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**ORGANIZATIONAL CHALLENGES IN (MODEL-
BASED) REQUIREMENTS ENGINEERING IN THE
AUTOMOTIVE INDUSTRY**



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ABSTRACT

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The development of modern technologies has led to major changes in the automotive industry. Requirements Engineering has become pivotal for the success of development projects. The way how organisations operate within a company or between several companies is one of the most important aspects of Requirements Engineering. This research study represents an extension of the earlier research studies in a way that it deepens and broadens the understanding of organizational challenges in the automotive industry. This paper addresses organizational challenges that occur in the automotive companies on a daily basis. The aim of the research study is to understand what kind of challenges exist when it comes to the Requirements Engineering practices. The study also aims to propose suitable solutions to improve the companies' operations based on the empirical evidence. Literature review is used as an approach for the theoretical part and this is used as a basis for the research study. The qualitative data was gathered from the companies using semi-structured interviews (n=22). The collected data was studied utilizing the thematical data analyzing method. The findings identify multiple challenges and improvement proposals which have been divided into three themes: Communication & Co-Operation, Organizational Culture and People Skills. Requirements Engineering practices in the automotive companies can be developed further when these challenges and proposed improvements are carefully studied and understood.

Keywords: Organisation, Organization, Organisational, Organizational, Challenges, Problems, Model-Based, Requirements, Requirements Engineering, Challenges, Communication, Automotive

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1 INTRODUCTION

The automotive industry has been under major changes in the past thirty to forty years. The first deployments of simplified software solutions in cars were introduced in the 1970s. In that time, software was developed to control the engine and, in particular, the ignition. The first software-based solutions were strictly functionally and technically isolated, and there was no connection between them. Nowadays the software has become the major factor to the value of modern cars, which has led to cost escalation. One reason for this trend was that the software enabled the implementation of the functionality that was believed to be impossible just 20 years ago. (Broy, Krüger et al., 2007).

The Requirements Engineering process ensures that the safety aspect is always covered, which is why safety aspect represents a great challenge in the automotive industry. This research study argues that the companies in the automotive industry face challenges on a daily basis related to Requirements Engineering operations. These challenges emerge due to demands related to safety-critical aspects of functionality and due to related certification processing of it. The aim of the study is to provide a wider understanding of the daily challenges that companies face internally and the challenges that appear among companies when they cooperate as a supply chain. Furthermore, the organizational challenges and strengths that appear in the automotive industry will be studied.

The research study argues that Model-Based Requirements Engineering practices do not efficiently follow manners in today's automotive industry. In addition to this, it identifies the organizational challenges that companies face daily. The main focus of the research study is on understanding organizational challenges within the automotive companies. Lastly, the research study argues that mature Model-Based Requirements Engineering processes and their practices are still quite rare in the automotive industry.

1.1 Backgrounds and Motivations

Despite the long history of the automotive industry, innovations in the industry have been driven by mechanical engineers for a long time. The software and electronics hardly had any impact on product development in the past. Different aspects of product designing, e.g. safety, consumers' needs, demands and expectations and changes in legislations, as well as evolvement of technology have led to the expansion of the areas of the software and electronics development in the automotive industry. Increasing size of the embedded software and the electronics will enable more functionalities in modern cars. The role of software platforms is becoming more important because it can provide a variety of functionalities and services for cars and passengers. It has been mentioned in several research studies that software development has also become one of the leading factors of today's technology innovation in the automotive industry. (Broy, 2006).

International Organization for Standardization (ISO) published a formal standard known as *ISO 26262 Road Vehicles – Functional Safety* in November 2011. The standard is specialized in road vehicles and it covers functional safety in electrical and/or electronic (E/E) systems in the automotive industry. (ISO, 2011).

According to the ISO 26262 standard, safety is achieved through a variety of technologies such as mechanical, hydraulic, pneumatic, electrical, electronic and programmable electronic (ISO, 2011). The ISO 26262 standard applies to functional safety of electrical and/or electronic systems by providing a standard framework. Within the framework, systems are based on other technologies and innovations.

Applications and products in safety-critical domains require a high-level of dependability. *Dependability* as a collective term is used to describe the availability performance and its influencing factors. Dependability consists of reliability performance, maintainability performance and maintenance support performance. (Strandberg, 1991; Avizienis, Laprie et al., 2001). Ziegler et al. (1994) claim that increasing complexity in automotive computer systems could be harmful for vehicle reliability and safety, unless the dependability issues are globally addressed at all levels of product development process.

Defects, failures or serious errors in such safety-critical areas can not only have a direct impact on people's lives, but can also cause environmental harm, material damages or business failure. Therefore, safety-critical aspect should be taken into account through different phases and organizational levels of the rigorous product development and Requirements Engineering processes.

Due to increasing speed of technology development and towards more software-based innovations and product development, even more complex and tightly embedded software and electronics are expected in the future. For

instance, there will be innovations such as connected cars, automated driving, and even self-driving cars. The product development skills and processes are not developed at the same pace in the automotive industry. Therefore, it is pivotal to develop new efficient practices in Requirements Engineering processes. This way, safety-critical product development will be ensured. The automotive industry is moving towards similarities in the process-wise way of operating which companies in the ICT industry already have.

1.2 Research Objectives

The main objective of the research study is to identify and analyze the current state of challenges in the organizations which apply Model-Based Requirements Engineering processes and practices, in the selected automotive companies. There are two main objectives of the research study:

- 1) to investigate the current state-of-practice of Model-Based Requirements Engineering in the automotive industry.
- 2) to provide a better understanding of why Model-Based Requirements Engineering process and practices still represent a challenge from the organizational perspective.

The research study aims to publish results concerning organizational challenges of Model-Based Requirements Engineering process and practices in the automotive industry. The aim of the research study is to provide guidelines for the identified challenges.

1.3 The Scope of the Research

This research study is positioned within the field of Information Systems Science (IS). Information Systems Science is an applied research academic discipline where theories from other disciplines such as economics, computer sciences, and the social sciences are applied to solve problems at the intersection of information technology and organizations. (Peffer, Tuunanen et al., 2007)

The scope of this research study is limited to identifying organizational challenges and proposing adequate solutions for those challenges. This takes place in the frame of product development projects with the focus on Model-Based Requirements Engineering processes and practices in the automotive industry. The specific solutions will not be offered for all identified challenges. The feasibility of proposed solutions will not be verified in this research study.

This research study represents an extension of the research study conducted by Liebel, Tichy et al. (2016) in a way that it deepens and broadens the understanding about organizational challenges in the automotive industry. All Requirements Engineering processes and practices in the companies operating outside the automotive industry are scoped out. In addition to this, comparison related to organizational challenges concerning Requirements Engineering practices between automotive industry and ICT domain is not discussed in the research study. These out-scoped topics are possible subjects for future research studies. For the purposes of this research study, the automotive industry is defined as a field that includes both car manufacturer companies and their external suppliers.

The research study focuses on Model-Based Requirements Engineering practices, but it is not only limited to them. It also includes automotive companies in the scope which does not apply Model-Based Requirements Engineering processes and practices to their daily operations.

In this research study, the definition of the *organization structure* is the same as the logical relations or the decision-making hierarchy between people in the organization. *Communication* is defined as transferring information between the people in the organization, between different organizations within a same company or between different companies within the automotive industry. (Liebel, Tichy et al., 2016)

1.4 Research Problems

It is a challenging to understand how existing research studies related to organizational boundaries (Santos & Eisenhardt, 2005) and the influence of organizational structure are connected to companies' performance (Hao et al., 2012). They can be combined with the research studies related to challenges in Requirements Engineering.

Several qualitative research studies focus on challenges in Requirements Engineering processes (Hansen & Lyytinen, 2010; Karlsson et al., 2007; Liebel et al., 2016). Requirements Engineering in other sectors e.g. ICT industry is in a more mature state than in the automotive industry. Therefore, it can be expected that Requirements Engineering in the automotive industry will be developed by following good practices in other industries to some extent.

Liebel et al. (2016) studied communication challenges in the automotive industry. Their research study included only two automotive companies, one automotive car manufacturer and one automotive supplier. Therefore, there is space for further research which will include more European automotive companies.

1.5 Research Questions

The research study aims to answer the following research questions:

Research Question # 1:

What is the (Model-Based) Requirements Engineering in the Automotive industry?

Research Question # 2:

What are the organizational challenges on different levels of organizations in the automotive companies which apply (Model-Based) Requirements Engineering process and practices?

Research Question 1 aims to provide a comprehensive overview of the Requirements Engineering covering Model-Based perspective in the academic literature. Research Question 2 aims to identify challenges that employees at different levels in the automotive companies face on a daily basis when it comes to Requirements Engineering practices. Research Question 2 will be answered through defined Proposition.

The research study also discusses possible answers to the question: *What are possible solutions addressed to challenges?* These solutions will be identified as an outcome of interview answers. This cannot be treated as a research question since defining solutions is outscoped from the research study.

1.6 The Structure of Thesis Research Study

The research study is divided into six different chapters including the Introduction chapter. The chapters are divided into four different parts that shape the overall structure of the research study. The structure is depicted in the Figure 1.

