attributes are added to a product or a service, the more the customer dissatisfaction will increase.

Questionable (Q)

In this classification all requirements that during the analysis receives an illogical response that could be due to misunderstandings during the interviews or problems with the formulation of the questions.

3.3.1 Kano Model survey

The Kano survey is a tool used in the Kano model for catching the product and service attributes based upon the VOC and is submitted to the respondents through a questionnaire. One functional and one dysfunctional question are formulated for each attribute that will be evaluated by using the model. (Vontivilu, 2005)

Examples of these questions are:

- If the package is of ecological material, how do you feel? (Functional)
- If the package is not of ecological material, how do you feel? (Dysfunctional)

For each question only five answers are accepted: I like it, it must be, I am neutral, I can live with it and I dislike it. These can be adapted but the stated answers are recommended (Matzler, 1996)

3.3.2 Kano model interpretation

The results of the Kano survey are analysed using the Kano evaluation table (Berger et al, 1993). Using Table 3, the dysfunctional and the functional answers of each respondent are used for classifying each attribute into one of the six categories.

Table 3: Kano evaluation table of customer requirement (Matzler, 1996)

Quality attribute		Dysfunctional					A = Attractive O = One-dimensional M = Must-be I = Indifferent R = Reverse Q = Questionable
		like	must-be	neutral	live with	dislike	
Functional	like	Q	A	A	A	O	
	must-be	R	I	I	I	M	
	neutral	R	I	I	I	M	
	live with	R	I	I	I	M	
	dislike	R	R	R	R	Q	

For each characteristic the answers provided by the different respondents are counted and grouped. In addition, the results of the analysis are displayed by using a pie chart (see figure 7) that represents in percentage (%) the frequency of each answer. Furthermore for each characteristic the customer satisfaction coefficients can be computed, see Equation (1) and Equation (2). (Matzler, 1996)

$$EXTENT\ OF\ SATISFACTION = \frac{A+O}{A+O+M+I} \quad (1)$$

$$EXTENT\ OF\ DISSATISFACTION = \frac{O+M}{(A+O+M+I)*(-1)} \quad (2)$$

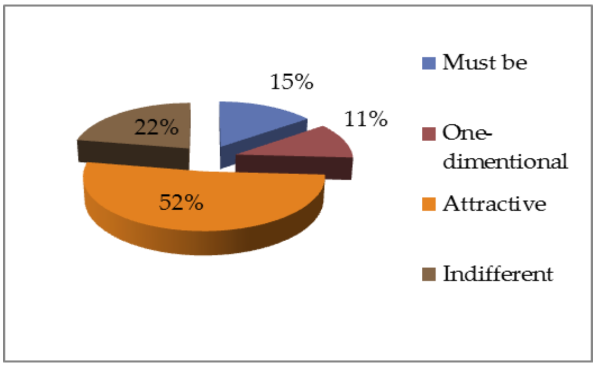

Figure 7: Example of analysis of respondents' answers

3.3.3 Evaluation rule

The results are evaluated keeping in mind that M > O > A > I, this means that the needs that will lead dissatisfied customers if not fulfilled must have higher priority. To conclude the analysis and summarise the results, a graph is created – reporting in the vertical axis the Extent of Satisfaction (see Equation 1) and in the horizontal axis the Extent of Dissatisfaction (see Equation 2) (see Figure 8). In this figure, all the different attributes are presented and classified inside their respective classifications area. (Matzler, 1996)

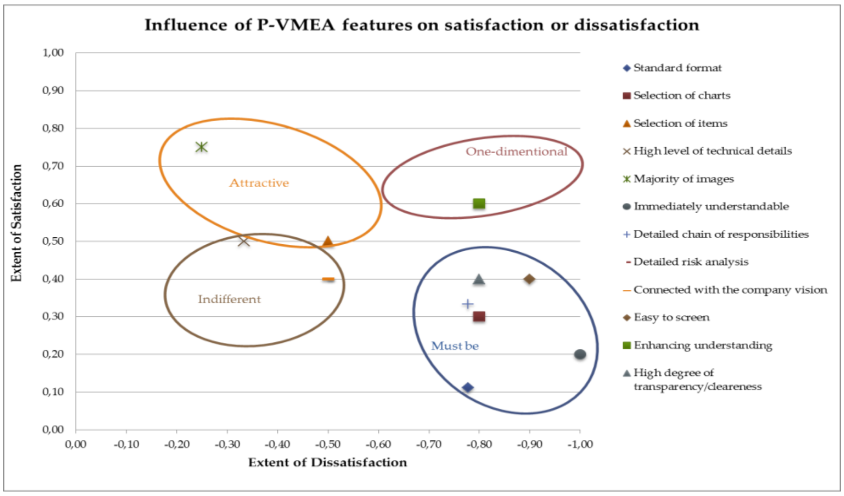

Figure 8: Example of Kano analysis

3.4 Variation Mode and Effect Analysis

Variation Mode and Effect Analysis (VMEA) is a method used in product development, seeking to help in a systematically way to identify noise factors and to assess the effects of them on Key Product Characteristics (KPCs) (Chakhunashvili et al., 2004). Similar to Failure Mode and Effects Analysis (FMEA), VMEA is an assessing method made by people. The main difference between the methods is that FMEA emphasise on failure modes while VMEA focuses on variation and the risks associated with them with respect to KPC.

"The goal of VMEA is to identify and prioritize noise factors that significantly contribute to the variability of KPCs and might yield unwanted consequences with respect to safety, compliance with governmental regulations, and functional requirements." Chakhunashvili et al. (2004:364).

By applying VMEA to a product, a structured way is used on how to prioritize noise factor that are contributing to and affecting the KPC's variability. Noise factors not only contribute to the variability but also increase the probability of unwanted consequences such as safety risks. A VMEA is performed in several steps and at different complexity levels depending on different factors which will be described below. There are three different types of VMEA: Basic VMEA, Enhanced VMEA and Probabilistic VMEA (Barone and Lo Franco, 2012). Basic VMEA is based on experts' judgements and does not demand a higher amount of quantitative data as the other two VMEA models. The probabilistic VMEA is almost impossible to apply without an extensive data access and cannot be performed with only experts' knowledge. However, all types of VMEA provide a Variation Risk Prioritization Number (VRPN), showing in which areas the variation is highly transmitted to the selected KPC. VMEA can be useful for companies when wanting to improve a selected KPC and can guide companies in decisions on what strategy to go for in efforts to create and attain robust and reliable products. For this study, the Basic VMEA will be explained in detail.

3.4.1 Key Product Characteristics (KPC)

Chakhunashvili et al. (2004) shows a way to break down the selected KPC into Sub-KPCs and NFs influencing each Sub-KPC. A Sub-KPC is defined as:

"Key varying elements of a product or subsystem through which variation is transferred to the KPC" (Chakhunashvili et al., 2004:365)

The breakdown of KPC and the different noise factors are presented in an Ishikawa diagram and are illustrated in figure 9 below. The number of Sub-levels and NF are decided by the performer of the method and can be done far more complex with increased number of levels or be kept at a general level.

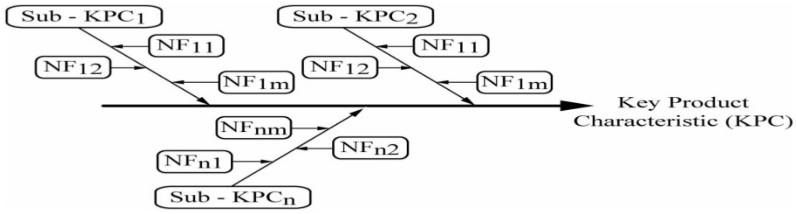

Figure 9: Variation Transfer Model - Ishikawa diagram (Chakhunashvili et al., 2004)

3.4.2 P-diagram

The P-diagram (see Figure 10) is a common conceptual model used within Robust Design Methodology (RDM) (see Arvidsson and Gremyr, 2008) to demonstrate the relationship between signal factors, noise factors, control factors and the response

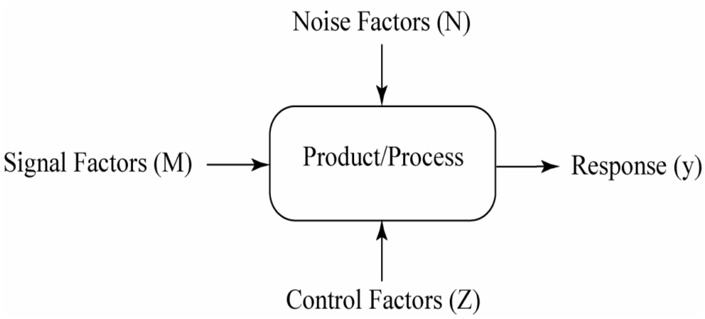

Figure 10: P-diagram (Chakhunashvili et al.2004 adopted from M.S. Phadke, Quality Engineering using Robust Design, 1989, Prentice Hall)

In Figure 10, the P-diagram illustrates how input (M) is affected by disturbances (N) that are mitigated by control factors (Z) to deliver an output (y) (Phadke 1989; Taguchi 2000). In an ideal state, the functional relationship between the signal factors (M) and the response (y) is expressed as Y=f(M), meaning that the function's target is equal to what comes into it, M.). This is harder to achieve in reality than in theory due to noise factors (N) affecting the input so that the response is not equal to f(M). (Chakhunashvili et al., 2004)

3.4.3 Noise factors

Sources of variation, also known as noise factors (NFs) are factors that can be unwanted, hard to control, expensive to control or difficult to eliminate (Chakhunashvili et al., 2004). NFs can be classified into: environmental variables, manufacturing variation and product deterioration. In order to control these NFs and mitigate the effects of them on the response, control factors (Z) are needed. Hence, Chakhunashvili et al. (2004) assumes the relationship between the elements in the P-diagram to be expressed as: Y=Y(M,N,Z). The expected outcome is wanted to be as close to targeted value f(M) as possible.

3.4.4 The General steps of VMEA

VMEA is preferably performed in a cross functional group and the general four steps of the methodology are similar for the Basic, the Enhanced and the Probabilistic VMEA model (Johansson et al. 2006):

3.4.4.1 Step 1 – Selection and breakdown of KPC

The KPC is broken down into Sub-KPCs, until the requested level of details is reached, and into NFs that affect them (see Figure 11).

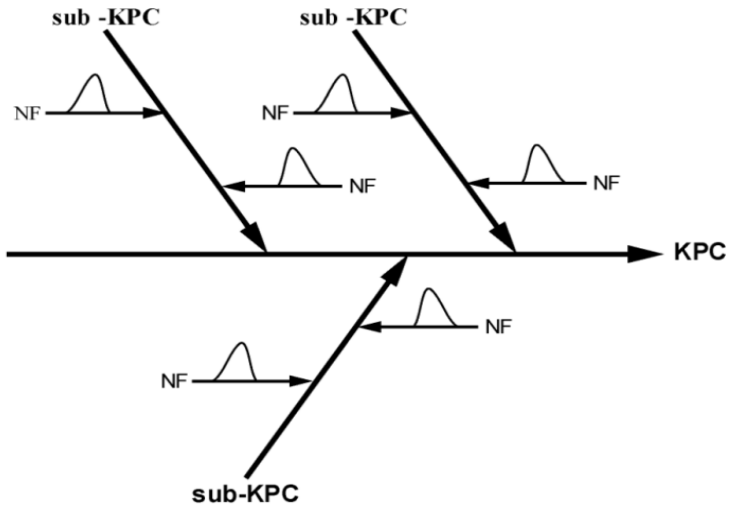

Figure 11: Breakdown of KPC into Sub-KPC and NFs (Johansson et al., 2006)

In product development an important concern is defining what product characteristics are important to consider for their impact on the KPC. To define product characteristics or for this thesis process characteristics, different alternatives can be chosen (Chakhunashvili et al., 2004). For example a brainstorming session using Affinity Interrelation Method (AIM) can be a method, especially for processes (see Chapter 6.4). Another commonly product development approach is having a Quality Function Deployment (QFD) session in order to identify product characteristics in order to know the needs of the customers. Why a cross functional groups is encouraged is because different people will contribute differently with experiences, knowledge and questioning the problem differently. In other words, cross functional teams will ensure to a larger extent that the whole product or system is considered to a wider domain.

3.4.4.2 Step 2 – Sensitivity Assessment

The second step of the VMEA methodology is to assess respectively the sensitivity of the KPC to each of the Sub-KPC's variation actions and the sub-KPCs' sensitivity to the NF actions. The sensitivity assessment criteria are shown in Table 4 which reports the different levels of sensitivity of KPC to Sub-KPC and Sub-KPC to NF. The sensitivity regards and should be decided upon how much of the variation that is transmitted to the above sub-level. The score is given in intervals of two, with a range of 1-10. (Johansson et al., 2006)

Table 4: Assessment criteria for assessing the sensitivity of NFs

Sensitivity	Criteria for assessing sensitivity	Score
Very low	The variation of NF (alternatively of Sub-KPC) is not (almost) at all transmitted to Sub-KPC (alternatively to KPC)	1–2
Low	The variation of NF (alternatively of Sub-KPC) is transmitted to Sub-KPC (alternatively to KPC) to small degrees	3–4
Moderate	The variation of NF (alternatively of Sub-KPC) is transmitted to Sub-KPC (alternatively to KPC) to moderate degrees	5–6
High	The variation of NF (alternatively of Sub-KPC) is transmitted to Sub-KPC (alternatively to KPC) to high degrees	7–8
Very high	The variation of NF (alternatively of Sub-KPC) is transmitted to Sub-KPC (alternatively to KPC) to very high degrees	9–10

Again, it is important to have a cross functional group making the assessment to get as reliable and close to reality assessment as possible. To enhance the sensitivity assessment the participants can use objective measures or subjective assessments, based upon participants' theoretical knowledge and their experience. What is important to have in mind is that some subjectivity will take place since 100% objectivity is impossible to achieve when people are involved. In early phases of development Johansson et al. (2006) favours to use participants' knowledge and experience about sensitivities since not so much information are present.

3.4.4.3 Sensitivity fan

Barone and Lo Franco (2012) suggest another way for assessing the sensitivity in the enhanced VMEA, namely the sensitivity fan. The purpose is to graphically represent the so called real nature of the sensitivity (Bergman, 2009). The sensitivity fan uses ten different lines differentiated by the slope, every slope represents a different degree of transmission of variation and a different sensitivity scores. The highest score, 60, is corresponding to an infinite number on an unrealistic scale and is therefore not vertical. The sensitivity fan is based on the studies of Box (1988) on how to modify the design of a product for minimising the effect of component variation. To explain this concept Box (1988) use the example of the pendulum length and its period, showing how the variation is transmitted to the period is not constant with the length. As a consequence, the engineers should build the pendulum as long as possible for reducing the transmitted variation. In the VMEA analysis, for values greater than 1 the variation is amplified when it is transmitted and for value lower than 1 it is reduced while at zero value means absolutely insensitivity and a value equal to 1 reflects proportional sensitivity (Barone and Lo Franco, 2012). Values greater than 1 are the most important because they indicate an inconsistency in the design (Bergman, 2009).

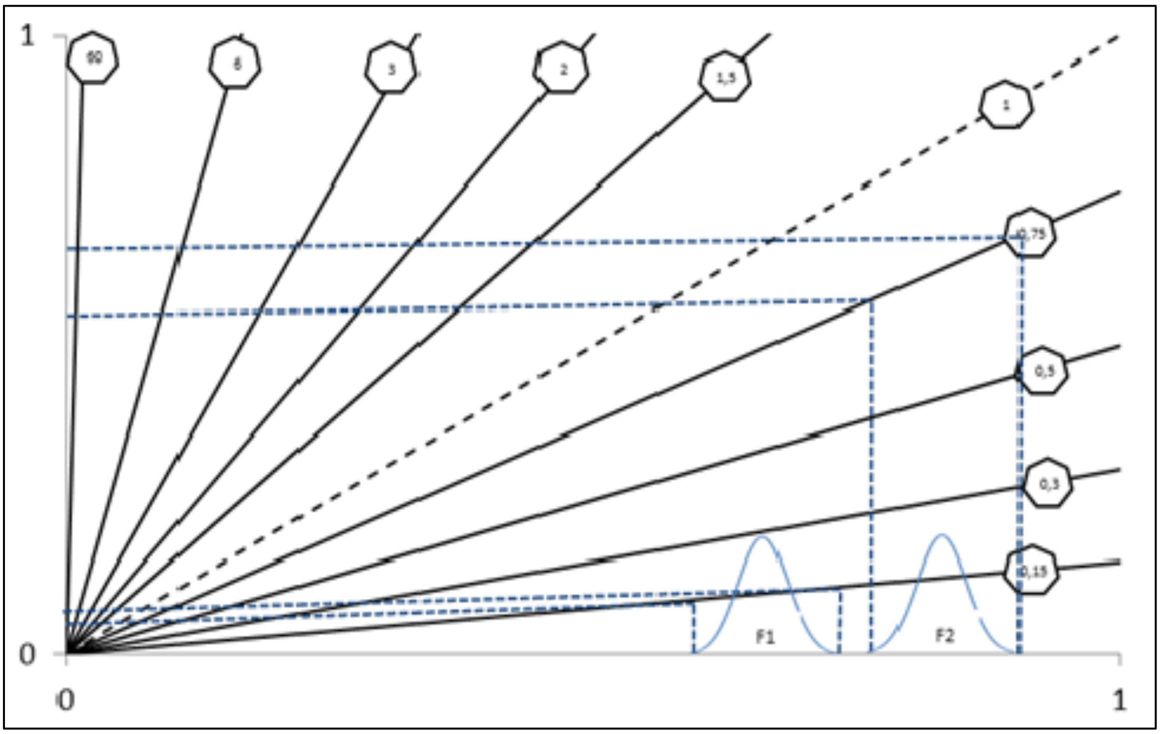

Figure 12: The sensitivity fan (Barone and Lo Franco, 2012)

3.4.4.4 Step 3 – Variation size assessment

An assessment is made on the variation size, the magnitude, of the NF based on certain criteria (see Table 5). The variation scale of the NF ranges between Very low up to Very high and similar scoring scale is used as in Step 2, ranging from 1-10 with a factor two in difference between each step. A value of 10 means very high fluctuations no matter in what the operating conditions are. A score 1 is the opposite and symbolises almost no variation at all, close to a non-existing variation.

Table 5: Assessment criteria for assessing the variation of NF

Variation of NF	Criteria for assessing the variation of NF	Score
Very low	NF is considered to be almost constant in all possible conditions	1–2
Low	NF exhibits small fluctuations or lies within a small interval in all possible conditions	3–4
Moderate	NF exhibits visible but moderate fluctuations in all conditions	5–6
High	NF exhibits visible and high fluctuations in all conditions	7–8
Very high	NF exhibits very high fluctuations in all conditions	9–10

The judgements, done by the cross functional group, should be based on real operating conditions. Important is for the group to separate between step 2 and step 3 as this step only concerns the size of the variation and not how much it is influencing the KPC or Sub-KPC.

3.4.4.5 Step 4 – Variation Risk Assessment and Prioritisation (VRPN)

For each Sub-KPC based on the assessment of the NFs, a Variation Risk Prioritisation Number (VRPN) is calculated where step 1, step 2 and step 3 are essential to provide the basic information. The VRPN is calculated following the below Equation (3):

$$\boldsymbol{VRPN_{NF} = S_1^2 S_1^2 V^2} \qquad (3)$$

'S1' stands for the sensitivity that the KPC has to the Sub-KPC, meaning how much the Sub-KPC influence and affect the KPC and is the value provided from Step 2. 'S2' is also linked to the number provided from Step 2 and concerns the Sub-KPC's sensitivity to NF. 'V' represents the variation size of the NF estimated in Step 3. By multiplying S1, S2 and V when all squared, a VRPN is calculated as a product of the factors. If a Sub-KPC is influenced by more than one NF an alternative formula to calculate VRPN is (see Equation 4):

$$\boldsymbol{VRPN_{SUB-KPC}} = \sum VRPN_{NF} \qquad (4)$$

In this formula, the VRPN for the Sub-KPC is set to be equal to the sum of all NFs' calculated VRPNs with respect to the specific Sub-KPC. If a NF affects more than one Sub-KPC an overall calculation can be made by using Equation (5):

$$\mathbf{VRPN} = \frac{NF}{Overall} \qquad (5)$$

The statistical background and theory behind formula (1) and (2) is further explained and to be found in Johansson et al. (2006).

3.4.5 Visualizing the VMEA results

The VMEA results can be illustrated in a bar-chart graph. The VRPN are organized accordingly to a Pareto distribution with the highest VRPN numbers on the left (Johansson et al., 2006).

3.4.6 An example of VMEA

Below in Table 6, an example is provided regarding a fuel injection case where three Sub-KPCs are shown in the second column followed by further details about the systems. Weighting grades of each Sub-KPC, showing the importance of each Sub-KPC to the main KPC, are illustrated. In the sixth to the tenth column the results of the VMEA Steps 2, 3 and 4 are presented. (Chakhunashvili et al., 2004)

Table 6: VMEA assessments and results table (Chakhunashvili et al., 2004)

#	Sub-KPC	Associated Sub-system	Sub-system's main funtion	Weighting of Sub-KPC	Noise Factor (NF) (disturbance)	Size of variation in NF	Sensitivity of Sub-KPC to NF	VRPN (NF)	VRPN (KPC)
1	Amount of air fed into combustion chamber	Turbo	Feed air into combustion chamber	4	Air pressure	5	6	120	344
					Air moisture	8	4	128	
					Unit-to-unit variation	4	6	96	
2	Amount of fuel delivered to combustion chamber	Fuel injection system	Deliver fuel to combustion chamber	10	Air pressure	6	5	300	780
					Air moisture	8	3	240	
					Unit-to-unit variation	2	4	80	
					Fuel quality	4	4	160	
3	Amount of exhaust gases recirculated to the combustion chamber	EGR-system	Deliver exhaust gases to combustion chamber	9	Air temperature	5	4	180	102
					Coolant water temperature	4	2	72	
					Coolant water flow	2	3	54	

3.5 Business Processes

In companies today it is common to have a structured way of working based on detailed standard procedures; the collection of these procedures is called "business processes".

3.5.1 What is a business process?

According to Hammer and Champy (1993), a business process is a set of activities that requires different kinds of inputs to deliver one or more outputs that is of value to the customer. The goal of a business process can be affected by internal and external factors, causing the goal to be missed. Davenport (1993) describes a business process in terms of structured and measured collection of activities during a particular time and space whose output has a specific customer or market targeted. Davenport (1993) also stress the point of having clearly defined inputs and outputs, knowing in the chain of activities, and what the expected activities' deliverables are in order to deliver value to the customer. Processes are considered a necessity for organisations in the customer value creation procedure. Rummler and Brache (1995) stress the focus of producing a product or a service while Willoch (1994) puts more emphasis on the value apprehended by the actual customer. The ISO standard 9000:2005 QUALITY MANAGEMENT SYSTEMS — FUNDAMENTALS AND VOCABULARY and Ould (1995) highlights the required resource allocations. Relevant roles in an organisation and collaborators are a necessity to create a network of activities to achieve a common goal and create value. Ko (2009) distinguish between two types of processes, private- and public processes. Private business processes are internal enterprise processes that can be found at strategic as well as operational and management levels, for example, an internal purchase process. Public business processes are external organisations' processes, for example, a goods delivery process from another company. Processes and their characteristics are different between organisations, but there are some general processes such as managerial processes, resource management processes, realization processes and also measurement, analysis and improvement processes (ISO 9001:2008). In other words, business processes can be defined differently but they all have in common: activities, inputs, outputs and customers.

3.5.2 What is a process map?

A process map is defined by the Quality Learning Australia Pty Ltd (2006) to be sequences of actions that pictorial represent a process. In the process map, the relationships between the different process components are specified such as the process activities itself, people involved, specific data and objectives. The constructed model should clearly show the specified output (Biazzo, 2002). A process map is either a snapshot of the process in one precise instant with the goal of showing how work is currently performed in the organization, or a wanting future state, helping to visualize how work should be performed (Damelio, 1996). There can be different levels of details to a process map and on what information to be included, for example, input, output, requirements, resources and time.

3.5.2.1 Why is mapping the process important?

Mapping the process can be useful in several ways and provide valuable information to the organisation in a relative inexpensive way (Biazzo, 2002). Process maps are widespread and can help to identify improvement areas and be useful in improving and re-designing business processes. This is supported by Colquhoun et al. (1996) who claims that process maps are practical and accessible and constitute an important role in analysis of the whole system as well as the sub-systems in a process. Complex matters can be simplified and understood by a wider audience by visualizing the activities on a map. Furthermore, according to Jacka and Keller (2002), there are some benefits associated with process mapping in addition to the global view and documentation of the different aspects of the process:

A customer-driven approach
The most important benefit of process mapping is that it is customer-driven and therefore has a strong focus on the customer. To complete a process map, everyone must understand what is being delivered to the customer and why it is delivered.

A holistic approach
Looking at the whole process or system and integrating various elements, the analyst sees not only what needs to be changed, but also how this affects the system. With an overall view, the benefits for one can be weighed against the detriments to another.

An employee's buy-in concept
Maps are developed during real-time and people can see what is being recorded and contribute with information.

A sense of pride
Process mapping provides employees with an overall view of how their work adds value and how they are part of a team.

3.5.2.2 Process variation and process mapping

Process maps are used for dealing with process variation and allow to display and consequently to understand the entire process (George, 2005) (Barone and Lo Franco, 2012). George (2005) highlights the use of process mapping tools to help improvement teams to quickly identify improvement opportunities in the process and to start defining critical underlying causes.

3.5.3 How to gain knowledge for building a process map

"All truths are easy to understand once they are discovered; The point is to discover them." (Galileo Galilei, 1564-1642)

With Galilei's citation in mind, this section aims to explain how to dig in the data and how it is possible to gain the right knowledge for building a process map. Starting to develop a business process map begins with looking at the organisation itself by using an organisation chart pointing the major functions, departments and responsible persons (Conger, 2011). A business process map should be:

- Correct
- Complete
- Unambiguous

Conger (2011) means that the map must be developed without leaving any uncertainties to the reader. Considering this, the process analyst have to have the skills to build a process map but does not necessarily, in general, need to be of an expert of the process or domain expert. In the development of the map, multiple stakeholders will be involved having different skills complementing each other with knowledge and experience (Dumas et al., 2013). Modeling a process can be of a complex procedure; therefore the process analyst should conduct a preliminary analysis for understanding the process's boundaries and needs to be clear about the analysis' objectives. Examples of objectives are to identify: process activities, process events, process and information flow, input, output, resources and activity responsible. For gathering needed and relevant information Dumas et al. (2013) describes three methods or techniques: evidence-based discovery, interview-based discovery, and workshop-based discovery.

Evidence-based discovery
Commonly, the first sources of information are internal documents which can be in terms of reports, project- and process descriptions and failure analysis reports containing important information. The analyst can then use this information for the first draft of the process map. Another effective technique is the direct observation of the process. During observations, the analyst can follow the entire process in silence or in obviousness in order to better understand how the process works practically.

Interview-based discovery
Interview-based discovery is built on collecting information from the people involved in the process, for example by interviewing domain experts about their part in the selected process (Dumas, et al., 2013). To gather as much relevant information as possible from the people involved directly in the process and to fill the gap between how the work is really performed and how it is described in the guidelines, interviewing is a recommended method. Walking and mapping the processes can be done by starting from either the process start activity and go towards the end of the process or the opposite. According to Dumas et al. (2013), both perspectives of starting in the beginning or in the end are important. The authors explain that by starting at the beginning of the process it enables the analyst to focus the attention on the results of every action. Walking the process from the end to the beginning, backwards, a higher focus is directed towards the input required for performing each of the process activities.