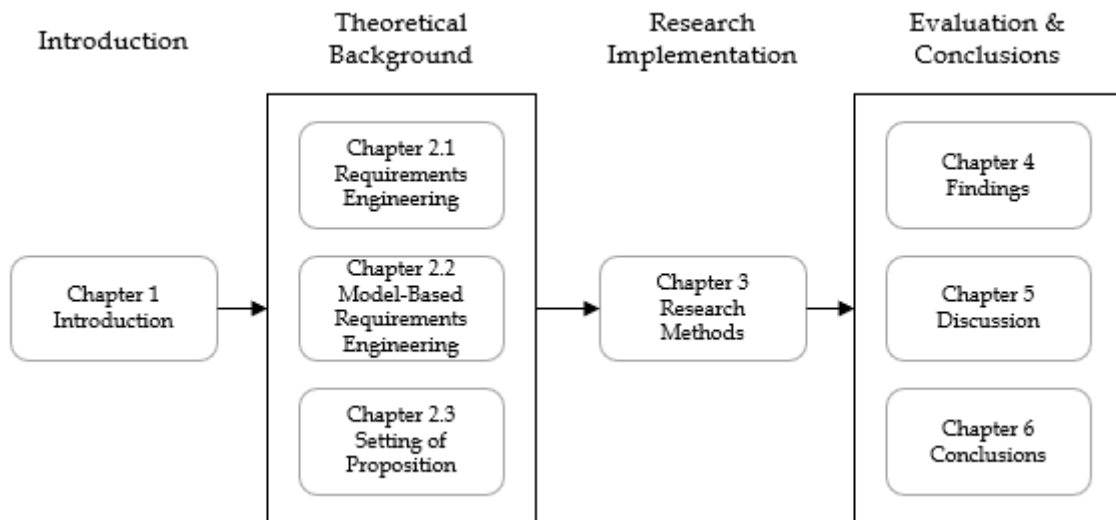


FIGURE 1 The structure of the research study

Chapter 1 introduces backgrounds and states the motivation for the research study. It introduces the research objectives and provides the scope of the research study. The scope serves as a guideline of the research study. The chapter describes two research questions. In addition, the chapter explains the structure of the research study. The chapter ends with the list of vocabulary terms used in the research study.

Chapter 2 titled *Theoretical Background* discusses the definitions of the Requirements Engineering and Model-Based Requirements Engineering. The chapter discusses why Requirements Engineering represents an important aspect of product development projects and it also discusses the general challenges of the Requirements Engineering. The chapter discusses the Model-Based Requirements Engineering by introducing three different kind of approaches.

Chapter 3 titled *Research Methods* discusses the research methodology. It introduces the design of the research study and the way how the field data was gathered through the interviews in the automotive industry. The thematic data analyzing method is explained in this chapter. The chapter ends with a discussion concerning the quality aspect of the research study.

Chapter 4 titled *Findings* introduces the definition of the guidance Proposition of the field study with their literature backgrounds. Then the chapter discusses the findings based on the data analysis for the Proposition. The Propositions analysis covers challenges and specified solutions to some challenges.

Chapter 5 titled *Discussion* answers the research questions and discusses implications to the previously conducted research and the literature. The chapter also discusses implications to practice how the research study results can be implemented in the automotive industry.

Chapter 6 titled *Conclusion* summarizes the research study and it briefly discusses the contribution of the study to academic research. Limitations and deficiencies of the research study are discussed in this chapter. The chapter ends with the recommendations for further research studies.

1.7 Terminology

TABLE 1 Terminology

Terminology	Definition
Customer Requirement	Customer Requirement describes more concrete source of the requirement. It refers to information which describe and aggregate needs of stakeholders. (Wiegiers & Beatty, 2013).
MBE	Model-Based Engineering
MDE	Model-Driven Engineering. Narrower scope from Model-Based Engineering. Models are used as the primary artefacts throughout the entire engineering process. (Liebel, 2018)
MDD	Model-Driven Development. Subset of Model-Driven Engineering. Focus is only on software and systems development. (Liebel, 2018)
MDA	Model-Driven Architecture. Subset of Model-Driven Development. Devised by the Object Management Group. (Soley, 2000; Liebel, 2018)
Implementation Requirement	The implementation requirements should accurately describe the intended system capabilities and properties which will satisfy the stakeholders' needs. The implementation requirements are properly derived from the customer requirements, system requirements, business rules, and other sources. (Wiegiers & Beatty, 2013).
NFR	Non-Functional Requirement describes qualities of the system to be developed and often influences the system architecture more than fuctional requirements. Non-Functional Requirements are typically about the performance, availability, dependability, scalability or portability of a system. (Pohl & Rupp, 2015).

2 THEORETICAL BACKGROUND

This chapter provides overall definition of Requirements Engineering and it discusses why Requirements Engineering is important for the success of product development projects. In this context, product development covers both hardware and software development projects. The aim of the chapter is to discuss Requirements Engineering in the scope of automotive industry. The chapter ends with three different aspects of Model-Based Requirements Engineering.

2.1 Requirements Engineering in the Automotive Industry

This sub-chapter discusses how Requirements Engineering process and practices are currently being managed by car manufacturers and supplier companies at various levels of supply chain in the automotive industry. Supplier companies deliver product components to car manufacturer companies and one or more supplier companies can participate in a supply chain.

This study does not provide a complete overview of the Requirements Engineering processes and practices in the automotive industry, since the topic is too broad and complex. The topic provides a wide range of possibilities for further research studies. This will be explained further in the chapter of 6.

The engineering and product development work in the automotive industry has changed from pure mechanical design and engineering to software development. The amount of software in one car model has increased from zero to over 1 gigabyte of software code - and it will significantly grow in the future. (Broy, Krüger et al., 2007). It has been estimated that amount of data in automated driving cars can reach four terabyte which is the amount a car itself will produce in a day in the future. (Burkert, 2017).

Technology development, increasing complexity in systems and software, and increasing demands for changes (such as shortening delivery times) are three major factors for implementation and improvements of efficient Requirement Engineering processes and practices. Concerted efforts have been made in order to improve the development practicalities of software-intensive systems. More efficient operating processes with supporting information systems and a respect of specific needs are becoming a crucial challenge for many companies in the automotive industry.

2.1.1 Requirements Engineering Definition

Requirements Engineering is not only limited to product development projects or ICT focused projects. Requirements Engineering is a fundamental part of all projects regardless of what the project produces. It is relevant to define what is required from stakeholders from the system perspective and what the system requires to be handled in order to fulfill stakeholders' needs (Agarwal et al., 2010; Ballejos & Montagna, 2011).

2.1.2 Definition of a Requirement

Requirements express the needs and constraints that are placed upon a product that contributes to the satisfaction of some real-world application (Kotonya & Sommerville, 2000).

The IEEE (2017), which is the world's largest technical professional organization for the advancement of the technology, has standardized the term *requirement* by following definitions:

- 1) statement that translates or expresses a need and its associated constraints and conditions.
- 2) condition or capability that must be met or possessed by a system, system component, product, or service to satisfy an agreement, standard, specification, or other formally imposed documents.
- 3) provision that contains criteria to be fulfilled.
- 4) a condition or capability that must be present in a product, service, or result to satisfy a contract or other formally imposed specification.

(ISO/IEC/IEEE 24765, 2017).

2.1.3 Definition of a Stakeholder

Stakeholders are the source of the requirements. There is a group of stakeholders called *key stakeholders*. The key stakeholders are usually representatives of customers, representatives of possible end-users, project sponsors or other external parties which are affected by the outcome of the project.

Hofmann and Lehner (2001) define the term *stakeholder*:

Stakeholders are individuals and organizations that are actively involved in a software project or whose interests the project affects. Stakeholders of any computer system can include customers, users, project managers, analysts, developers, senior management, and quality assurance staff (Hofmann & Lehner, 2001).

The IEEE (2017) standardized the term *stakeholder* by following definitions:

- 1) individual or organization having a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectations.
- 2) An individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project.
- 3) individual, team, organization, or classes thereof, having an interest in a system.
- 4) individual, group or organization that can affect, be affected by, or perceive itself to be affected by, a risk.

(ISO/IEC/IEEE 24765, 2017).

2.1.4 Definition of Requirements Engineering

Zave (1997) defines *Requirements Engineering* in her study:

Requirements Engineering is the branch of software engineering concerned with the real-world goals for functions of and constraints on software systems. It is also concerned with the relationship of these factors to precise specifications of software behavior, and to their evolution over time and across software families. (Zave, 1997)

The ISO/IEC/IEEE (2011) has standardized the term *Requirements Engineering* by following definition:

Interdisciplinary function that mediates between the domains of the acquirer and supplier to establish and maintain the requirements to be met by the system, software or service of interest. (ISO/IEC/IEEE 29148, 2011)

Khanom (2014) defines *Requirements Engineering* in her study:

Requirements Engineering understands and clarifies external conditions, determining what capabilities the proposed system must possess in order to conform to external conditions, and documenting required capabilities as requirements for a system. (Khanom, 2014)

It is quite challenging to find a satisfactory definition of Requirements Engineering because of requirements inter-connectedness with other aspects of systems engineering and project management. (Hull et al., 2011). In conclusion, it is very challenging or even impossible to have one, clear overall definition of the term.

2.1.5 Requirements Engineering Process

Requirements Engineering is not a separate and distinct process which is conducted only at the beginning of every project. (Sommerville, 2013)

The Figure 2 depicts that Requirements Engineering process is usually placed between activities of system acquisition and system design, and requirements are developed as a part of those processes. Requirements also may be refined, and new requirements can occur during the system design phase. (Sommerville, 2013)

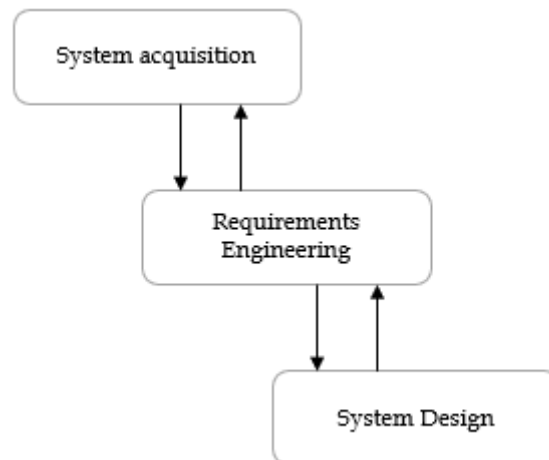


FIGURE 2 The context of Requirements Engineering process (Sommerville, 2013)

The Requirements Engineering process consists of two major processes, *Requirements Development* and *Requirements Management* as depicted in the Figure 3. (Hofmann & Lehner, 2001)

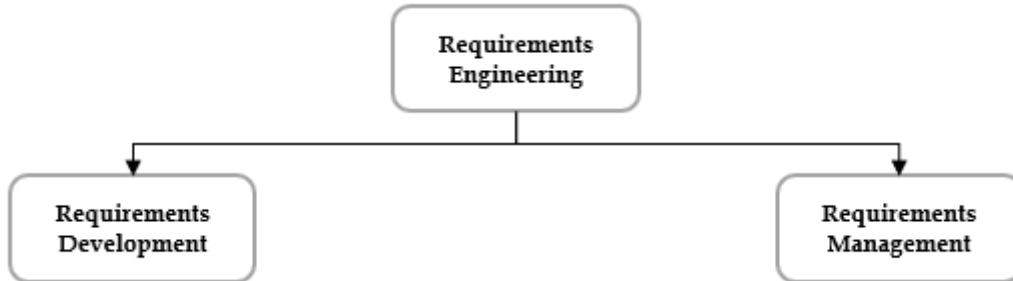


FIGURE 3 Requirements Engineering Process on the high-level (Khanom, 2014)

The life-cycle of Requirement Engineering process covers five separate but related activities. Requirements Development includes *Requirements Elicitation*, *Requirements Analysis*, *Requirements Specification* and *Requirements Validation*. *Requirements Management* covers management of Requirement documents and possible change requests for those after passing all phases of Requirements Development. (Hofmann & Lehner, 2001; Cheng & Atlee, 2007)

In daily operations, the activities vary in timing and intensity between the projects. (Hofmann & Lehner, 2001) The connections of the life-cycle activities are depicted in the Figure 4.

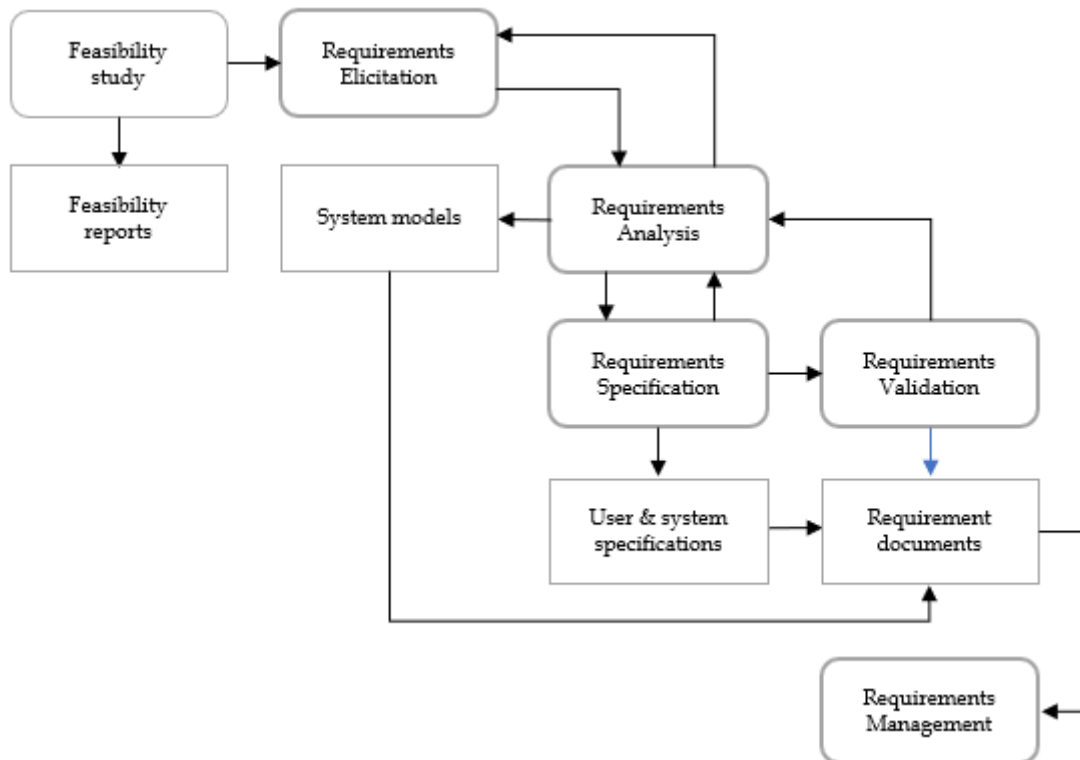


FIGURE 4 Requirements Engineering process (Sommerville, 2013)

The Figure 5 depicts different outputs during the Requirements Engineering process. The output are artifacts e.g. agreed requirements, user and system specifications and system models. All these artifacts represent requirements for product development process.

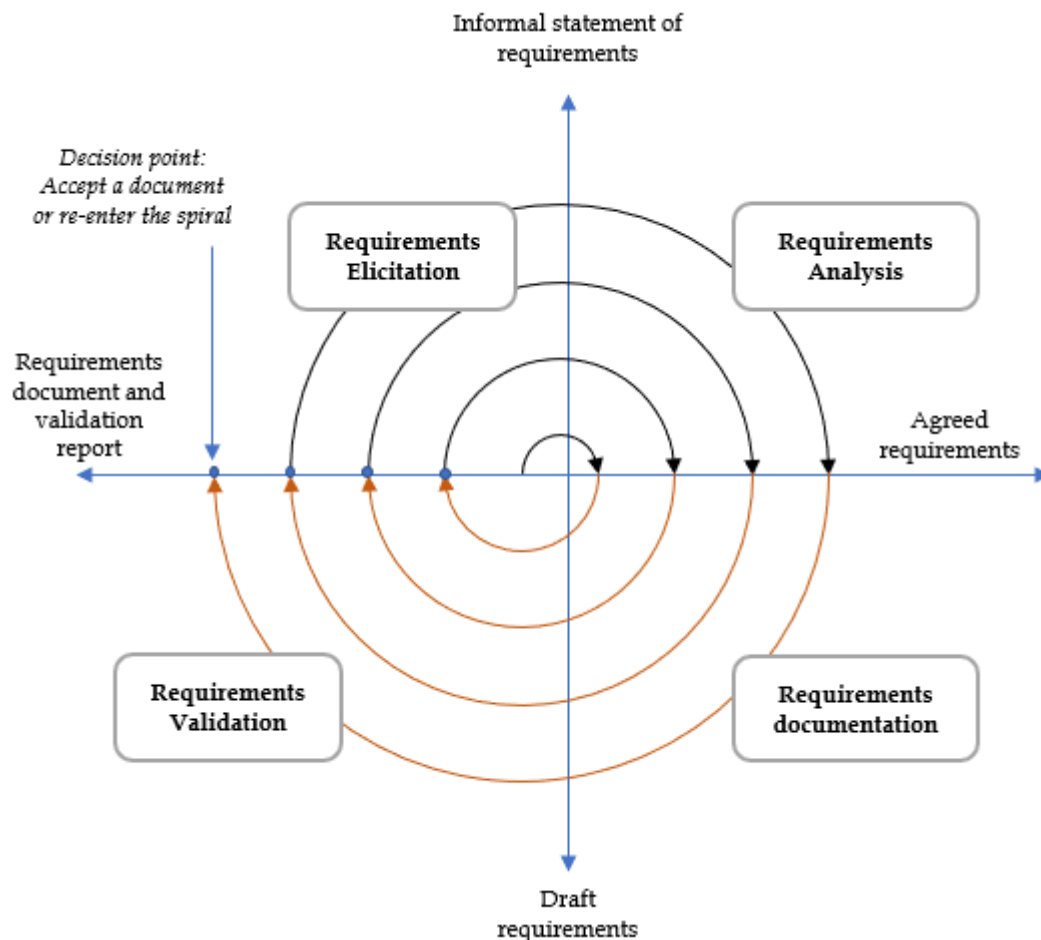


FIGURE 5 Requirements Engineering process as incremental spiral format (Sommerville, 2013)

Different sources of the requirements

In the Requirements Engineering process, there are three main types of sources for requirements: (1) Documents, (2) Stakeholders and (3) Systems in Operation.