Workshop-based discovery
This technique involves more participants and the goal is to get the participants discussing about the process. Recommended is to have a workshop facilitator in order to steer the discussion to ensure the relevance level of the information.

By using the three above methods, a map of the process should be possible to sketch and will provide a solid starting point for the final process model. Table 7 summarises the three techniques in a comparison table showing the difference in objectivity, richness of the data collected, time consumption and immediacy of feedback.

Table 7: Comparison of different information gathering techniques (Dumas, et al. 2013)

Aspect	**Evidence**	**Interview**	**Workshop**
Objectivity	High	Medium-High	Medium-High
Richness	Medium	High	High
Time Consumption	Low-Medium	Medium	Medium
Immediacy of feedback	Low	High	High

3.5.4 Analysis of different process mapping tools

In literature, various types of different process mapping tools are presented, they can have different purposes and some are more well-known than others. According to Ko (2009), a process mapping tool should be easy to comprehend by people and human-readable. Biazzo (2002) distinguishes between different techniques of representation in terms of syntax, used sets of symbols and combinations of these. Depending on what process mapping tool is selected for the use, different information can be gathered depending on the purpose of the chosen tool (Curtis, 1992). Biazzo (2002) presents four important focus aspects of process mapping tools:

Functional mapping tool
Focus on the elements and the flow of the process.

Behavioural mapping tool
Focus on *when* and *how* the activities are performed.

Organizational mapping tool
Focus on *where* and by *whom* the activities are performed.

Informational mapping tool
Focus on the structure and the relationships of the informational entities that are being manipulated by the process.

Different selected process map techniques are introduced, analysed and evaluated in Section 4.2. The selected tools are: Basic Flowchart, IDEF0, IDEF3, BPMN, UML-Activity Diagram, VSM, EPC and Volvo GMS-PD.

Basic Flowchart

The basic flowchart was introduced in the 1921 by Gilbreth and Gilbreth, two members of the American Society of Mechanical Engineering (ASME) with the purpose of providing a simple tool for mapping the process flow (Gilbreth and Gilbreth, 1921). A basic flowchart is characterised by a step by step process map with supporting decision points and loops where needed in order to capture different actions (Desai, 2010).

BPMN

Business Process Modelling Notation (BPMN) is a standard of the Object Management Group (OMG) (Princeton.edu. 2013). The OMG consortium was founded by several tool sellers; among them were Hewlett-Packard, IBM, Sun Microsystems, Apple Computer, American Airlines and Data General. OMG in 2013 had over 800 members. BPMN is considered a graphical technique that is similar to a flowchart and is often directed towards business process analyst and process map developers (Havey, 2005). In the standard BPMN map, several symbols are used such as: events, gateways, tasks, sub-processes or activities, the flow of the sequence and text notations. In addition, pools and swimlanes are representing the actors in the process. BPMN provides a visualization of the communication flow, facilitating the understanding of the internal and external collaborations as well as the business transactions within and between organisations. (OMG.org. 2013)

EPC

In 1992, Keller introduced EPC, "Event-driven Process Chain, as a modeling concept to represent temporal and logical dependencies in business processes (Mendling and Nüttgens, 2006). The technique aims to describe the logic of the process and should be easy to apply and understood by process analysts and process stakeholders. The name of the methodology is due to its particular diagram, an event-driven process chain, which shows the control flow structure of the process as a chain of events and functions. An EPC consists of the following elements: functions and basic building blocks corresponding to an activity such as tasks and process steps which needs to be executed. A function is linked by events, describing the situation before and/or after a function is executed and logical connectors are used to connect activities and events. (Van Der Aalst, 1999)

IDEF 0

IDEF stands for "Integrated computer aided manufacturing DEFinition" and was developed by the US Air Force in the 1981. The technique is used to produce a function model that is a structured representation of the functions of a manufacturing system or environment and of the information and objects which interrelate those functions (Us Air Force 1981). It is a derivation of the SADT technique in fact also in IDEF the ICOM (Input, Output, Mechanism, Control) code for the graphical representation is used. (Cheung and Bal, 1998) (Congram and Epelman, 1995). The essence of IDEF0 stands in its hierarchical approach to the process mapping (Fülscher and Powell, 1999), in IDEF0, the more appropriate level of detail can be chosen by using different levels of decomposition for each activity, so called on a granularity level. (Dumas et al., 2013)

IDEF 3

Belonging to the IDEF family described in the paragraph before, but unlike IDEF0, IDEF3 shows precedence and casualty relations between situations and events in a form that is natural to domain experts (Wang et al., 2006). Two types of diagrams are present in IDEF3: the Process flow and the Object state transition network diagrams. (Plaia and Carrie, 1995)

UML - Activity Diagram

UML stands for Unified Modeling Language and it is another OMG standard. UML is used for modeling high-level business processes by capturing a single use case or usage scenario (Ambler, 2004). UML uses an Object Oriented terminology and as Ambler affirmed "In many ways UML activity diagrams are the object-oriented equivalent of the flowcharts" (Amber, pag 6, 2000), it consists of: Activities, Guards (or conditions), Parallel activities, Swimlanes and Action Objects (Ambler, 2005)

VSM

The Value Stream Map rose from the need of the business analyst to look at the operation from a value stream perspective (Liker and Meier, 2006). According to Rother and Shook (2009), the VSM is created in order to show the flow of material and information when a product or service makes its way through the value stream and to identify waste and non-value added activities. Rother and Shook (2009) as well as Liker and Meier (2006) illustrates the different standard elements that are supplied to the business analyst for representing the flow and for computing the ratio between the value added and no value added activities.

Volvo GMS-PD

The Volvo Group Management System - Process Documentation supplies an intern tool for building a process map. It can be explained as an extended version of the SIPOC (Supplier – Input – Process – Output – Customer), but a little bit core complex because there are different levels of decomposition and different tasks within each sub process. This technique allows the business analyst to show Output and Input for every task or process as well as the actors and users involved.

Development of Process-VMEA Framework

In this chapter, the findings of the Process-VMEA (P-VMEA) development will be presented. The focus will be on the analysis of the data gathered both from interviews and from own experiments and how they are combined with theory and own creativity in order to establish the P- VMEA Framework. Cheung and Bal (1998) affirms that even the best framework will fail if not having right tools and techniques to support it

.

4 DEVELOPMENT OF PROCESS-VMEA FRAMEWORK

4.1 Interview session one – Identification of P-VMEA attributes

The purpose of the analysis is to understanding the customers, the potential users, and their needs and to obtain a solid starting point for later deciding the most suitable process mapping and communication tools. The interview questions are presented in Table 8.

Table 8: Interview questions

Area	Questions
Process Variation Management	I. How do you gain and share knowledge about variation in your processes? II. What methodology(ies) do you use for managing process variation? III. What do you base your decision on regarding process variation?
Decision Making	I. What are relevant information to you for making high quality decisions? II. How do you ensure that relevant information are provided to you regarding process variation? III. What level of information are you interested in? IV. What is the most challenging when you make decisions for managing process variation?

Concerning the first area, Process Variation Management, the results from the interviews show that the participants, depending on the hierarchy level and on the working field, understand and view variation very differently. The obtained impression of all the interviews is that for some respondents, especially higher up in the organisation, variation is considered not to affect their working activities so much as they decide what others should do.

"At this high level, we are not dealing with variation because I am giving the instruction they need to follow and I observe the results". (Candidate number 4)

Some candidates instead agreed that variation is a part of their everyday activities but that often is approached in a reactive way, when something happens we act upon it and solve it.

"Variation is often not reduced but is managed" (Candidate number 2)

These two inputs from the candidates mentioned above strengthen the conclusion that P-VMEA should be developed as a tool for generate awareness of variation and to work more in a proactive way. Moreover, from the interviews the main attributes of the P-VMEA Framework are generated and it can be concluded that P-VMEA should have the following characteristics:

Be a statistic support
The interviewees expressed the need of having a statistical supporting tool to help them to manage variation.

"No really statistical tools are now present within the company for managing variation" (Candidate number 5)

What is clear from the interviews is that process variation is often managed by using a root cause analysis but as several interviewees stated sometimes decisions are often based upon on the judgments of the experts rather than on real facts and numbers. Seeking facts is sometimes considered as very time consuming and obtaining information via judgements goes quicker.

Include the "real" process map
What is expressed by the candidates is that there is an inconsistency between the process maps in the organisations' database and the real process.

"The main problem is that the process is defined by the top players and often does not match with the real process in the plant". (Candidate number 1)

This gap between the real process and its process map leads to confusion among the employees that creates complications when decisions about process variations need to be taken.

Prove that there is a problem according from different angles
This characteristic is obtained as many respondents explicitly expressed that for making decision of high quality, different points of view of the same problem is highly beneficial.

"The problem has to affect the organization in more than one way". (Candidate number 2)

Different aspects of a problem can allow new areas of improvement and opportunities to be detected. Also, in order to raise attention to a problem area, different inputs can increase the validity of the analysis.

Have different level of details and allow the data screening
The level of details is differently required and wanted depending who receives the information, where the person is situated in the organisation, when information is needed and for what purpose.

"Hard to see the fully variation problems". (Candidate number 9)

"Many times too many details are thrown at me". (Candidate number 6)

All the interviewees are interested in the "general picture" of the problem but some also prefer to have a more detailed analysis provided to them.

4.1.1 Analysis of the Kano survey

For the Kano model, different attributes were selected for the analysis. The Kano results were analysed using Equations (1) and (2) and are summarized in Figure 13 (see Section 3.3.2). The results show that the P-VMEA report should be used in a standard format, with appropriate selection of charts and items, be immediately understandable and include a detailed chain of responsibilities. As well, P-VMEA must contain a detailed risk analysis, be connected to the company's vision and goals, be easy to screen and understandable as well as having a high degree of transparency and clearness. All above mentioned needs are all "must be" and they are therefore highly important to be fulfilled in the development of the P-VMEA methodology. Having a majority of images is considered an attractive need to 50% of the respondents. For 25% of the candidates, a majority of images is an indifferent need but the remaining 25% answered in accordance to a one-dimensional need. Therefore, images are important to consider when developing the P-VMEA methodology and especially for the P-VMEA report development.

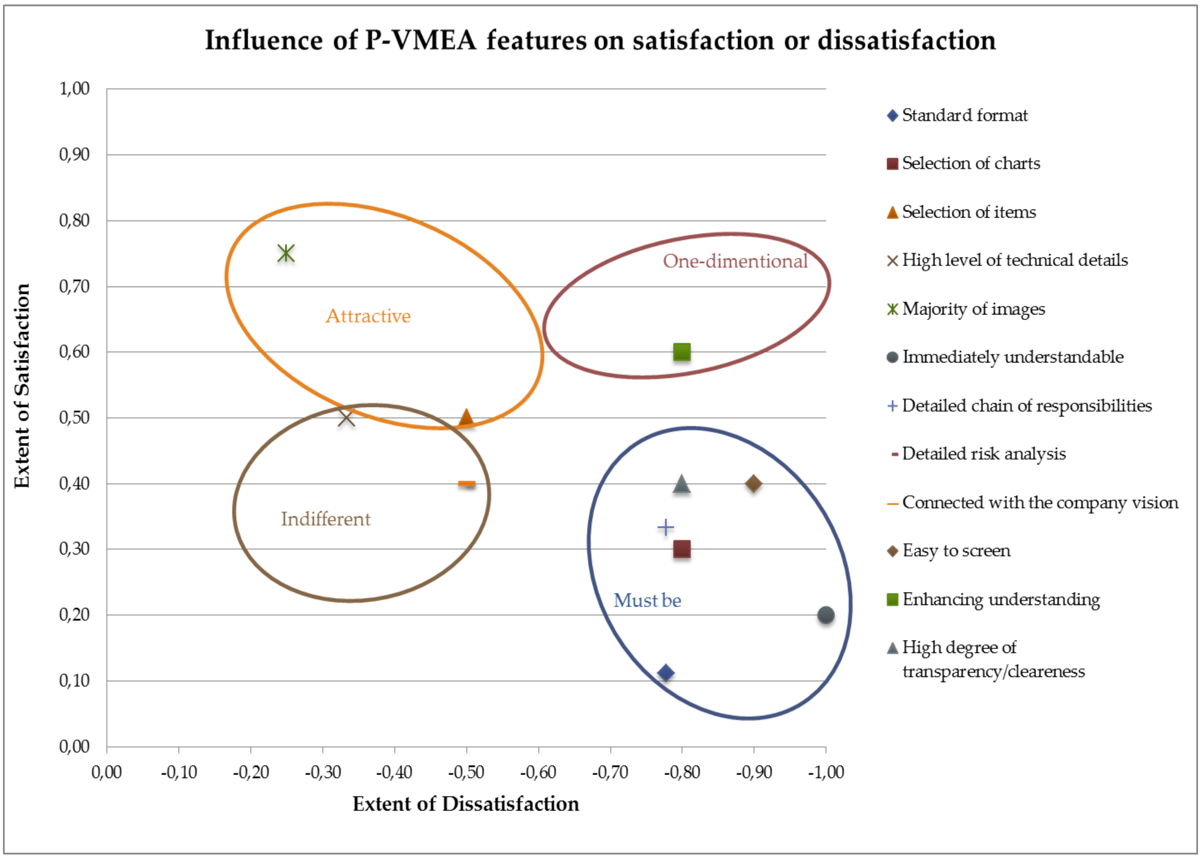

Figure 13: Kano results

The three top attributes for the P-VMEA report that will get the highest focus are:

1. Immediately understandable
2. Standard format

3. Easy to screen

The Figures 14, 15 and 16 show the rate of response for the three main attributes, all the other results instead are presented in Appendix 3.