- 1) Universal documents such as standards, legal documents, domain or organization specific documents e.g. requirement documents or error reports of legacy systems.
- 2) Stakeholders are people or organizations that directly or indirectly influence the requirements of the system. Stakeholders can be e.g. end-users of the system, operators of the system, developers, architects, customers, and testers.

- 3) Systems in Operation can be legacy or predecessor systems as well as competing systems.

(Pohl & Rupp, 2015)

The Figure 6 depicts the inputs and outputs of the Requirements Engineering.

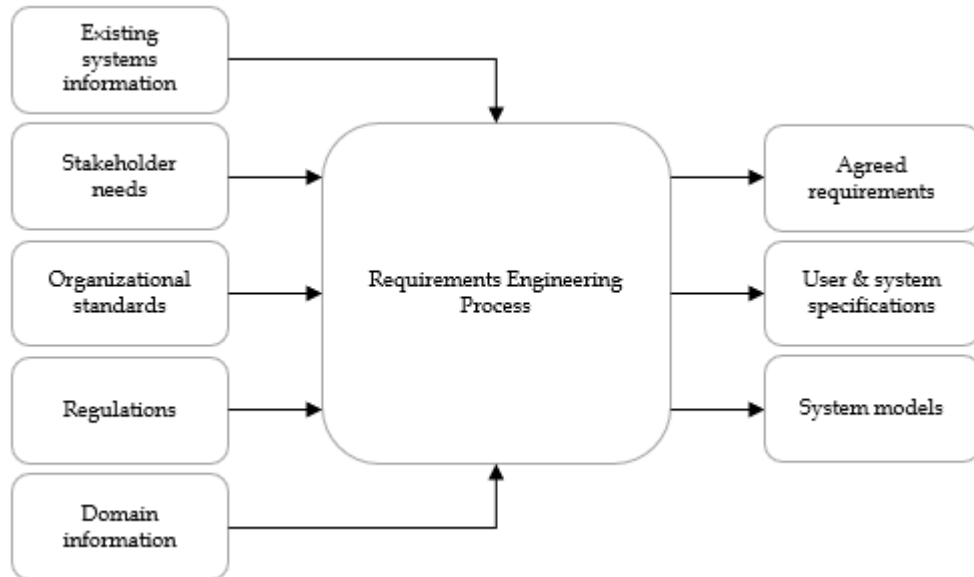


FIGURE 6 The inputs and outputs of Requirements Engineering process (Sommerville, 2013)

The main sources of requirements can be classified against different artifacts as depicted in the Table 2.

TABLE 2 The categorized sources of requirements

Sources for requirements	Artifacts
(1) Documents	<ul style="list-style-type: none"> - Organizational standards - Regulations - Domain information
(2) Stakeholders	<ul style="list-style-type: none"> - Stakeholder needs
(3) Systems in Operation	<ul style="list-style-type: none"> - Existing systems information

Customer Requirements

In some literature *business requirements* are referred to as *customer requirements*. Actually, they are synonyms. In this research study, the term *customer requirements* is used to make a clear difference between other type of requirements, *implementation requirements*.

Term customer requirements describes more a concrete source of the requirement. It refers to information which describes and aggregates the needs of the stakeholders. Customer requirements lead to one or several projects delivering a solution and the desired business outcomes. Statements of business vision, business opportunities, business objectives and business metrics set up the customer requirements. The customer requirements provide a reference for decision-making related to proposed requirement changes and enhancements. Therefore, customer requirements must be discussed, and possible conflicts should be resolved before the functional and non-functional requirements can be fully specified. (Wiegiers & Beatty, 2013).

Implementation Requirements

In some literature *implementation requirements* are called *software requirements*. That term restricts the context only to software development projects. It should be kept in mind that Requirement Engineering applies to all kind of projects and therefore is not limited only to software development. In this research study, the term *implementation requirement* is used to describe the nature of this requirement type. The concrete implementation will be based on this requirement.

The implementation requirements should accurately describe the intended system capabilities and properties which will satisfy the stakeholders' needs. The implementation requirements are properly derived from the customer requirements, system requirements, business rules, and other sources.

All implementation requirements are necessary, and the entire set is sufficient to meet the business objectives. The requirements in overall should be complete, feasible, and verifiable. All the requirements' representations are consistent with each other. (Wiegiers & Beatty, 2013)

Requirements Development

The objective of Requirements Development is to systematically capture requirements by studying stakeholders' needs. The requirements are to be analyzed and turned into implementable specifications. (Hofmann & Lehner, 2001) Requirements Development can be described in four distinct activities, which are discussed next.

1. Requirements Elicitation

Several terms are used to describe this phase. Literature recognizes terms such as Requirements Elicitation, Requirements Discovering, Requirements Gathering, and Requirements Capturing. (Alexander & Beus-Dukic, 2009; Hull, Jackson & Dick, 2011; Pohl & Rupp, 2015)

Pohl and Rupp (2015) define the elicitation phase as one of the core and most critical activities in the Requirements Engineering process. Requirements elicitation is a cooperative activity enabling realization and understanding of the stakeholders' needs. Elicitation requires an involvement with multifaceted stakeholders (Luna, Rossi & Garrigos, 2011). The activity is probably one of the most complex phases of the process because it requires intensive communication between all participants (Coughlan & Macredie, 2002).

The requirements from different sources are gathered during this phase. There is no universal method for performing elicitation for requirements (Hickey & Davis, 2004). The main goal for all elicitation methods or techniques is to support Requirements Engineer or any other person who works with stakeholders by gathering their knowledge and requirements for the project. There are always elicitation techniques available supporting the project in an efficient way. Some of these techniques are questionnaires, introspective, observations, scenarios, brainstorming, focus groups, joint development projects, workshops, prototyping, task analyses, domain analyses and knowledge acquisition. (Zowghi & Coulin, 2005; Khanom, 2014; Pohl & Rupp, 2015). In which way and when the technique can be applied depends on the given conditions. (Pohl & Rupp, 2015). Every project has its individual constraints and individual characteristics.

Hickey (2004) stated that a poor execution of elicitation almost guarantees that the project will be a complete failure. Since failures in software projects are so rampant, it is quite likely that improvements in the way industry performs elicitation could have a dramatic effect on the success of the industry (Hofmann & Lehner, 2001; Hickey & Davis, 2004).

2. Requirements Analysis

Stakeholders' needs are discussed after the elicitation phase. The goal of the analyzing is to have clear and deep understanding about stakeholders' needs, and it should be possible to transfer the understanding into requirements. Requirements should be analyzed in the context in which they arise while taking into account users' expectations. (Garcia Alcazar & Monzon, 2000). Each stakeholders' needs are analyzed within criteria whereby requirements can achieve completeness, consistency and feasibility, and must have firm understanding of the requirements specification (Agarwal, Tayal & Gupta, 2010; Wiegers & Beatty, 2013).

Requirements analyzing phase seeks to determine which of stakeholders needs represents functionality and which represents non-functionality of the

system. The analyzed requirements may be used in negotiations to resolve conflicts that might arise among the stakeholders regarding the requirements. Conflicts can occur during the decision-making activity about which requirements can be accepted or rejected. Analyzed information is also used when setting priority levels for accepted requirements. It can happen that this sort of visualization is required to support gaining of understanding of certain perspectives in requirements. (Khanom, 2014).

The result of analyzing phase can be identification of missing requirements. It can also be identification of inconsistencies or conflicts in the requirements. In cases like these, the elicitation phase must be re-entered in order to find additional information and also to resolve these problems.

3. Requirements Specification

The purpose of the specification phase is to document requirements by describing them as natural language text or by using any modeling languages. Good requirements are consistent, accessible, and reviewable in a way that they are readily understandable by the intended audiences.

Stakeholders may include customers, users, developers or any other required stakeholder (Wiegiers & Beatty, 2013). It is important to define business cases or business justifications for all requirements when all stakeholders know why each requirement is needed and what is an expected business benefit of the requirement. It should be possible to trace back the business benefit in a requirement to its origin.

It might happen that inputs from several requirement sources differ and in many cases they are inconsistent. (Wiegiers & Beatty, 2013; Khanom, 2014) Specification merges inputs from several sources and compromises them to be consistent. Requirement Analysts create a suitable solution proposal for the problem. Audience has to understand what the Analysts propose (the specification) and accept, modify, or discard it. This should be done before starting the product development. Analysing and specifying the requirements is not a linear but rather cyclic and iterative process. (Garcia Alcazar & Monzon, 2000).

Developers will implement a solution. When the solution does exactly what it is specified to do, it might not meet stakeholders' expectations. To avoid such a problem, Requirement Engineer, who discusses about the solution with stakeholders in the elicitation phase, needs to go beyond the functionality discussion. Therefore, Requirement Engineer needs to understand thoughtfully the stakeholders' actual needs of the quality characteristics which are important for success. These quality characteristics are called Non-Functional Requirements.

Non-Functional Requirements include performance, reliability, usability, modifiability, and many other features that are not specific functionalities. (Chung, Nixon, Yu & Mylopoulos, 2012; Wiegiers & Beatty, 2013). Stakeholder input is relatively important for these quality attributes. This input supports the developer in making appropriate implementation decisions such as specifying external interface requirements, design and implementation constraints,

internationalization issues, and other non-functional requirements. (Wiegiers & Beatty, 2013). The outcome of this phase is Implementation Requirement artifact that works as a baseline for product developers who plan and implement work.

4. Requirements Validation and Requirements Verification

There is much confusion and uncertainty in the literature and daily practices in using the terms *Requirements Validation* and *Requirements Verification*. By reading the literature or discussing with professionals, a person might conclude that these two terms represent the same thing. However, this is not the case.

A requirement is *an identifiable element of a function specification that can be validated, and its implementation can be verified* (Society of Automotive Engineers, 2017). In Systems Engineering, requirements validation and verification are described as *Do the right thing* (Validation) together with *Do the thing right* (Verification) (Boehm, 1981). Being able to *do the right thing right* becomes the essential attitude in the Requirements Engineering process. Therefore, the quality factor becomes essential at all levels: the quality of a single requirements must be measured, as well as the quality of all requirements. The quality assessment becomes relevant, and perhaps the main reason to provide this field with a specific engineering discipline. (Fanmuy, Fraga & Llorens, 2012)

The purpose of *Requirements Validation* is to ensure that all requirements support the delivery of value to the business by fulfilling business goals and business objectives, as well as by meeting stakeholders' needs. (Hull, Jackson & Dick, 2011). Requirements validation takes place throughout the lifecycle of the project. While doing the requirements elicitation and later requirements analysis and specification, the information should be constantly questioned and clarified so the requirements' validity can be checked. The formal requirements' validation process is used to ensure that Implementation Requirements are complete, consistent, modifiable and traceable. This is done so as to be sure that the requirements' statements are complete, correct, feasible, necessary, prioritized, unambiguous and verifiable. This phase is essential for filling the gaps or fixing errors in order to minimize defects later. Requirements Validation answers the question: *Are we building the right product?* (Pohl, 2010; Kotonya & Sommerville, 2000; Wiegiers & Beatty, 2013). The validated requirements enable the development team to build the solution that satisfies the business needs. (Khanom, 2014)

If the requirements are not validated, requirement validation and product verification will be done together with the product design and its development activities. The basis for estimating verification costs and verification schedule are provided when the verification is supported by the requirements. This is how verification costs are reduced. When requirements are unverifiable, it means that they are described poorly, or they represent unnecessary requirement. When the description of the requirement cannot be validated, the implementation cannot be designed nor built. The reason for this is that

verification is based on validated requirements. Possible missing specifications or invalid requirements cause rework and significant cost overruns. (Pohl, 2010)

Requirements Verification can be conducted by performing inspections, tests, and analyses throughout the product lifecycle. These activities are necessary to carry out to make sure that the design, implementation and the finished product address the requirements. Another reason for performing the verification is to prevent rework and reduce costs for that. (Pohl, 2010)

Requirements Management

Requirements Management refers to management activities that include maintaining the accuracy, currency and integrity of requirements throughout the lifecycle of the project. (Wiegiers & Beatty, 2013). For maintaining these activities, Requirements Management can be divided into five major activities as depicted in the Figure 7.

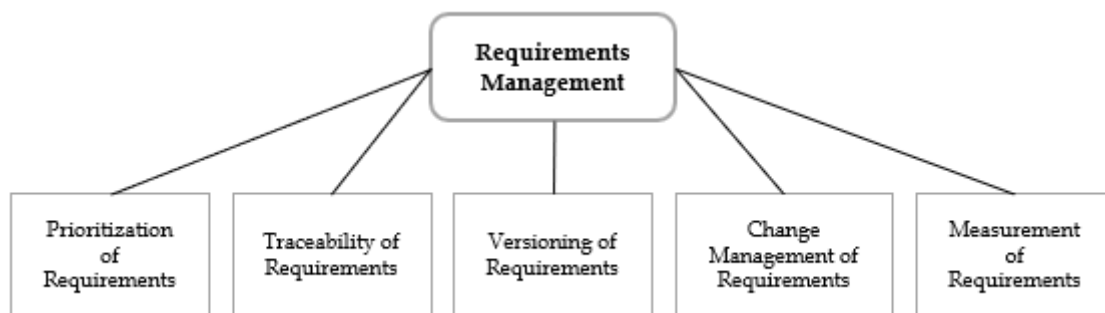


FIGURE 7 Major Requirements Management activities (Wiegiers & Beatty, 2013; Pohl & Rupp, 2015)

Major Requirements Management activities in the automotive companies include on a daily basis, concrete activities such as the ones depicted in the Table 3.

TABLE 3 Major Requirements Management activities (Wiegiers & Beatty, 2013; Pohl & Rupp, 2015)

Prioritization	Tracking & Traceability	Versioning	Change Management	Measurement
<ul style="list-style-type: none"> • Prioritizing Requirements 	<ul style="list-style-type: none"> • Defining requirement statuses • Recording the status of each requirement • Tracking the status distribution of all requirements • Defining links between the requirements • Defining links to other system elements • 	<ul style="list-style-type: none"> • Defining a version identification scheme • Tracking individual requirement versions • Tracking versions of requirement sets 	<ul style="list-style-type: none"> • Proposing changes • Analyzing impact • Making change decisions • Updating individual requirements • Updating sets of requirements • Updating plans 	<ul style="list-style-type: none"> • Measuring requirements volatility • Measure product metrics • Measure process metrics

When a large number of requirements is elicited, negotiated, specified, documented and validated during Requirements Engineering activities, the understanding of the involved stakeholders evolves together with the expected outcomes of the project. Therefore, the content of the requirements changes during the project, and possible new requirements arise. This affects workload, schedule, budget and also quality demands of the project. Therefore, there is a need for the evolved views of the project through its lifecycle. Each requirement artifact has several basic properties like source, description, priority, status and linking information on how it is related to other requirement artifacts. This makes the Requirements Engineering process complicated, which is why planning, controlling and measurement of the requirements become truly valued. (Pohl, 2010; Wiegiers & Beatty, 2013)

2.1.6 The Importance of Requirements Engineering

Requirements Engineering practices are the most essential factor for the success or failure of projects. The importance of Requirements Engineering activities is often underestimated during the product development process. Several research studies conclude that certain problems might occur within a project due to incomplete Requirements Engineering practices. These problems can be expanded through the system and they can have some negative effects on other components, even on those which work independently in the system (Pohl, 2010; Wiegers & Beatty, 2013; Khanom, 2014).

The level of active involvement of stakeholders in Requirements Engineering practices drives the success of the project. One of the most common reasons for the cancellation of a project is incomplete requirements and their management. Managing the requirements covers changes in requirements and it covers changes in the scope of the project during the delivery phase. (El Emam & Koru, 2008)

Requirements specifications details may contain serious errors. Errors in requirement specifications and later in implementations are often notified during late development phases. About 80 % of avoidable rework come from 20 % of the errors. (Boehm & Basili, 2001). Nearly 50 % of failures found in the source code and can be traced back to defects in requirements. The later the error in the development phase is identified, the higher are the costs of removing it from requirements. The cost of fixing errors can be approximately 20 times higher than if they were detected and fixed during the Requirements Engineering. If the error in requirements specification is not detected until the acceptance testing phase, the effort for fixing the error can be up to 100 times higher. (Boehm & Basili, 2001). The motivation should be to detect and to remove errors in requirements' specifications as early as possible. The required activities should be completed during the Requirements Engineering so as to ensure that the requirements specification has no serious errors or gaps. (Pohl, 2010)

Langenfeld (2016) highlights that the most expensive requirements errors fall into the categories of inconsistency, incompleteness and incorrectness. (Langenfeld et al., 2016). The Table 4 depicts the three categories and how much extra work is needed to fix the errors in the requirements.

TABLE 4 The most expensive error categories in requirements (Langenfeld et al., 2016)

Category	Required time to fix errors per requirement
Inconsistency	29 hours
Incompleteness	17 hours
Incorrectness	12 hours

Lagenfeld's research study emphasized that there are single cases, where work effort and costs of fixing the error in *inconsistency* category can be much higher. The work effort can be even 86 hours in the case when the error in requirements is detected in source state machine during a system testing. The reason for this is that the error was not detected in the requirements reviews. Another reason was that there were 16 requirements from different requirements documents impacted. Regardless of the category, the later errors are detected, the more effort is required to fix the error and its consequences.

Understanding the increasing costs whilst correcting errors emphasizes the importance of the Requirements Engineering practices. Errors can be caused by human errors when different tasks in Requirements Engineering are overlooked and proper specifications of requirements are neglected. The result of this is that requirements are ambiguous, incomplete, or probably contradicting. Based on these conclusions, Requirements Engineering has the main role in supporting and facilitating the success of the product development projects.

2.1.7 Challenges of Requirements Engineering

There is a variety of Agile methods which decrease the number of documentation and also fully engage users in the development process to receive rapid feedback. The elemental expectations of all development processes are twofold. Firstly, they should derive a complete and explicit set of requirements from users. Secondly, they should detect unidentified needs or desires as soon as possible (Sommerville, 2011). Despite the great awareness to the core of Requirements Engineering, the way in which requirements are handled is still a matter of intuition and is therefore, unaccomplished. Although numerous techniques have been created to support Requirements Engineering process, the syndrome of the failure in projects has not been overcome (Hofmann & Lehner, 2001; El Emam & Koru, 2008; Cerpa & Verner, 2009; Hansen & Lyytinen, 2010). Stakeholders who have no background in software engineering are only able to identify development needs when they see or interact with the final result (Cheng & Atlee, 2007).