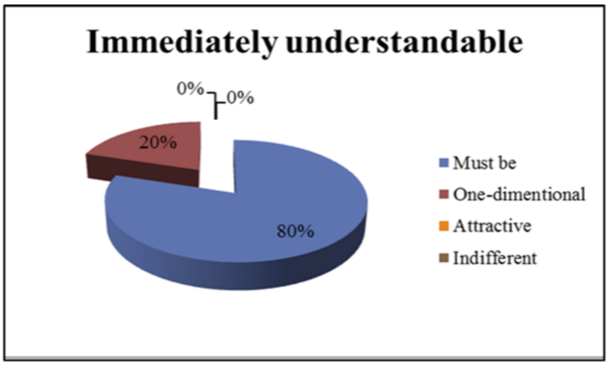

Figure 14: Rate of response for "immediately understandable" attribute

80% of the respondents considered immediately understandable to be a Must-be and for 20% this attribute is One-dimensional.

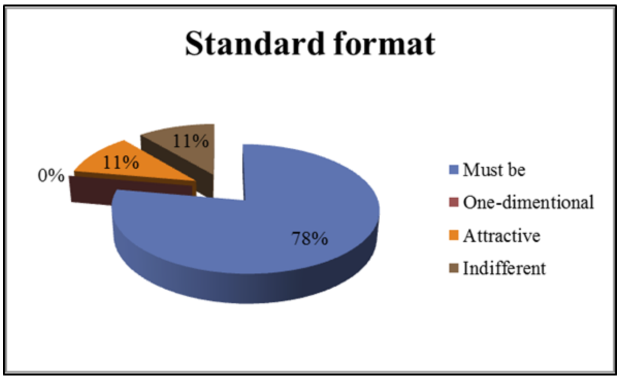

Figure 15: Rate of response for "standard format" attribute

Having a standard format is almost as important as immediately understandable as 78% considered it as a Must-be. However, 11% of the respondents are indifferent to the format.

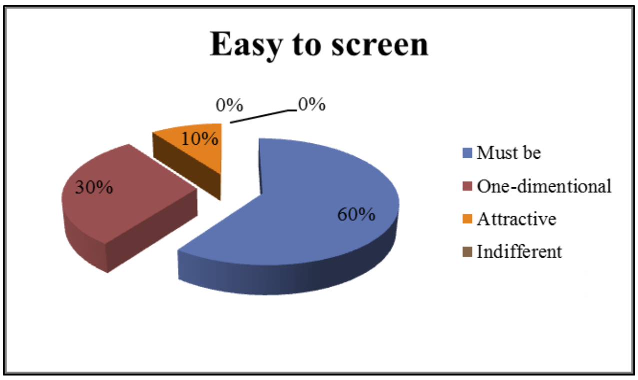

Figure 16: Rate of response for "easy to screen" attribute

The report should be easy to screen and received a 60% score on Must-be.

4.2 P-VMEA development tools

One important attribute, coming from a director at Volvo GTT, is that the methodology needs to be developed in a way that the user friendliness of the P-VMEA must be high. If the P-VMEA process map and report are excellent but are difficult to bring forward, the user will be dissatisfied and demotivated using the methodology. This is supported by Conger (2011), stating that a business process map should be: correct, complete and unambiguous.

4.2.1 P-VMEA interview template

A P-VMEA interview template was constructed by the authors and is a powerful tool for building the P-VMEA process map. The template consists of a structured form that supports the investigator and allows not forgetting to collect all the necessary data during the investigation. This form was built based upon Dumas et al. (2013) theory about how to gain knowledge for building a business process map. Inspiration was also taken from Chakhunashvili et al (2004) concerning data about variation that should to be taken into account for the VMEA analysis. By using the P-VMEA interview template, the inputs and outputs of each activity, the responsibilities, the task performers and the sources of variation for each step can be gathered (see Appendix 4).

4.2.2 P-VMEA process map

Different researches have been conducted in the literature comparing the different process mapping tools (see Section 3.5.4). As mentioned in previous chapter 3, different tools have different purposes and they address different needs. The goal is to select the best suitable tool to use in the P-VMEA framework for highlighting the variation and managing the risk. High focus will be on creating understanding for the methodology, bring forward an easy process mapping tool to perform and to understand.

The selection of the P-VMEA process mapping tool is based upon an analysis of different models regarding fictive case example processes, one Espresso coffee making process and one Taxi service process”. The results were analysed according to different criteria (see Table 9) which were inspired by the interviews’ output. The different process mapping tools were judged according to the possibility of having different levels of decomposition, the easiness of illustrating the process flow, the completeness of information, and the easiness of using. The last criterion used for the selection is the scope, it means if the tool seems suitable for the P-VMEA framework.

Table 9: Process mapping tool comparison

	Decomposition views	Easy to map the flow	Completeness of information	Ease of use	Scope	SCORE
Flowchart	✗	✓	✗	✓	✗	2
IDEF0	✓	✗	✓	✗	✓	3
IDEF3	✓	✗	✗	✗	✗	1
BPMN	✓	✓	✗	✓	✓	4
UML activity diagr.	✗	✓	✗	✓	✗	2
Value Stream	✗	✓	✓	✗	✗	2
EPC	✗	✗	✗	✓	✗	1
Volvo system	✓	✗	✗	✗	✓	2

In Table 9, it is clear that BPMN is the most preferable tool. Furthermore, the P-VMEA process mapping tool can be complemented by integrating the essence of IDEF0 in the BPMN diagram. This decision enables all the necessary criteria to be reached.

Table 10 shows the benefits of BPMN and IDEF0 inspired by Havey (2005), OMG.org. (2013), Cheung and Bal, (1998), Congram and Epelman (1995), Dumas et al., (2013), Fülscher and Powell (1999) and Us Air Force (1981).

Table 10: Comparison IDEF0 vs BPMN

BENEFITS	
IDEF0	BPMN
• Top-down hierarchical decomposition • Structured representation • Indefinitely collection of ordered diagrams •Well defined information thanks to the ICOM notation	• Clear sequence flow • Clear message flow • Decision nodes • Well defined responsible and actors • Easy to read • Easy to represent

In Figure 17 below, an example of the P-VMEA process map for the Espresso coffee making process can be found. The process map is built according to the BPMN standard, for further information see OMG.org. (2013), while the IDEF0 contribution comes with the notation on the process activities' boxes.

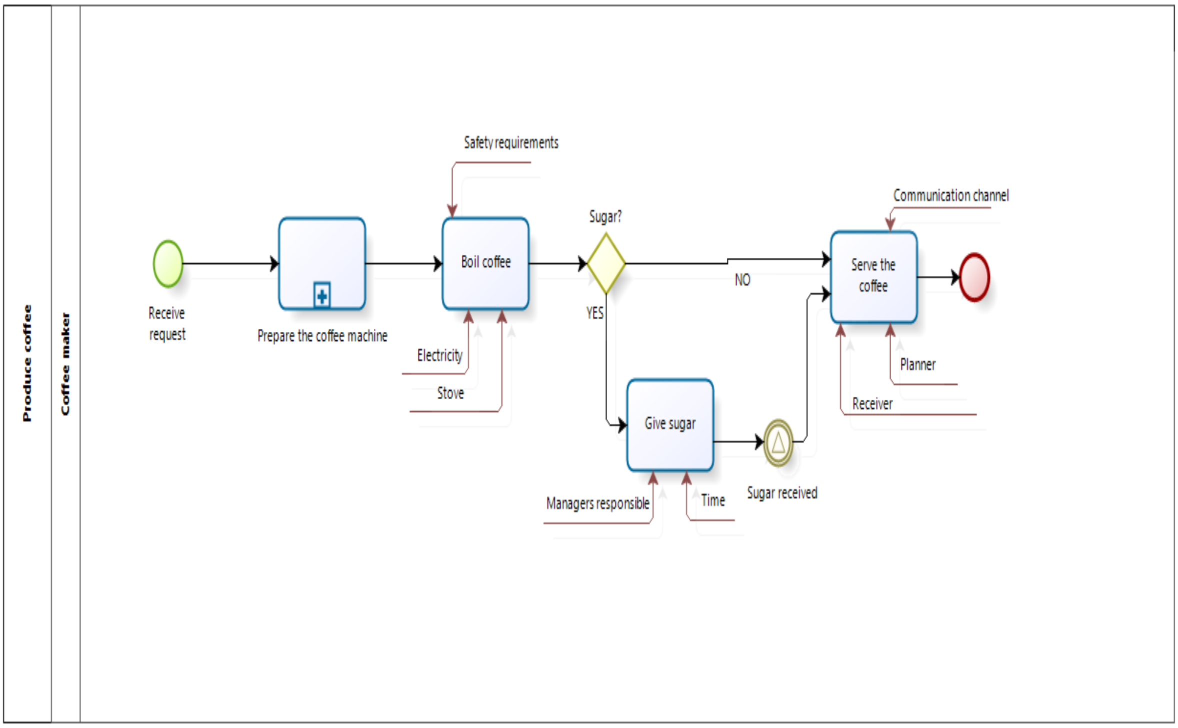

Figure 17: Example of BPMN and IDEF0 combination

The benefits of combining BPMN and IDEF0 provide the possibilities of:

Integrating the variation thinking in the process map
The integration is done by adding for each activity the different sources of variation on the top and bottom of the activity box (see Figure 18). For making the use of this tool smoother, a distinction between the bottom and the top is applied. Specifically, the top of the box is reserved for all the checklists, policies, procedures and environment issues while the bottom of the box is reserved for machines, tools and people. This distinction also allows re-adapting the model easily if some changes are made in the process or if another KPC is selected.

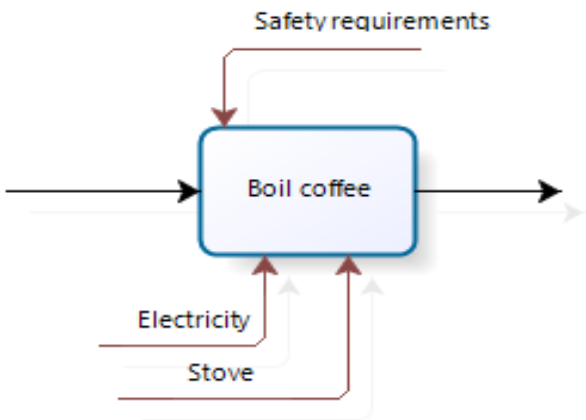

Figure 18: Example of P-VMEA notation

High process visualization
Having a high process visualization and a visual process breakdown enables organisations to show the process at different levels (see Figure 19).

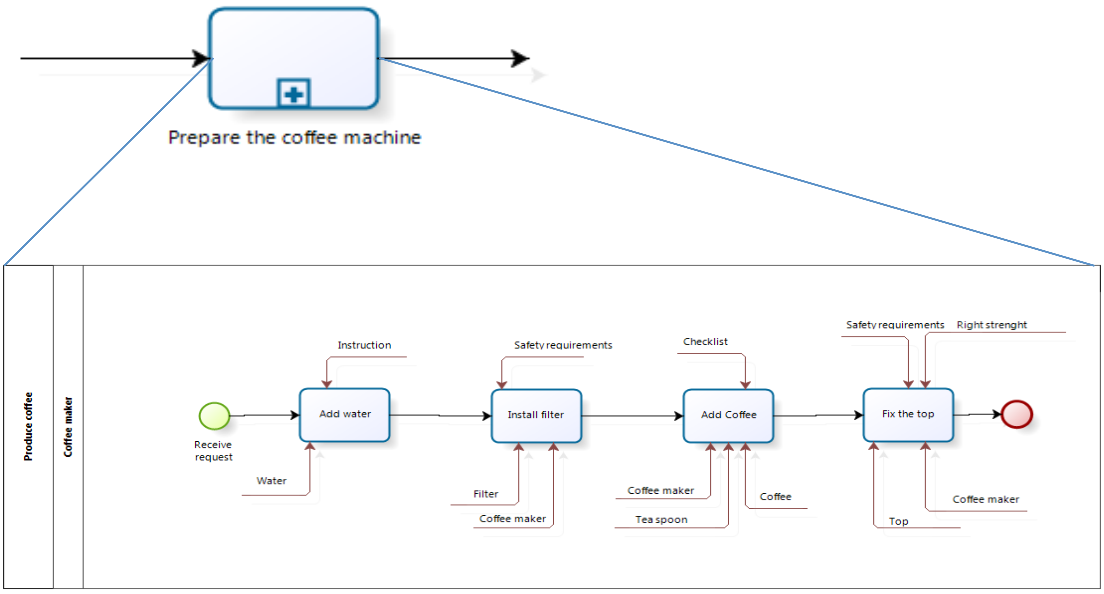

Figure 19: Example of process map breakdown

RASCI Matrix combination
Integrating the responsibilities for each activity and to quickly convert them in a RASCI matrix, see Figure 20. The responsible person, group or department is placed on the top x-axis and the process steps on the y-axis. (Cabanillas 2011; Cabanillas 2012)

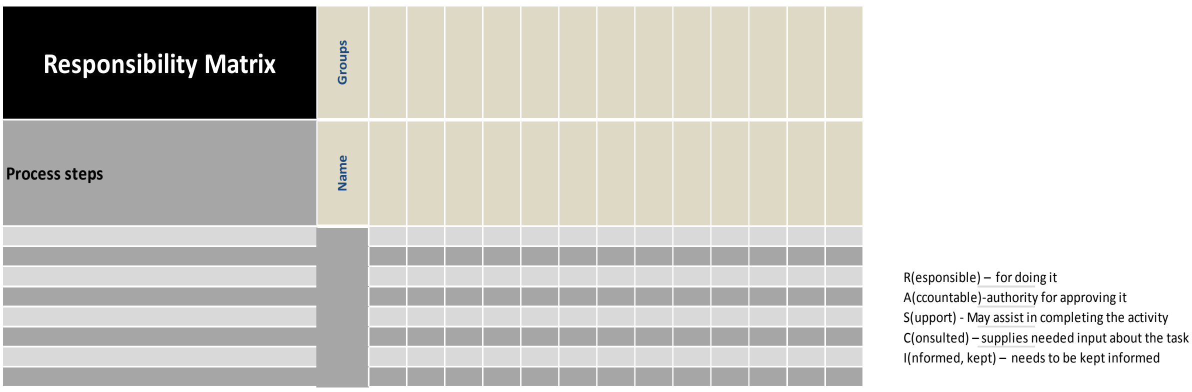

Figure 20: RASCI-Matrix example

4.2.3 Integration between Basic VMEA and Enhanced VMEA

A result of the interviews was that the methodology should be easy to screen and built in a hierarchical way. To do this, the authors of this thesis thought to make the numbers of levels of the decomposition within each sub process flexible, which is allowed by the

VMEA methodology. However, the authors discovered in existing VMEA methodology that doing this can create inconsistency in the grades among different sub-KPC and be misleading. In fact, the final VRPN is strictly dependent on the level of the decomposition. As mentioned in Section 3.4.4.5, the VRPN is the result of the multiplication of sensitivities and variation size, therefore an additional sub-level will increase the numbers of factors in the multiplication by one and consequently the final VRPN increases. During the P-VMEA framework development, this limitation of the VMEA methodology was mitigated by suggesting to keep an even level of decomposition among the different sub-processes and by using the sensitivity fan from the Enhance VMEA for assessing the sensitivity. The same Table 5 (see Section 3.4.4.4) of the basic VMEA is used for assessing the variation size of the NFs. As shown in Figure 12, the result is that an additional sub-KPC can have a sensitivity number lower or greater than 1 so we cannot know in advance if it will increase or decrease the VRPN. Thus, it can guarantee a more objective competition among NFs acting on different sub-KPCs.