Houdek and Pohl (2000) made a hypothesis that defining the comprehensive model of Requirements Engineering process and practices is impossible to implement in the automotive industry. In their research study, they made an empirical study in DaimlerChrysler company was conducted, where they tried to make an assessment of existing Requirements Engineering practices. They justified their hypothesis with the statement:

"In each interview we tried to decompose the existing Requirements Engineering process into smaller pieces to identify activities and their interrelations. We never succeeded. In general, at least the process we observed, was an amorph object, without a

clear structure. However, we were able to identify some micro-processes which can be defined in quite detailed". (Houdek & Pohl, 2000).

Examples of some of micro-processes are: *getting a decision, evaluating a prototype, performing an inspection, setting up and performing a kick-off meeting.* These observations supported their previous research studies where they argued that Requirements Engineering process could not be described as monolithic end-to-end process.

From their perspective, it would not be feasible to define a comprehensive Requirements Engineering process for the current practices in the automotive industry. Therefore, it would not be possible to differentiate it from classical Requirements Engineering activities (e.g. elicitation, validation and tracing). They claim that those classical activities were never performed as process steps which have clear input and output results, but instead they were heavily intertwined. Their recommendation and conclusion was that Requirements Engineering process should be defined as process chunks. (Houdek & Pohl, 2000)

2.2 Model-Based Requirements Engineering

Model-Based Requirements Engineering will be defined in this sub-chapter. In addition to this, it will be discussed why Model-Based Requirements Engineering is one of the success factors for Requirements Engineering practices in the automotive industry. The sub-chapter also discusses what are the challenges when to apply Model-Based Engineering, and in what kind of situations Model-Based approach can be applied. Three approaches for the Model-Based Requirements Engineering will be provided.

2.2.1 Models Definition

Pohl and Rupp (2015) define *models as abstracting presentations of an existing reality or a reality to be created*. Models were and still are of the central importance for many scientific contexts. Different science areas rely and are also based on different kind of models. Different phenomena e.g. physics or chemistry are mostly described, explained and justified as models. Thinking about models at the abstract and philosophical level raises questions in semantics (i.e., the representational function performed by models), ontology (i.e., the kind of things models are), epistemology (i.e., how to learn through or from models), and philosophy. Mathematics and other formal descriptions have been extremely useful in all fields for modeling and for building upon models. (Brambilla, Cabot & Wimmer, 2012). This is the reason why saying that models are simplifications of reality from different viewpoints and from different research approaches could be considered as generalization. Models also provide important information to support our understanding of basics manners.

Fowler (2015) published a classification for different types of models. He suggests that models can be divided into three categories as depicted in the Table 5.

TABLE 5 Classification of types of Models (Fowler, 2015)

Classification	Description
Models as blueprints	Models are used to provide a complete and detailed specification of the system.
Models as programs	Models, instead of a code, are used to develop the system.
Models as sketches	Models are used for communication purposes. Only partial views of the system are specified and modeled.

Models have at least three properties which can describe the abstraction of reality. These properties are depicted in the Table 6.

TABLE 6 Properties of Models (Brambilla, Cabot & Wimmer, 2012; Pohl & Rupp, 2015)

Property of a Model	Description
Mapping of reality	The models and their elements are based on the observed reality in a form of a prototype. The prototype abstracts and generalizes the reality as a model. (Brambilla, Cabot, & Wimmer, 2012; Pohl & Rupp, 2015)
Pragmatic property	The models are described for a special need within its context and they should focus on for interpretation of the reality. The model should contain the information which is necessary for its purpose. (Pohl & Rupp, 2015)
Reduction of reality	The models reduce the mapped reality and describe a selection of relevant properties of the reality. In the process of selection, only relevant aspects of the system are modeled. (Brambilla, Cabot, & Wimmer, 2012; Pohl & Rupp, 2015)

Models can be both descriptive and prescriptive at the same time. The model can be descriptive to stakeholder who designs the model and it can be prescriptive for the system to be developed based on the model. (Pohl & Rupp, 2015). The Table 7 depicts the differences between these two purposes.

TABLE 7 Purposes of Models (Brambilla, Cabot, & Wimmer, 2012; Pohl & Rupp, 2015)

Purpose of a Model	Description
Descriptive purposes	The model for descriptive purposes describes the existing reality of a context or the system. (Brambilla, Cabot, & Wimmer, 2012; Pohl & Rupp, 2015).
Prescriptive purposes	The model for prescriptive purposes describes a scope with details of prototype for a fictitious reality, and it defines how a system shall be developed. (Brambilla, Cabot, & Wimmer, 2012; Pohl & Rupp, 2015).

It could be said at the philosophical level that *everything is a model*, and human mind can only process things by modeling them. The reason for this is that the observer alters the reality itself. Therefore, models have become important in the technology development fields such as mechanics, computer science and computer engineering. Models and modelling enable studying, discussing, documenting and verifying variety of properties of products during product development processes. (Brambilla, Cabot & Wimmer, 2012)

2.2.2 Backgrounds of Model-Based Requirements Engineering

Graphical representations are created by utilizing sketches or via digital diagrams among natural textual requirements and requirements lists. (Sikora, Tenbergen & Pohl, 2011). The purpose of this activity is to illustrate requirements. The main tools used for drawing graphical representations were PowerPoint or Visio. They were used because they provide large icon libraries. In addition, natural text was included because the diagrams have limited semantics. It is not always clear how readers understand the semantics without any textual explanation. (Faudou & Bruel, 2016).

These diagrams are important for engineers because they represent two aspects: guidelines when designing a system and as a design for the system structure. These diagrams were not reusable and needed to be created from scratch for every project. There were also several disadvantages concerning standardization, reusability and model integration due to missing object-oriented model base. (Sikora, Tenbergen & Pohl, 2011)

The automotive companies are in a challenging situation due to the increasing speed of the technology development and due to increase of the system complexity. (Xiaojian, Xuqin et al., 2010). There is a need in the automotive industry for improved methods for managing the complexity of systems and demanding quality criterias for system development. (Sikora, Tenbergen & Pohl, 2011). Therefore, the automotive companies should have a capability to describe the requirements in a concise and manageable way by utilizing formal models. They should also be capable of integrating the models in a form of consistent, complete and manageable way so as to provide understanding of the software to be modeled. (Xiaojian, Xuqin et al., 2010).

Using the models as one of the Requirements Engineering practices has become more common in the automotive industry. (Broy, Krüger, Pretschner & Salzmann, 2007; Liebel, Marko, Tichy, Leitner & Hansson, 2014). Requirements are usually formulated with a natural language. In practice, this means that requirements are ambiguous and hard to utilize as some subsequent steps. (Brambilla, Cabot & Wimmer, 2012). Model-Based techniques which cover methods and tools have progressed within past years. Therefore, the automotive industry is moving from a document-centric activity towards a model-centric activity where models are used in addition to natural language requirements. (Faudou & Bruel, 2016). Models also partly replace requirements which are written using the natural language. (Pohl & Rupp, 2015).

The purpose of the Model-Based approaches is to support and to facilitate efficient communication between the stakeholders and product developers. Models are used to provide a complete view of the overall system. This supports the success of high-quality component delivery within the agreed project schedule. (Bera & Evermann, 2014).

Model-Driven and *Model-Based* terms are synonyms in this context. However, in some literature, model-driven is a subset of model-based approach. Model-driven has a narrower scope. It is an approach where models are used as the primary artefacts during the whole product development lifecycle (Liebel, 2018). It can be concluded that all model-driven processes are model-based, however not vice versa. The hierarchy of model-driven and model-based approaches is depicted in the Figure 8.

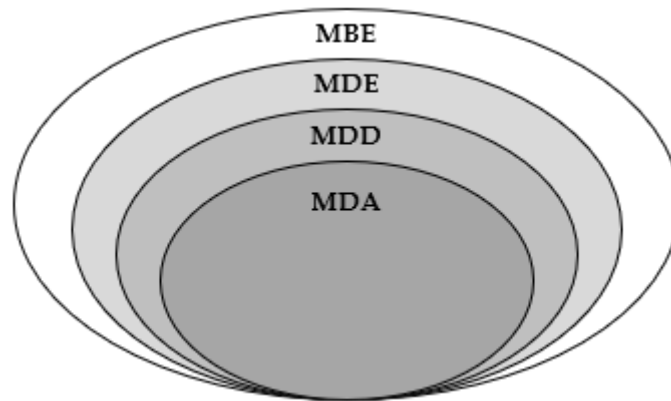


FIGURE 8 The hierarchy of Model-Based approach (Liebel, 2018)

Model-Based approach is a method where the actual work is concretized and where different viewpoints are approached in a concrete way. This can be done by transforming models into development artifacts. The various purposes of using models may vary from communicating between people to executability of the designed software. The way models are described and organized is the base of the needs they address. (Brambilla, Cabot & Wimmer, 2012).

2.2.3 Model-Based Requirements Engineering

Kirstan & Zimmermann (2010) concluded that the automotive industry is forced to develop its state of practices. The reason for this is fear of falling behind in the next generation development practices and technology. This is combined with the competitive pressure and the experience that innovative functionalities can only be developed with Model-Based approach. (Kirstan & Zimmermann, 2010).

Model-Based Requirements Engineering is an approach where models are used as an integral part of the Requirements Engineering process. (Faudou & Bruel, 2016). Requirements modeling is the key activity during the Requirements Engineering process. The Figure 9 depicts the relationship between Requirements Engineering as a subdomain of the Systems Engineering and Model-Based Engineering in the automotive industry.

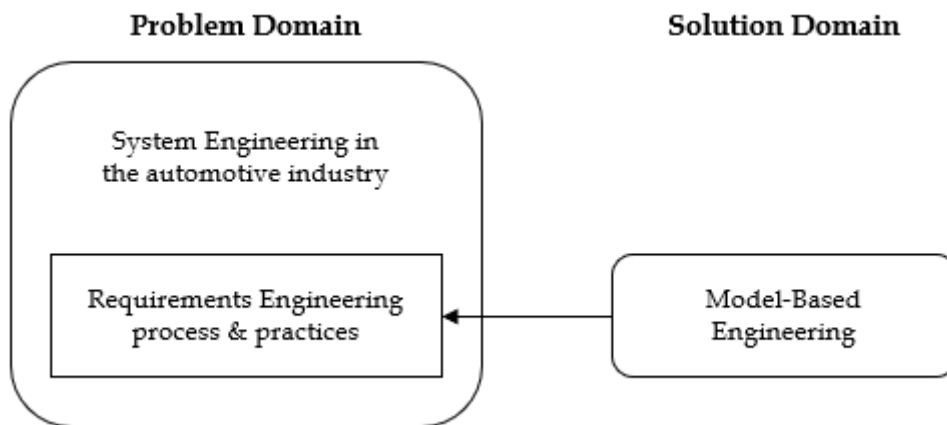


FIGURE 9 Model-Based Requirements Engineering (Liebel, 2018)

Graphical models are utilized in a way that modeling elements describe material or immaterial objects or people in reality. The needs from business and organization can be described and formalized through the models. (Pohl & Rupp, 2015). Models such as conceptual models or business domain specific models represent the application domains and they have been created for analyzing, understanding, and communicating the application domain. Models are also used as an input for the requirements specification. They have been developed to be independent when it comes to implementation. (Bera & Evermann, 2014).

Formalizing requirements by utilizing models means that both modeling language and modeling tools should support Requirements Engineering activities regardless of the format of the requirement. Requirements can be in various formats such as text, table or graphical format, and the requirement can be formalized by utilizing natural language or modeling language. The requirements should be always engineered in a way that they can be traced afterwards. (Faudou & Bruel, 2016).

Certain steps were proposed (Xiaojian, Xuqin et al., 2010) when it comes to specifying requirements by utilizing modeling methods to make sure that requirements are concise and manageable. Firstly, requirements should be categorized from different aspects. Secondly, the most suitable modeling notation language should be selected for each aspect. Finally, all aspects should be merged in order to have complete and consistent understanding about all

requirements. Requirements should cover all perspectives of required stakeholders who participate in the product development process.

Three perspectives, which have been depicted in the Table 8, have been developed to support achieving complete and consistent understanding, and to support information gathering for the requirements.

TABLE 8 Different perspective for gathering information for requirements (Xiaojian, Xuqin et al., 2010)

Perspective	Description
Behavioral	Behavioral information captures how functionality reacts to the stimulus coming from the environment. Since the automotive systems are real-time systems, engineers need to have the ability to model timing behavior. (Xiaojian, Xuqin et al., 2010). Behavioral information can be captured with e.g. Simulink software. Simulink is a block diagram environment for multidomain simulation and Model-Based Design. (Simulink, 2015)
Communication related	Communication information specifies the properties of communication media. Media can be wired network, serial transmission lines and wireless channels i.e. Bluetooth, WiFi and mobile phone network. (Xiaojian, Xuqin et al., 2010).
Structural	Structural information specifies the interface information, i.e. input and output ports of the functionality and the decomposition of a functionality. (Xiaojian, Xuqin et al., 2010). Systems Modeling Language (SysML) is an example of notation language for structural aspect. The Systems Modeling Language is visual modeling language for systems engineering applications. SysML is defined as a dialect of the Unified Modeling Language (UML) standard, and SysML supports the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems. (SysML Open Source Specification Project, 2015)

The goal of Model-Based Requirements Engineering activities is to utilize modeling in all phases of Requirements Engineering and product development, and to enable transition from models to other models or to text like source code. (Mohagheghi, Gilani, Stefanescu et al., 2013).

2.2.4 Benefits of Model-Based Requirements Engineering

According to research studies in cognition sciences, information can be recognized and memorized efficiently when it has been described graphically in comparison to natural languages. (Glass & Holyoak, 1986; Kosslyn, 1988; Mietzel, 1998). Model-Based Requirements Engineering improves this situation by introducing a notation language for supporting modeling of requirements graphically. The research studies (Kirstan & Zimmermann, 2010; Sikora, Tenbergen & Pohl, 2011; Mohagheghi, Gilani, Stefanescu, et al., 2013; Pohl & Rupp, 2015) concluded the benefits of using Model-Based approached. These benefits are depicted in the Table 9.

TABLE 9 Benefits of using Model-Based Requirements Engineering

Benefits	Description
Automation	Improved automation through the code generators and artefacts. (Mohagheghi, Gilani, Stefanescu, et al., 2013)
Business	Possibilities for cost-savings during the development phase. (Kirstan & Zimmermann, 2010)
Common framework for product development	A common framework for product development process at all levels of the organization and supports phases of the development life-cycle. (Mohagheghi, Gilani, Stefanescu, et al., 2013)
Communication	Improved communication and other information sharing between the stakeholders and other interest parties during the Requirements Engineering and product development processes. (Mohagheghi, Gilani, Stefanescu, et al., 2013)
Consistency	Development and maintenance of architectural consistency from analysis phase to implementation in the Requirements Engineering and product development processes. Supports the development of Platform-Independent Models for long life-span. (Mohagheghi, Gilani, Stefanescu, et al., 2013)
Different perspectives of documentation	Different modeling elements within the same modeling language describe the level of abstraction. The modeling languages have a strictly defined focus. These create a contrast comparing to natural languages. (Pohl & Rupp, 2015)

Increased understandability	Modeling supports the communication, collaboration and analysis activities by increasing understanding of complex requirements in the structure, functions, and behavior of the products. (Sikora, Tenbergen & Pohl, 2011)
Productivity	Improved productivity and shortening the life-cycle for complex product development or systems of systems. (Kirstan & Zimmermann, 2010); Mohagheghi, Gilani, Stefanescu, et al., 2013)
Quality Assurance of Requirements	Simplifies quality assurance in Requirements Engineering. Modeling supports determining the type and extent of quality assurance based on the results from safety analysis covering safety integrity level of a component or function. (Sikora, Tenbergen & Pohl, 2011)
Software quality	Improved the software quality because of the quality of the code generators has improved. Also, improvements in the quality of intermediate models and detections of bugs or defects through the model-based simulation and testing. (Mohagheghi, Gilani, Stefanescu, et al., 2013)
Support for high system complexity	The use of models supports coping with high system complexity. Requirements are often described on different abstraction levels. The number of different abstraction levels may vary between two and six. The use of different abstractions is important with high system complexity. (Sikora, Tenbergen & Pohl, 2011)

2.2.5 Challenges of Model-Based Requirements Engineering

Requirements modeling and analyzing is one of the main challenges in the automotive industry. They are particularly challenging due to three identified reasons (1) automotive software has close interactions with its environment, (2) software's distribution over networks and (3) software's complicated timing behavior and the other non-functional properties.

The problems concerning the modeling and analyzing are (1) how to describe requirements as formal models which are concise and manageable and (2) how to integrate models from different abstraction levels to form a consistent and complete understanding of the product to be developed.

To solve these challenges, there is a need to find a suitable modeling notation language to support all the mentioned system characteristics. It is challenging to find a single modeling notation language which covers all the mentioned aspects. (Xiaojian, Xuqin et al., 2010)

Model-Based approach is dependent on tool vendor companies. Possible bugs in used tools as well as the need of Requirements Engineering process re-design are seen as a possible downside of implementation and deployments of Model-Based approach. Some research studies have shown that developers cannot trust tool's own code generators to be able to produce safety-critical and efficient code. They compared that with the same quality as hand-written code, while others did not agree. (Xiaojian, Xuqin et al., 2010; Kirstan & Zimmermann, 2010).

The change towards using models and therefore modeling notation languages requires that all stakeholders and other relevant parties share a common understanding of models involved in the process. They also need to agree on formalities of information and data exchange across the organizational boundaries. This way of operating is not obvious in all companies because it depends on the background, culture and employees' experience. These varies between the companies and even within the company. The companies have learnt that changing their internal ways of operating is more valuable than trying to change their interfaces with external stakeholders. Therefore, the companies and organizations are evolving the ways of operating from textual requirements to model-based approach. (Faudou & Bruel, 2016).

2.2.6 Situations or expectations for Model-Based approach

Model-Based Requirements Engineering is the most used method for describing requirements at different levels of abstraction since models provide support for understanding and knowledge sharing in a complex software design and product development processes. (Brambilla, Cabot & Wimmer, 2012).

The Table 10 depicts conclusions from the research study (Mohagheghi, Gilani, Stefanescu et al., 2013) for situations where the Model-Based Requirements Engineering approach should be considered and is seen as useful.