4.2.4 P-VMEA report

In this Section the P-VMEA report is introduced, the intention was to deliver to managers an exhaustive document for making decisions. To do this, different literature researches were conducted in the field of VRM and Decision Making (see Sections 3.2). The findings from the researches were combined with the results of the Kano model and the first session of interviews (see Figure 13-16 and Appendix 5). Five different P-VMEA reports were developed by the authors. All the reports were structured in order to cover the identification, assessment and mitigation areas that characterized the VRM theory (Thornton, 2004). ´Each report was unique and had different structures; one of the reports was constructed in a two-page word document while the others were constructed into different A3 formats. The final P-VMEA report is presented in Appendix 5. All the reports enhance the decision making process by providing managers with the wanted information and by creating a bridge between the domain expertise and the management. The three VRM areas will be complemented with a “Management area” as from the decision making theory is important to address the persons responsible and to follow up the actions (De Brujin et al., 2010)

4.3 Interview session two

After the results of the first session of interviews (see Section 4.1), the initial scope of the second session was revised as it became clear that the interviewees had different knowledge about variation, VMEA and process mapping tools that would have led to conflicting results. In the second section, the different examples of P-VMEA reports as well as the final process mapping integration were presented to the interviewees. The aim was to validate the results of the first interview session and to improve the final integration model developed by the team. In the second cycle of interviews, the respondents expressed the need of having a P-VMEA report that is easy to understand, preferably in an A3 format because it is frequently used within all companies as an effective way to communicate information. Moreover the report should contain relevant sections and it should be easy to understand for everyone. The final model of the P-VMEA report is shown in Figure 21.

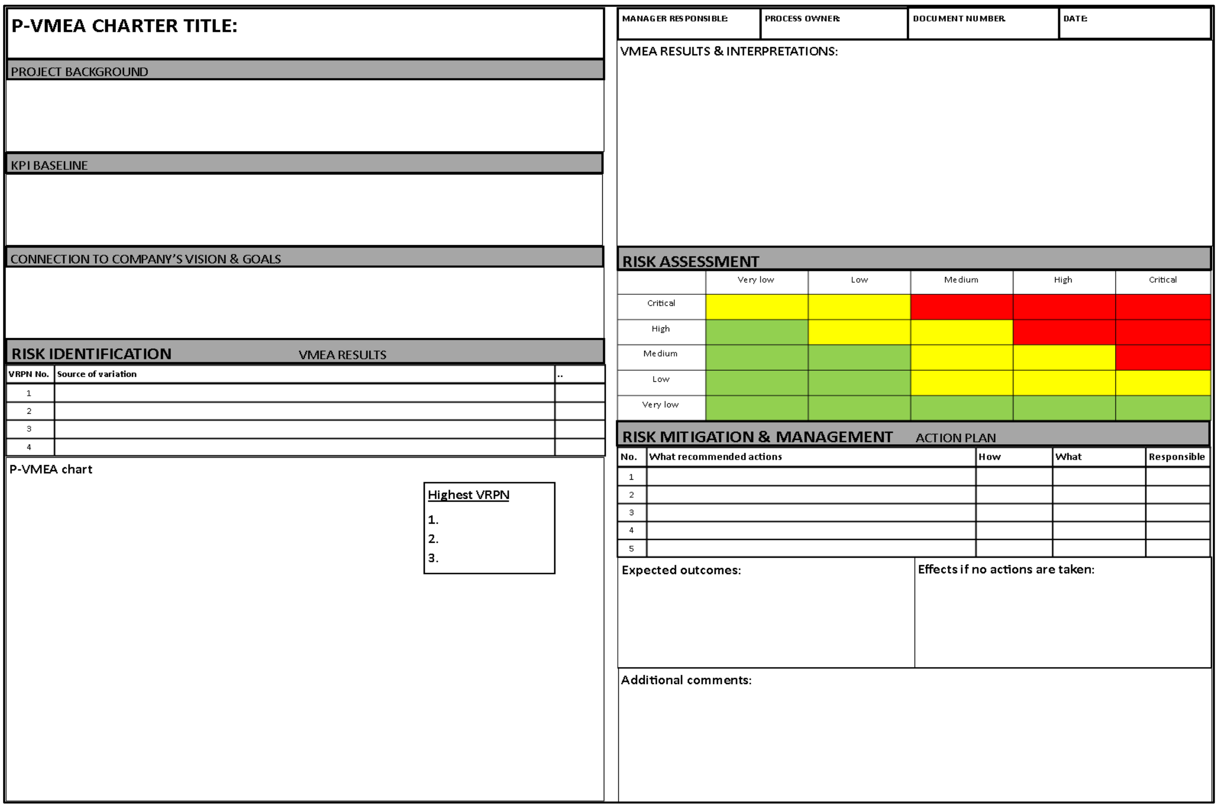

Figure 21: P-VMEA Report

The interviews results also confirmed that the managers preferred different complexity levels on their decision data and information which needs to be considered for the P-VMEA. To meet this requirement the report is showing all the necessary information for making decision but it can be enlarged with comments concerning the P-VMEA analysis and the final results. Furthermore, the P-VMEA report can be attached with all the additional documents that have been developed during the analysis. How and when the risks are to be mitigated and managed should also be stated in the P-VMEA report together with an assigned responsible person. A summary and any additional information to the stakeholders of the report should be stated in the end of the report. The final P-VMEA report template is divided into the following sections:

Project background
State the background of the project, describe why this area is important.

KPC baseline
Describe why the selected KPC was chosen and why it is important to the company.

Connection to company's vision & goals
Explain how the chosen area and KPC are related to the company's vision and goals. A connection was shown to be an important area for almost all managers in order to get attention from the upper management according the interview results.

Risk Identification
The purpose is to identify the risks associated with the variations that affect the KPC and Sub-KPCs.

Risk Assessment
The sensitivity (on the top X-axis) and the variation size (on the left Y-axis) of the most relevant NFs are inserted in the Risk Assessment grid. This will provide a visual overview how the risk is spread among the NFs, to complement the VMEA bar-chart.

Risk Mitigation & Management
An action plan is included in the P-VMEA report where it should state how the risks are to be mitigated, who is the responsible person and when in time this is planned to take place. How the risks are to be managed should be clearly stated in this section.

Comment fields
-Expected outcomes
A summary of the expected outcomes – aiming at highlighting the main findings and conclusions of the P-VMEA analysis.

-Effects if not actions are taken
Effects if no actions or the incorrect actions will be taken.

-Additional comments
The comment field aims to provide a space to the creator for adding additional information or expressing her or his opinion.

Investigating the Process-VMEA Framework

In this chapter, the results of the Process-VMEA (P-VMEA) testing will be presented. The P VMEA was tested at Volvo Group Trucks of Technology in the In-service conformity (ISC) test process for analysing the application of P-VMEA and its efficiency when it is applied to complex industrial processes. The ISC process is an appropriate testing ground due to its complexity and to the awareness of the economic and social impact that a failure in this test can generate.

5 INVESTIGATING THE PROCESS-VMEA FRAMEWORK

In the modern automotive industry, the competition is partially based on the respect for the environment and therefore on the elimination of the polluting emissions in order to meet the European Commission Requirements. Year by year, the EU Regulations have gotten stricter, the new legislation Euro VI has increased the challenge by reducing of a 97 % the admissible gas emissions compared with 20 years ago (see figure 22). (Volvotrucks.com, 2013a)

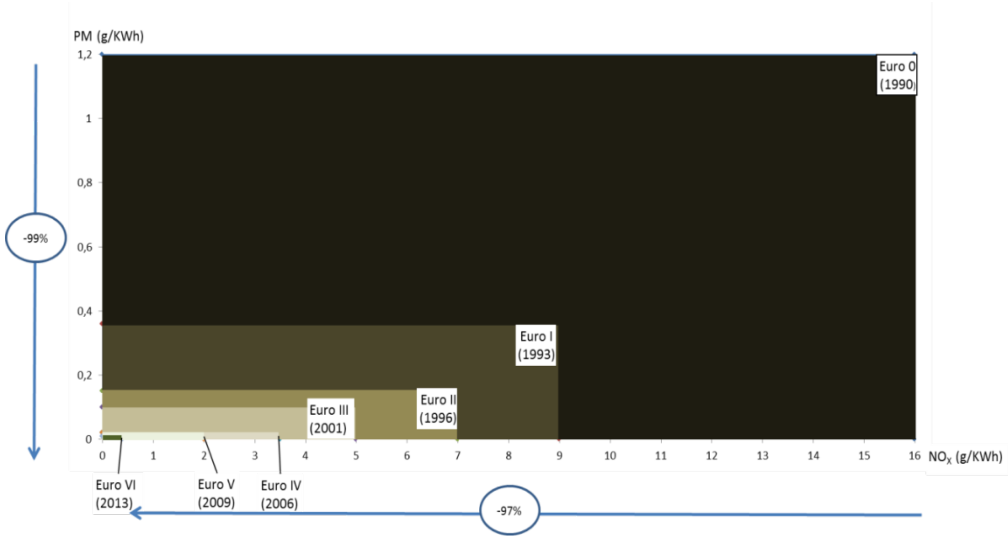

Figure 22: EU test requirements (Volvotrucks.com, 2013a)

5.1 Presentation of the company - Volvo GTT

AB Volvo is one of the world´s leading manufacturers of trucks, buses and construction equipment and drive systems for marine and industrial applications, which headquarter is located in Gothenburg, Sweden. (Volvo, 2013) Volvo employs more than 100,000 people and has facilities in 19 countries and sales its products in 180 markets. (Volvotrucks.com, 2013b)

Volvo Group Trucks of Technology is a division of Volvo that develops trucks for the group, it employs about 1700 employees and it is located globally in Lyon (France), Hagerstown (USA), Ageo (Japan) and Curitiba (Brazil) and which headquarter is located in Gothenburg.

5.2 ISC process

The ISC test stands for In-Service Conformity test, it is a test used for analysing the emissions of vehicles in order to check the conformity of in-service engines and vehicles. The Exhaust Emissions Design Guideline, Regulation 49 (2013), from here on referred as “Regulation”, is unquestionably clear concerning all the parameters for the test. The purpose of the test is to be representative for the performance of the vehicles while they are driven on real driving routes, with a normal load and with the usual driver (Regulation, 2013). The test results are sent to Type Approval Authority (TAA) for the approval. The TAA plays a strategic role since it approves the selected engines and vehicle configuration for the tests and it monitors that the test plan and test parameters for the incoming tests are in accordance with the Regulation. The Regulation defines the characteristics of the route and the payload, the minimum number of vehicles that need to be tested, the condition for performing the test, the minimum length of the test and the criteria for accepting the test results. According to the regulation, for the particular engine family tests must be repeated every two years and they should stop five years after the end of the production. Moreover, tests must be conducted on vehicles over their useful life period within 18 months after their registration for the test. The decision on the test results is a pass or fails decision based on the statistical test: "Cumulative number of nonconforming test". The test is passed if the test statistic is lower that the limit threshold "Pass decision number" while the test is failed if the statistic test is greater than the limit threshold "Fail decision number" otherwise for all the other situations we continue the test. The regulation fixes also a maximum number of 10 trucks that the company can test before declaring failed the test (see Table 11).

With a minimum sample size of 3 trucks, this procedure for the test fixes the producer's risk and the consumer's risk equal to 10%, in fact there is a 90% of probability that a lot passes the test with 20% of vehicles or engines defective (producer's risk = 1-0,9 = 0,1) and there is a probability of 10% that a lot is accepted with 60% of vehicle or engines defective.

Table 11: Pass or fail decision numbers.

Cumulative number of engines tested (sample size)	*Pass decision number*	*Fail decision number*
3	-	3
4	0	4
5	0	4
6	1	4
7	1	4
8	2	4
9	2	4
10	3	4

5.2.1 Equipment

These tests are conducted using the PEMS equipment, this instrument registers the engine emission and in particular Carbon monoxide (CO), total hydrocarbons (THC), Non Methane Hydrocarbons (NMHC), Methane (CH_4), Nitrogen oxides (NOx), Particulate Matter (PM) mass, Particulate Matter (PM) number. The PEMS must be powered using a specific/dedicated power generator. The PEMS should be installed in a location where it will not be impacted by ambient temperature and pressure changes, electromagnetic radiation, mechanical shock and vibration or ambient hydrocarbons. Furthermore, the data from the equipment must be aligned with the data from the engine, for checking this, a linear regression is conducted.

5.2.2 Vehicle

The vehicle must be a customer truck and it has been in-service for at least 25 000 Km and been properly maintained. It is important for the test that there are no significant failures in the system On-Board Diagnostic (OBD), that the electric control unit (ECU) is working and that no major component has been changed.

5.2.3 Test conditions

The payload should be 50% - 60% of the maximum vehicle payload. Ambient conditions pressure should be greater than 82,5 KPa and temperature greater than 266 K and less than $T = -0{,}4514 * (101{,}3 - p) + 311$ (pressure in KPa). During the test, market or reference fuel, lubricant and reagent should be used and a sample should be taken.

5.2.4 Test trip of the truck

The road trip for the test must be mixed among urban, rural and motorway driving and it should be as long as to obtain 5 times the work performed or 5 times the emission of CO_2 during the World Harmonized Transient Cycle test (WHTC).

5.3 ISC process at Volvo GTT

In Volvo GTT, the ISC test is still in evolution, although being strictly controlled by the regulation there is still room for improvement in order to better tie the process closer to the company. Today, it is possible to observe an increasing demand of requested test per year (see Figure 23) that makes the problem more complex. This new demand affects the utilization of the PEMS equipment, spare parts, and container for the equipment. Furthermore a new system for procuring the trucks is about to be implemented, this solution adds more uncertainties to the process analysis because it has never been tested.

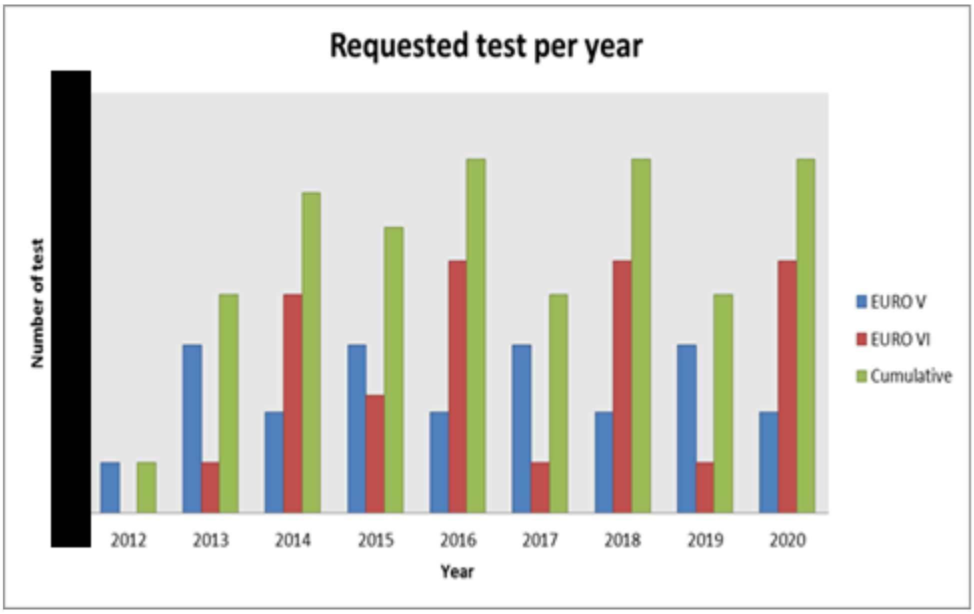

Figure 23: Yearly ISC demands

5.4 Implementation of P-VMEA

During the investigation, different actors from different departments were actively involved in one to one interviews. In addition, weekly meetings were conducted with the ISC team for analysing the ISC process progresses. In conclusion, two different group sections were exclusively dedicated to the P-VMEA development, the first one for displaying the final process map while the second for the grading phase.

5.4.1 Step 1: Define the problem

The problem was given by the engineering department in Volvo GTT. The problem was already defined and accepted.

5.4.2 Step 2: Choose the Key Process Characteristic

After the first meeting together with the Manager Engineering Quality at the engineering department and from the analysis of the ISC records, it has clearly emerged that the results of the tests are good in fact they are in accordance with the regulation requirements. The analysis of the records shows that the 80% of test are successful and many of the remains 20% tests are potentially still good but they are invalidated by failures in the instruments. In the meanwhile the equipment has a low utilization rate approximately equal to 50%. Therefore, at the end of the meeting, we identified the need to make the process stable in order to answer the question: “can we afford the incoming amount of tests or we need to increase the capacity production?” and we agreed upon a first KPC “Number of ISC test per year”, that is aligned with the company’s strategy to increase efficiency. Later we modify our KPC to “Number of *good* test per year” because the improvement process must not compromise the quality of the test and this is in accordance with the company vision that aims at preserving the well-being of the environment. Subsequent to the first meeting, an analysis using the Effective scoping template was performed (see Appendix 6), (see Section 6.4). The results confirmed that the number of good test per year is a valid variable for investigating the problem and the KPC´s baseline was set according to the test journal 2012.

5.4.3 Step 3: Walk the process and develop the P-VMEA process map

The next step was to walk the process and to conduct the interviews, in order to build the first stage process map. The team started walking the ISC test process from the beginning (see Section 3.5.3) meeting up with the Certification Engineer at Certification Department at Volvo GTT and using the P-VMEA interview template developed by Andréasson and Catalano (2014) (see Section 4.2.1 and Appendix 4). Simultaneously events based discovery methodologies (See Section 3.5.3) were used for analysing the process, documents related to process and the current Volvo process maps were analysed but they were found old and not accurate. At the end of the Phase 2 (see Section 6.5), interviews were collected with Certification Engineer, Planner, Test Engineer, Measurement System engineer and Group Manager Vehicle Calibration and the interviews’ responses were used for building the first draft of the process map. In this phase, two tools in particular were used: Bizagi and MS Visio (Bizagi.com, 2013 and Office.microsoft.com, 2013).

By using the P-VMEA interview template and by discussing with the ISC team, different sources of variation had been already collected, but in accordance with the methodology they had not been displayed in the map yet. This allowed the team to keep the first draft of the map as simple as possible.

5.4.4 Step 4 Walk the process – 2nd round

After that the process map was completed, it was exposed to the entire ISC team in order to confirm each activity step. The main goal was to make the participant agreeing upon the process map. It was important that everyone was aware of the process and that there were not process gaps. Furthermore, the language and the words were checked in order to create a common understanding on the process map. In this step, more information regarding the sources of variations was collected. To do this, yellow post-its were distributed to each participant and starting from the first activity they were asked to write all the possible sources of variation. In the end, when all the activities were investigated the post-its were added in the wall with the process map (see figure 24).

Figure 24: Process map ISC test- Volvo Group Trucks of Technology

5.4.5 Results of the process mapping stages

The final version of the current state of the ISC process is shown in a high-level process map (see Appendix 7) and it starts from the definition of the guidelines after that the authority has communicated the new standards and it ends after that the report is submitted to the Type Approval Authority.

Within the ISC process, 8 Macro sub-processes were distinguished:

Agreement with the Authorities
This includes all the activities related with the regulation and the communications with the authority. In general these activities aim to inform the TAA regarding the test plan for the incoming years and to get the TAA approval. These activities take place years in advance of the test execution and they are conducted by the certification engineer.

Create detailed test plan
In this stage of the process the preliminary test plan that was negotiated with the TAA is

entered in the planning system. It happens once per year although the information regarding the number of tests is collected years in advance. It means that the Certification Engineer usually negotiates the test for the next 5 or 6 years but this information is not immediately entered in the planning system. The goal of this stage is to book the equipment and the spare parts, to have the preliminary information for collecting the trucks and to clarify the prioritization if either the equipment is already booked or there are hindrances for the test.

Secure vehicle
Since the vehicle must be owned by a customer and it must have particular characteristics, the goal of this stage is to find the available customer truck that will be used in the test. So in this stage an early contact with the customer is established in order to agree upon the availability of the truck on the particular test date. Furthermore, the responsible needs to ensure the availability of spare trucks in case that one of the first three performed test are not good (see Table 11). In this stage a pre-check of the vehicle must be performed in order to avoid failures on the truck during the test.

Collect vehicle
Few days before the test, the vehicle must be collected. In this stage a responsible will go and take over the customer truck and give him a replacement vehicle.

Last ocular check of the vehicle
When the vehicle arrives to the workshop it needs to be checked before starting the test.

Perform test
In this stage, the Test Operator and the Test Engineer work together with installing and calibrating the equipment for preparing the truck and for running the test. In the end of the test, the Test Engineer will submit a report to the Certification Engineer; this report will contain the test results.

Submit report
In this stage the final report is submitted to the Type Approval Authority.

Return truck to the customer
After the test is performed the truck is returned to the customer.

5.4.6 Assessing ISC process variation

The results of the investigation (brainstorming with post-its, process map and interviews) were collected and organised in the P-VMEA template (see Section 4.2.1). In the end of the investigation, more than 150 sources of variation were collected and again another meeting was arranged with the ISC team in order to assess the sensitivity and the variation size of each noise factor. Due to the high number of sources of variation, this procedure can take a long time. To manage this, a decision was made to speed up the procedure by focusing the attention on the macro sub-processes that receive the highest sensitivity numbers. This simplification has also a mathematic support. As discussed in previous chapters, the VRPN is the product of multiple sensitivity numbers and the variation size (see Section 3.4.4.5). Therefore, if the sensitivity has a low value the final VRPN will be relatively low. The solution is inspired by the Branch and Bound technique that was developed by Little in 1963 for solving the problem of the Travelling Salesman. In our case we aim to find the "optimum" VRPN, that is the VRPN that needs to be mitigated.

5.4.7 Tables of results and RASCI matrix

The results of the P-VMEA template were summarized using the VMEA bar charts (see Section 3.4.5) which are shown in Figure 25 below.

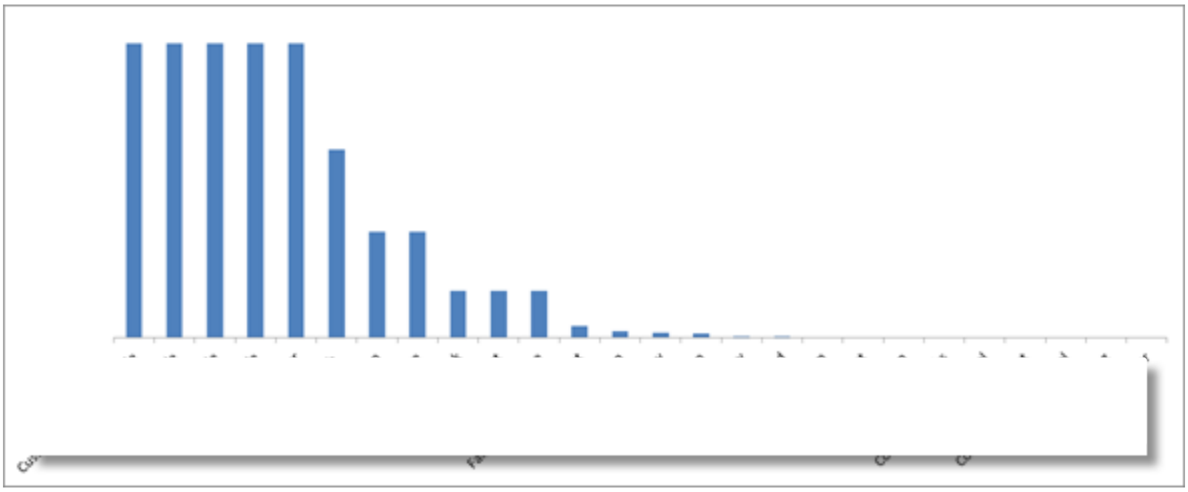

Figure 25: P-VMEA Bar-chart

This graphs point out that the customer list responsible, Responsible for the ISC and Vehicle responsible are the main sources of variation that affect the KPC the highest. They are the responsible persons for the pointed out improvement areas. To complete the analysis a RASCI matrix (see Section 4.2.2) was developed (see Appendix 8).

5.4.8 Create the P-VMEA report

In order to communicate the achieved results a P-VMEA A3 report was created (see Section 4.2.). The report (see Appendix 9) was communicated to the ISC team and to the manager responsible.

5.5 Conclusions of the experimentation

Overall, the experimentation was satisfactory; the results show that a driver and a test coordinator, responsible for the vehicles and the customer list, are needed. One more driver will lead to a maximisation of the equipment utilisation; moreover since the test is new, a coordinator can ensure that everything will be performed according to the schedule. The outcomes of the experimentation were in accordance with the results of an internal investigation that was conducted in parallel at Volvo GTT, which confirmers the goodness of the methodology. The strength of the P-VMEA is to prove the already known findings in a more statistical way and consequently to give support for making decisions based on facts. The test showed possible improvement areas, such as the tables used for the grading step, which will be taken into account during the development of the P-VMEA framework in chapter 6.

Process-VMEA Framework

In this section, the P-VMEA framework is introduced. The newly developed methodology P-VMEA will be described in details and examples are formulated in order to help the reader in the application of the methodology.

6 PROCESS-VMEA FRAMEWORK

6.1 Aim of P-VMEA

The methodology is developed with an aim to create awareness- and understanding for process variations. The aim is also to use the awareness and understanding obtained in order to create robust processes or processes insensitive to variations.

6.2 What is P-VMEA?

Process-VMEA (P-VMEA) is a methodology developed by the Master of Science students Isabelle Andréasson and Gabriele Catalano at Chalmers University of Technology and Università degli Studi di Palermo. The methodology was a central part of the students' Master Thesis and was developed during the autumn of 2013, sponsored by Volvo Group Trucks Technology and benchmarked at: Volvo Group Trucks Operations, Ericsson AB and Tetra Pak. P-VMEA has been developed based on the needs of people working in different levels at different companies such as engineers, project leaders and managers at different hierarchical levels ranging from first line managers to senior vice presidents. P-VMEA is divided into four phases: (1) Scoping the project, (2) Collecting data, (3) Analysing data and assessing variation (4) Presenting data. The P-VMEA framework is illustrated in Figure 26. Each phase consists of different steps guiding the P-VMEA driver through the methodology. For providing methodology inspiration, examples will guide throughout the methodology. Each phase will have an example, following the P-VMEA methodology procedure at a fictive coffee store company or a real application case.

6.3 How is P-VMEA useful to companies?

P-VMEA is based on identified characteristics and needs of managers, engineers and project leaders at different large organisations. P-VMEA is developed to meet the requirements of the people that will do the actual data collection for P-VMEA, the receivers of the P-VMEA report, process owners and managers. P-VMEA raises attention to process variation and organisations can benefit from the methodology by reaching a higher level of understanding of a selected process to a larger extent. Also, organisations can gain higher knowledge regarding activity steps within the process, the linkages between each step, understanding factors that might vary and cause variation to the end results or process goal – mitigating the risks of getting dissatisfied customers. In P-VMEA, a specific Key Process Characteristic (KPC) should be chosen and will be the main focus of the variation analysis.

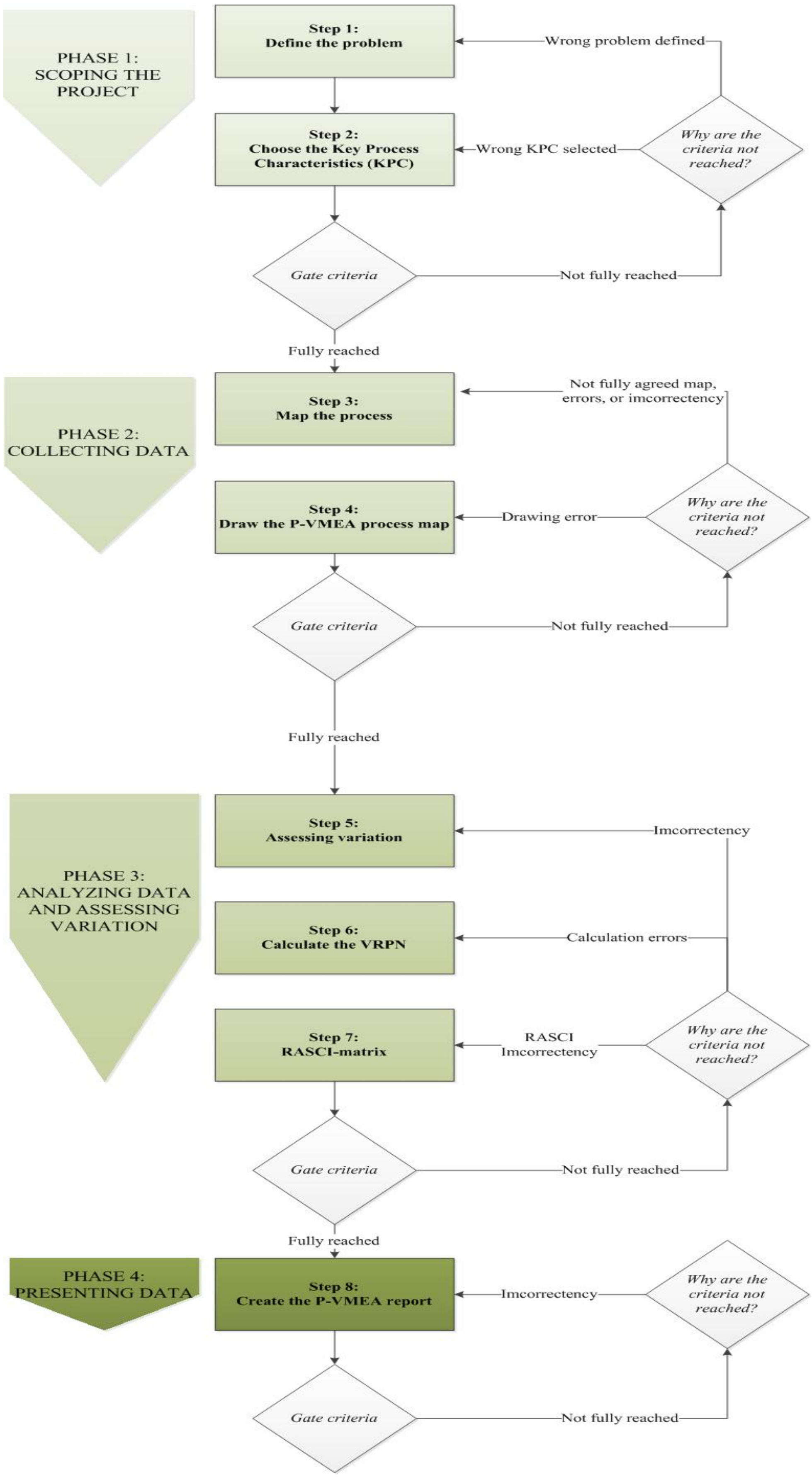

Figure 26: P-VMEA Framework

6.4 PHASE 1: SCOPING THE PROJECT

Knowing what area to focus on and defining the problem are pre-requisites for driving improvements. Selecting an appropriate Key Process Characteristic (KPC) will guide the P-VMEA user throughout the methodology towards the final P-VMEA report.

Step 1: Define the problem

WHAT?
Decide what improvement area to focus on by defining the problem. The basis of using P-VMEA is to know where variation is affecting the KPC the most and be able to decide where to invest time, resources and money.

WHY?
If the problem is not correctly defined, the end results will not provide the necessary information for making high quality decision.

HOW?
There are several approaches towards defining the problem. Commonly used tools are mentioned below:

Interviewing
Interviewing people working in the process is an effective way for building process understanding. For more information, see Section 2.4.1.

Focus groups
Gathering focus groups in order to discuss the area of improvement and related problems as well as opportunities can be a time effective method.

Brainstorming session, Affinity Interrelationship Method (AIM)
Using the AIM method in a cross functional group to discuss around the improvement area in order to create a common view of the problem and enhance understanding for the chosen process scope (see section 3.4.4.1).

Supporting reports and documents
Finding reports that can provide the organisation with fact about the process can increase understanding and contribute with additional relevant information that could help to define the right problem.

Pitfalls and how to avoid them
"The 'problem' was not the problem". Later in the P-VMEA methodology the P-VMEA driver might discover that the problem defined is just a symptom of the real problem. Reasons for this could be due to lack of information or that the participants in the investigation group are too homogenous. Thus, it is important to include the right mix of people and correct the problem definition and understand *why* the problem was not defined correctly from the beginning. Treating symptoms as problem will not help organisations to solve the actual root causes of the problems.

Example: The Coffee Shop

As a manager of a coffee shop with 20 employees, you want to increase your sales revenues of espresso coffee. You gather a cross-functional group of 4-6 people that are involved in the espresso process. After a first group discussion, you determine to proceed with the AIM. From the AIM results together with other data sources such as increased number of customers' complaints about the coffee not tasting good, customers not finishing their espresso at the cafeteria and the decreasing sales, you are concerned that too much variation is existing within your process.

Problem definition: Customers are not satisfied with our espresso coffee.

Step 2: Choose the Key Process Characteristic (KPC)

WHAT?

After the problem is defined one measurement, one KPC, should be decided. The KPC should be carefully selected and be well motivated as it will be the main focus in the P-VMEA methodology.

WHY?

Choosing an appropriate KPC is the first fundamental Phase in P-VMEA methodology, in order to know what to improve and to establish a KPC measurement system for following the progresses.

HOW?

One way is to use the effective scoping:

Effective Scoping Template

The Effective Scoping template is a tool for framing the project and defining the project scope (Hammersberg, 2013) (see Appendix 6). By using this template the user has to concretise the scope of the project in a structured format. The Effective Scoping is divided into different sections: Supplier, Input, Process, Output and Customer – clarifying what it is going to be improved, selecting the measurement system, defining the needed resources and the project limitations or restrictions.

Pitfalls and how to avoid them

Not selecting a KPC that is align with the organisation's strategy could lead to lower the attention since it is not within a high prioritized area. Make sure to communicate the KPC as early as possible to the management.

Example: The Coffee Shop

Customers complain that the espresso coffee does not meet their expectations in terms of taste. The complaints have increased over the last few years and they are correlated with the annual decrease of the espresso sales. You as a manager, together with a couple of employees, determine to focus on improving the taste of the espresso in accordance to customers' needs.

KPC: The taste of the espresso coffee in accordance to customer needs

Gate Phase 1

Before you move on into Phase 2, the following questions should be answered:

- The improvement area is connected with the company's vision and goals?
- The improvement area is aligned with the company's business strategy?
- The defined problem is a real problem and not a symptom?
- Is the relationship between what is measured and what is improved correct?

6.5 PHASE 2: COLLECTING DATA

By walking the process from the defined starting point to the end, necessary data can be collected in order to understand the selected process. The process can be visualized and information can be gathered by using P-VMEA interview template.

Step 3: Walk the process

WHAT?

Walk the process and interview people involved in the process steps, starting from the beginning of the process and continue towards the end. Identify the activity steps, inputs and outputs in structural way. Confirm each activity steps with the people involved in the process chain.

WHY?

The purpose of this step is to get an overview of the process and to create a common understanding of the selected process.

HOW?

Use the P-VMEA interview template (see Section 4.2.1 and Appendix 4) to map the process and collect data in a structured way. Later, the results in the P-VMEA interview template must be confirmed with the interviewees, ensuring that there is no gap in the process between what is delivered as output and what is expected as input in the next step.

Pitfalls and how to avoid them

Important process steps and/or information can be missed. To prevent this, the inputs and the outputs between two following activities must be checked. Moreover, to be sure to not miss relevant information the P-VMEA interview template is strongly recommended.

Example: The Coffee Shop

The example of the coffee are shown in Section 4.2.2.

Step 4: Draw P-VMEA process map

WHAT?

Convert the process activities into the combined BPMN/IDEF0 P-VMEA process-map. Draw the process map at a main level and then break it down into smaller sub-process steps.

WHY?
To visualise the process and get an overview of the activity steps involved. This is important for later use when confirming the process steps in Step 5.

HOW?
Use the P-VMEA process map combination tool (see Section 4.2.2) of BPMN and IDEF0 to convert the information from the template into a visual illustration.

Pitfalls and how to avoid them
Drawing and language errors are potential pitfalls that can cause confusion for the readers. To prevent this, other people should be consulted during the drawing phase and the language should be checked in order to create a common understanding of the used words. Another pitfall is to have a too detailed process map that makes it difficult to others to interpret it. Therefore, the process map should be decomposed into suitable numbers of sub-process levels, in order to easier communicate the process.

Example: Real case
Application of P-VMEA to the ISC process at Volvo GTT, see Appendix 7.

Gate Phase 2

- Relevant activity steps with the respective information are collected and displayed in the process map
- The P-VMEA process map is verified with the interviewees and process stakeholders.

6.6 PHASE 3: ANALYZING DATA AND ASSESSING VARIATION

Analysing the collected data in order to find an agreement on the final process map and grade the sources of variation in the process.

Step 5: Assess Variation

WHAT?
Walk the process, again confirm process map and assess sensitivity and variation size.

I. Check, confirm and agree upon the P-VMEA process map with the interviewees or other key persons involved in the process
II. Identify the NFs and Requirements for each activity
III. Assess the variation and the sensitivity together with each participants for each process activity step the KPC's and Sub-KPCs' sensitivity to the NFs
IV. Check and confirm the grade together with all participants for each process activity. In case of different opinions, assess the magnitude of the sensitivity and variation again.

WHY?
The P-VMEA process map needs to be validated so that no information are missed or

incorrect. This is also an extra opportunity for the interviewees to add any additional information. Furthermore in this step the data for the P-VMEA analysis are collected.

HOW?

Display the entire process map on the wall and add extra information if needed by using yellow post-its. After that all the participants agree upon the map and all the sources of variation are identified, the grading phase will be done by using the P-VMEA template (Appendix 10). To facilitate the grading process the Authors developed two useful guidelines (see Tables 12 and 13). In Table 12 examples are given about how to grade the variation size are listed. Table 13 provides an example of how to use the sensitivity fan in terms of interpretations by example of the Espresso coffee making process. The intention of the authors is to provide the reader with some guidelines and not with "easy solutions" in the meaning that they should be used moderately and every answer should be questioned. The grading phase can be quicker, using an approach similar to the branch and bound, as explained in Section 5.4.6

Table 12: Variation size grading guidelines

	Grades	Procedures/Instruction/Checklist/Instruction/Checklist	Resources	Machine
Variation size table	10 - 9	• Not previous experience or limited • Procedures/Instruction/Checklist docs are not available	• Strongly lack of resources	• Strongly lack of resources
	8 - 7	• Previous experience • Procedures/Instruction/Checklist docs are not available	• Resources present • Do not meet the capacity demand	• Resources present • Do not meet the capacity demand
	6 - 5	• Previous experience • Procedures/Instruction/Checklist docs are in place • Procedures/Instruction/Checklist docs are not well defined • Procedures/Instruction/Checklist docs are not applied • Procedures/Instruction/Checklist docs are not communicated	• Partially available • Sometime shared	• Partially available • Sometime shared
	4 - 3	• Previous experience • Procedures/Instruction/Checklist docs are in place • Procedures/Instruction/Checklist docs are well defined • Procedures/Instruction/Checklist docs are not applied • Procedures/Instruction/Checklist docs are communicated • Missing control on Performance Ind.	• Present • Competence • Not well trained	• Present • Need to be adopted • Variation in models
	2 - 1	Natural/Intrinsic variation	Natural/Intrinsic variation	Natural/Intrinsic variation

Table 13: Sensitivity size grading guidelines

Explanation	Examples - (KPC coffee taste)
If the slope is greater than 1 it means that the NF variation is heightened when it is transmitted to the process	The taste of the coffee extremely depends on the time we let the coffee machine on the stove ***so*** the variation of the time is transmitted in a heightened way because 30 sec. more on the flame can seriously compromise the taste of the coffee.
If the slope is equal to 1 it means that the NF variation is equally transmitted to the process	The taste of the coffee will vary proportionally to the quantity of sugar ***so*** the variation in the tool "spoon" is equally transmitted to the coffee taste.
If the slope is lower than 1 it means that the NF variation is reduced when it is transmitted to the process	The taste of the coffee is little affected by the quality of the cup ***so*** the variation in the material of the cup is transmitted to the coffee but its effect is reduced. There are a lot of material that can be used for building the cup but the variation in the taste is little affected from the material we choose

Pitfall and how to avoid them

One pitfall is to not focus on the KPC when grading the variation. To avoid this, make sure to introduce the aim and purpose of P-VMEA and clearly state the KPC to ensure that it is fully understood by everyone to avoid lack of focus on the KPC target. It is important that all people involved in this process understand the grading definitions and that all participants have an agreed view of the process.

Example: Real case
Application of P-VMEA to the ISC process at Volvo GTT. See Appendix 11.

Step 6: Calculate the VRPN

WHAT?
Calculate the Variation Risk Priority Numbers (VRPNs) and display them by using the VMEA bar chart.

WHY?
For classifying the different sources of variation and create a prioritization order.

HOW?
Use the results from the P-VMEA interview template (see Section 4.2.1 and Appendix 4), and transfer them into the P-VMEA template (see Appendix 10). When all the field are fulfilled the VRPN will be automatically generated according to the VMEA theory.

Pitfall and how to avoid them
Wrong numbers are inserted in the P-VMEA template. To prevent this, review the numbers carefully and let another person check the document.

Example: Real Case
Application of P-VMEA to the ISC process at Volvo GTT, see Appendix 11.

Step 7: RASCI-matrix (optional)

WHAT?
Define for each activity step who is the task: Responsible, Accountable, Support, Consulted and Informed. Fill in the RASCI matrix (see Appendix 8) by using the information from the P-VMEA interview template (see Section 4.2.1).

WHY?
This is an optional step, but it is strongly recommended for clarifying the roles and the responsibilities in an illustrative and visual matrix that clarifies the human resources responsible for each process activity step.

HOW?
Use the RASCI-matrix by filling in the roles and responsibilities in the selected process on the template found in Appendix 8.

Pitfall and how to avoid them
Not identify the right responsibilities. Support of the management is needed for identifying the responsible people in the process.

Example
Application of P-VMEA to the ISC process at Volvo GTT, see Appendix 8.

Gate Phase 3

- The Process map is confirmed
- VRPN is calculated correctly
- RASCI-matrix is filled in (optional)
- RASCI responsibilities are transferred into the P-VMEA table (optional)

6.7 PHASE 4: PRESENTING RESULTS

Step 8: Create the P- VMEA report

WHAT?
When all relevant information are gathered about the process, the P-VMEA report can be created including a description of the process variation, its noise factors and related risks to the Key Process Characteristic. Mitigation and management actions have to be added as well as a summary of the P-VMEA results and further relevant information to the P-VMEA report stakeholders.

WHY?
To communicate the information gathered in a structured A3 format (see Appendix 5).

HOW?
By using the P-VMEA report template (see Section 4.2.4).

Pitfall and how to avoid them
Drawing and language errors are potential pitfalls as well as errors in the displayed information. To prevent this, the language should be checked in order to create a common understanding of the used words. The fields should be filled in by the P-VMEA driver and later complemented with information by management support if necessary.

Example
Application of P-VMEA to the ISC process at Volvo GTT. See Appendix 9.

Gate Phase 4

- The P-VMEA report template is correctly filled in
- The P-VMEA report is clearly communicated to the stakeholders

Discussion

In this section, the development of P-VMEA framework and the results of the empirical findings and analysis will be discussed.

7 DISCUSSION

The main focus of this thesis work was to answer the main research question (see Section 1.5): "Can VMEA be applied to any processes and be used as an effective variation risk management tool to provide information for making decisions?". During this thesis work, the concept of VMEA was tested on different processes, but we soon come to the conclusion that the VMEA methodology as it is, is not suitable for processes. Therefore, we decided to adapt the VMEA concept and combining it with the VRM and decision making theories in order to create suitable tools that can support the VMEA application to processes. Moreover, thinking about variation already in the process mapping stage led us to develop a framework that will save both time and money for organisations by collecting essential data from the beginning of the process analysis. The result of this study is a Process-VMEA (P-VMEA) framework.

As a first step, the we started to develop the methodology by identifying the Voice Of the Customers (VOC), where managers, engineers and project leaders were intentionally selected as major stakeholders for the P-VMEA. This choice was done since managers are the major decision makers in organisations and for using their expertise concerning decision making procedures. The attention was focused on finding what managers need for making decisions and the key characteristics of a tool for managing process variation. With this purpose in mind, semi-structured interviews were conducted. Interviews were time consuming but however they were important for setting the baseline of the research. The VOC was somehow difficult to identify due to the unspoken customer needs, for this reason a Kano analysis was conducted. The main result was that managers seek for a methodology that can allow them to make decision based on fact and that can provide the fact in a standard way, with a good selection of the information to show. Due to the time restriction the sample size for the interviews was kept relative small. Probably it could have been enlarged in order to get more and detailed attributes, but it was preferable to focus the attention on few "good" interviews, this was done by selecting carefully the participants, paying attention on having interviewers at different managerial levels and in different companies and different skills. Furthermore, a literature research was previously conducted in order to support the interview phase. The literature research was helpful also for building the Kano questionnaire.

A specific attention was given to the integration of the VMEA thinking in the process mapping stage as we during our thesis discovered some limitations to the VMEA methodology. As the Sub-KPCs are decomposed into several sub-levels, the VRPN will increase and be much larger for the NFs acting on Sub-KPC with higher numbers of levels. Therefore, the obtained VRPN can lead organisations to make wrong decisions. After having developed several possible different suggestions, the proposed integration between basic and enhanced VMEA represents, according to us, the best solution. In fact, on one hand the VMEA methodology is still easy to implement since it is still based on the judgment of the experts (Basic VMEA philosophy). On the other hand, the sensitivity fan (Enhanced VMEA tool, (see Section 3.4.4.3) allows to have more accurate judgments among noise factors acting on different sub-process levels. However, another solution that can be discussed is the possibility to use the Basic VMEA and to keep the same level of decomposition for each sub-process. We suggest this solution when the participants involved in the grading phase have poor knowledge about statistic and transmission of variation. Instead, in all the other cases, this solution can enlarge the time for the analysis because the sources of variation can not be screened but all of them must be graded. Moreover, the goodness of the results can be affected. In fact, important information as for instance the sensitivity between the sub-process and its sub-sub-processes will be lost.

Later in the analysis, different tools for managing processes variation were analysed, especially in order to give to the study a deeper validity, several process mapping tools were judged. The judgments for each process mapping tool were obtained both according to our own opinions, concerning the different models developed during the analysis, and according to a literature research of case studies, research papers and articles. During the investigation we thought to have also the participants' point of view on the different tools, especially on the developed models. However, during the analysis this idea was rejected because we believed that our knowledge gained from the literature research and from our own experiments with different process mapping tools was adequate. As well, other people might only be familiar with using one or two and have difficulties to compare them. At the end of the analysis, the combination of the IDEF0 philosophy in the BPMN diagram was the one giving the best results, in terms of representation and completeness of the information. In our opinion, the IDEF0 has a standard representation but the process flow is difficult to follow and to represent, BPMN instead allows to more clearly representing the process flow and to better show the different actors involved in the process. Moreover, it results from the literature research that the BPMN model can be easily converted in a RASCI matrix allowing better representing the responsibilities in the process. The process map is built taking into account the logic behind the Ishikawa diagram, which is present in the VMEA methodology. However, we do not suggest using the Ishikawa diagram in the P-VMEA framework since the P-VMEA interview template includes the same elements.

By talking with the managers responsible for the previous Six Sigma project where the VMEA was for the first time applied to a process and by analysing how the project results were accepted, we noticed a difficulties of the organisation to make decisions about what actions to take from the provided results. Thus, the P-VMEA methodology was developed aiming to enhance the communication among different departments and groups. With this in mind, starting from the VRM theorem, a tool for showing the methodology's results and making decision was developed. The P-VMEA A3 report is the final output of the P-VMEA analysis. The P-VMEA report was thought to be a powerful tool for involving the experts' knowledge in the decision making process. Our idea to use an A3 format was inspired from the Lean theory. The structure of the template was built upon the VRM theory but the content is strictly based upon the results from the interviews and the Kano analysis. Having an A3 format can be beneficial to use as it has become quite spread within the enterprises and people are familiar with it. We believe that the second section of interviews was really helpful for us to improve the final A3 P-VMEA report as it is highly important that the right content will be included and communicated effectively in the report to the organisation and the decision makers. Moreover since P-VMEA should enable the decision making process, the three steps of the VRM were complemented by a management section on the P-VMEA report.

During the analysis the P-VMEA framework was tested in a real industrial case. The first test of the methodology gave satisfactory results, although the methodology was hard to implement at the beginning. The impression was that the main difficulty with the methodology was the level of statistical knowledge that is required for being applied. To overcome this obstacle, several example of how to assess the sensitivity and the variation size were generated. The test at Volvo showed as Six Sigma trained participants could easier follow the grading while others needed more explanations, as well it was clear that the goodness of the results depends quite a lot on the ability of the facilitator that leads the discussion. The information acquires a higher value if the facilitator has a good leadership skills, the facilitator should lead a discussion in a proactive way, going fast when it is needed and stressing the attention on the focus points. However, the achieved results during the test at Volvo GTT were according the expectations, in fact they confirmed in a statistical way the process criticalities that were already known and they highlighted new ones.

The methodology is still new and it needs to be validated, this can be done testing and testing it again. There is still room for improvement; there is not a clear relationship between the output(s) of one activity that becomes immediately the input for the following activity. This relationship is expressed only in terms of attributes of the output but it can be further investigated taking into account a different way of representing it, for instance by looking at the output variation and considering its affection on the following activity. Anyway, the methodology acts on each activity in the belief that if every activity is stable, also its output becomes stable and does not affect the following activity performance too much. Another limitation derives from the VMEA methodology itself, in fact in the methodology it is not mentioned how to take the correlation between different noise factors into account. In the P-VMEA this problem was not further investigated but instead the VMEA theory was applied.

We perceive the P-VMEA as a proactive approach to solve the problems rather than P-FMEA that has a solving problem philosophy and consequentially by definition a reactive approach. No further investigation is conducted about the difference between VMEA and FMEA. We believe that this topic was satisfactory analysed by the VMEA authors. Furthermore, we do not aim to create any comparison between the P-VMEA and the P-FMEA since they apply different tools and templates.

Conclusion

In this section, the conclusions of this dissertation are presented. The conclusions are based on the results of the P-VMEA investigation especially how they answer the research questions. At the end, recommendations for applying the P-VMEA are suggested.

8 CONCLUSION

8.1 Conclusion

Variation is present everywhere, to different extents, at work and in daily life, affecting expected outcomes. Variation causes targets not to be reached and impacts performance and costs. Dealing with variation can be very time consuming and a process must be seen both on a system level and on detail level in order to identify the root causes to the variation in order to make high quality decisions. This thesis work was set out to explore the concept of VMEA and if an application of the tool can be used for not only building robust products, but also for creating robust processes and managing process variation. The aim was also to build a framework in accordance to the principles of VRM (Thornton, 2004) and VMEA (Johansson et al. 2006; Chakhunashvili et al. 2004; Barone and Lo Franco 2012; Bergman 2009) that can increase peoples' and organisations' understanding for variation. The aim also consisted of providing a structured methodology for enhancing the ability of making decisions based on facts in terms of qualitative and quantitative data. The main empirical findings are found in Chapter 4 and 5. In this concluding chapter, the empirical findings will be synthesized to answer the research question:

Can VMEA be applied to any processes and be used as an effective variation risk management tool to provide information for making decisions?

The study shows that an application is possible with some modification of the three already known VMEA approaches. The aim and the goal of this study have been reached and a framework has been developed, tested, improved, tested again and finally improved. The result is the P-VMEA framework (see Chapter 6).

Essential information was collected from interviews where the needs of the stakeholders and people in decision making positions were identified and analysed. This set the basis for the P-VMEA framework that was further developed by the creativity, experience and judgements of the thesis authors.

Many theories were discussed during the thesis development, this provided different theoretical contributions which supported the exploration of new research areas. The P-VMEA methodology is consistent with existing theories. This study contributes to the research field in the meaning that a new application area of VMEA was established together with a framework for identifying, assessing, mitigating and managing process variation, inspired by the VRM theory. This study is targeted towards any decision maker such as directors, managers, project leaders. P-VMEA will help to quantify and prioritize qualitative data and to support high quality decisions.

Even though P-VMEA was successfully accepted by the people involved in this thesis, P-VMEA is a statistical complex tool that requires high knowledge about variation and how to conduct the analysis of data. Due to restricted time, the P-VMEA was only applied to one industrial case and needs further validation. Moreover the amount of respondents was limited as well due to this time restriction.

For future research, as this study concerns a new research area, further tests of the P-VMEA are necessary in order to strengthen the validity of the methodology. The authors' ambitions are to improve P-VMEA and to test it on more cases. Important is for the methodology's success to simplify it, making it easier to use and more understandable for someone without any familiarities with variation and the concept of Six Sigma.

What we can conclude is that understanding variation risk management is important. P-VMEA is a way to trying to seek the root cause of the variation and not accepting it for what it is. Organisations must be aware of their process variation in order to optimize the expected process outcome to avoid targets not to be reached. A change in behaviour, by working in a pro-active way, is necessary for identifying and managing the variation in an earlier stage. This change enables organisations to make high quality decisions, to build robust processes and to save both time and money.

8.2 Recommendations

Educate people within organisations about the concept of variation
Since variation is differently understood and known by people within organisations, educating people about the concept of variation is highly important in order to have a common understanding of what is variation and use of terminology. Organizations must understand what is deviating and why it is worth putting any effort into it.

Follow the P-VMEA framework step-by-step
The P-VMEA framework is strongly recommended to be followed step-by-step. However, what tool to use within the methodology could vary depending on the organisation's or the facilitator's preferences, for example the selected tool used for identifying the problem. Instead, the most important when applying P-VMEA is that each of the gates' criteria are met before proceeding to the next phase.

Assign a skilled facilitator for applying the P-VMEA framework
For applying the P-VMEA framework, a skilled leader, preferably with Six Sigma Black Belt skills, is recommended. Even though step by step guidelines and a real industrial case have been provided in Chapters 5 and 6, an understanding of process variation and some statistical knowledge are recommended.

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Appendices