TABLE 10 Model-Based approach should be considered (Mohagheghi, Gilani, Stefanescu et al., 2013)

Model-Based approach should be considered	Description
Abstraction and hiding details	<p>Utilizing the models is efficient during the development of the complex system or systems of multiple systems. Then the target system can be described as several layers or as a breakdown structure from multiple perspectives. (Mohagheghi, Gilani, Stefanescu et al., 2013).</p> <p>Techniques like model composition and model traceability are important and considered as highly recommended activities when managing the development of large and complex models. (Mohagheghi, Gilani, Stefanescu et al., 2013)</p>
Communicating with non-technical stakeholders	Improved communication with business analysts, subject matter experts and non-technical stakeholders can be organized in efficient manners when utilizing domain-specific modeling languages or notations from UML (Unified Model Language). Utilizing UML or domain-specific languages helps to hide non-relevant technical details. (Mohagheghi, Gilani, Stefanescu et al., 2013)
Model-Based testing	Utilizing models in a testing process, decreases amount of unnecessary work load and improves testing activities. The testing process can utilize the Model-Based approach when emulating the hardware is in a black-box testing. (Mohagheghi, Gilani, Stefanescu et al., 2013)
Simulation and Model-Based execution	While evaluating and improving the quality of system in a sense of architecture, system design and performance, then the target system should be analyzed during the design phase. Utilizing models and simulations are to support the analyzing activities. (Mohagheghi, Gilani, Stefanescu et al., 2013).

Models can be utilized at the different stages of Requirements Engineering and for different purposes. It is important to define a goal and context of the modeling activity. Models can be utilized for clarification, formalization and structuring of stakeholders needs. Only then models reflect stakeholders' needs through simple concepts. In cases like this, it is important that models are designed to be simple enough, so stakeholders can verify that the models expresses their original needs. Models can be utilized to detach issues with completeness, correctness or consistency from requirements which are described in natural language (e.g. simulation models used to check some ranges of values for particular performance properties). These same models can be utilized later to describe requirements for the product development and also to avoid existence of multiple duplicate requirements. Models can be utilized to support validation of defined requirements by stakeholders in a pivotal format. For instance, a model describes a mock-up which validates described functional requirements. This setup is challenging to execute only in a textual format. It requires embedment between initial textual requirements, pivotal model format and mock-up that is validated by stakeholders (also called early validation). It represents good engineering practices when requirements fulfill natural language or when they are formalized by utilizing models. Regardless of the approach, the purpose remains the same: to ensure efficient requirement engineering in order to support product development process. (Faudou & Bruel, 2016).

When using a natural language and models as a combination in Requirements Engineering, it provides the advantages to documentation techniques while it minimizes their disadvantages. Requirements on the natural language can be concluded and their relationships can be described by using models. Natural language can improve models and modeling elements with additional information. (Pohl & Rupp, 2015).

Modeling in Requirements Engineering process supports the analyzing and designing in phases of Requirements Elicitation, Requirements Analysis, Requirements Negotiation and Requirements Specification. This research study introduces three modeling approaches which are Goal-Oriented Approach, Object-Oriented Approach and Viewpoint Oriented Approach. These presented approaches are used to support Requirements Engineering practices. The better the understanding of different modeling approaches is, the more efficient model practices are. Therefore, it is important to use the right approach in a certain situation in the Requirements Engineering process.

2.2.7 Goal-Oriented Approach for Requirements Engineering

What is Goal-Oriented Approach?

Goal is defined as *an intention with the regarded to the objectives, properties, or the use of the system.* (Pohl, 2010).

Goals describe requirements at different abstraction levels covering requirements from strategic objects on high-level of abstraction going down into technical details on low-level of abstraction. Goals are used to cover different types of requirements: functional requirements describing directly implementable functionalities and non-functional requirements describing quality properties such as accuracy, performance, safety and security. (Rolland & Salinesi, 2005).

Goal-Oriented approach is concerned to be used in different phases of Requirements Engineering process; such as eliciting, elaborating, structuring, specifying, analyzing, negotiating, documenting and modifying requirements. (Van Lamsweerde, 2001; Rolland & Salinesi, 2005).

Why is Goal-Oriented Approach needed?

Goal-Oriented Approach brings added value to Requirements Engineering process and its practices from multiple perspectives. The Table 11 depicts eight perspectives how Goal-Oriented approach brings value to Requirements Engineering.

TABLE 11 Reasons for Goal-Oriented Approach

Reason	Value for the Requirements Engineering
Identification of requirements	Potential requirements identification with stakeholders, during the elicitation phase, is done more efficiently when Goal-Oriented approach is used together with other methods like scenarios. (Dardenne, Fickas, & Van Lamsweerde, 1991; Rubin, & Goldberg, 1992; Dardenne, Van Lamsweerde, & Fickas, 1993; Anton, & Potts, 1998; Dubois, Petit & Yu, 1998; Kaindl, 2000; Van Lamsweerde, 2000; Van Lamsweerde, 2001; Pohl, 2010).
Securing requirements completeness	Using goals supports completeness of requirements specification. The completeness of the specification can be stated when all goals can be identified from the requirements specification and when the properties of the domain are known and considered. (Yue, 1987; Van Lamsweerde, 2001; Pohl, 2010).
Decreasing irrelevant requirements	Goals provide a precise criterion for requirements justification. A requirement is justified with a set of goals from domain. The requirement can be considered as justified when its specification is used as the proof of one goal at least. (Yue, 1987; Van Lamsweerde, 2001; Pohl, 2010).
Explaining requirements	Goals provide rationale for requirements, in a way similar with design goals in design processes (Mostow, 1985; Lee, 1991). A requirement appears due to the goal which justifies an existence of a need or a problem. (Ross & Schoman, 1977; Dardenne, Fickas & Van Lamsweerde, 1991; Sommerville & Sawyer, 1997). Goals provide views for traceability and for required linking from high-level strategic objectives to low-level technical requirements. Goals are used to describe how the solution should be in organizational and business context. (Yu, 1993; Pohl, 2010).
Structuring requirements	Goals are mechanisms for structuring complex requirements and possible complex network of linked requirements or requirements which are dependent on each other. Using Goals increases readability. (Van Lamsweerde, 2001).

Alternative goal refinements	Alternative goal refinements provide the right level of abstraction of requirements whereby stakeholders can be involved in validating choices to be implemented or in making suggestions for other alternative implementations. Alternative goal refinements allow alternative system proposals to be discussed and decided. (Van Lamsweerde, 2000; Pohl, 2010)
Managing conflicts	Goals support recognizing and solving conflicts among requirements. Conflicts are caused by different intentions of stakeholders. Solving a conflict should start by solving conflicts in Goals. (Robinson, 1989; Van Lamsweerde, Darimont & Letier, 1998; Pohl, 2010)
Reaching a right level of abstraction	Goals are an important tool to separate stable information from draft information while managing requirements evolution. Requirement represents its information and it should archive some goals. The requirement will most likely evolve and achieve the original goal and the goal will evolve further. The better the goal is defined, the more stable it will be. Therefore, the comparison with functionality or quality requirements, goals are more stable. (Van Lamsweerde, 2001; Pohl, 2010)

Four methods of Goal-Oriented Requirements Engineering

There are four most recognized Goal-Oriented methods or frameworks. (Anton, 1996; Yu, 1997; Dardenne, Van Lamsweerde & Fickas, 1993; Brachman & Levesque, 1985; Mylopoulos, Chung & Nixon, 1992; Chung, Nixon, Yu & Mylopoulos, 2012). The Table 12 depicts a short overview of each recognized method. Two of them, *i** and KAOS, were most often mentioned during the literature review.

TABLE 12 Methods in Goal-Oriented Requirements Engineering Approach

Name of the Method	Description
Goal-Based Requirements Analysis Method (GBRAM)	<p>Goal-Based Requirements Analysis Method (GBRAM) is used for preliminary identification and abstraction of goals from various sources of information. It is assumed that there are no goals documented or elicited for stakeholders. Existing diagrams, textual statements, interview transcripts, etc. can be used in the elicitation phase. GBRAM contains the activities: 1) goal analysis and 2) goal refinement.</p> <ol style="list-style-type: none"> 1) Goal analysis is used for exploring information sources so as to identify goals from the organization. It is also used for classification of goals. 2) Goal refinement is an activity used to develop goals during their lifecycle: starting when they are identified ending when they are translated into operational requirements. (Anton, 1996; Anton, 1997; Lapouchnian, 2005).
<i>i*</i>	<p><i>i*</i> is a comprehensive agent-oriented modeling framework. This means that the framework is based on the idea that an actor depends on the other actors to achieve goals. The <i>i*</i> framework is for documenting and analyzing goals and their dependencies. (Pohl, 2010).</p> <p>The <i>i*</i> framework can be used for requirements engineering, business process engineering, organizational impact analysis, and software process modeling. When the framework supports the modeling activities which take place before the system requirements are created, <i>i*</i> can be used for both early and late phases of the requirements engineering process. In the early phase of requirements, the <i>i*</i> framework is used for modeling the system-to-be environment. During the late requirements phase, the <i>i*</i> models can be used to model the new configurations and new processes. The <i>i*</i> framework can be used for evaluating how well late requirements meet the functional and non-functional needs of the stakeholders. (Yu, 1997; Lapouchnian, 2005).</p>

KAOS	<p>KAOS is an abbreviation of Knowledge Acquisition in autOMated Specification (Dardenne, Van Lamsweerde & Fickas, 1993) or Keep All Objects Satisfied (Van Lamsweerde & Letier, 2004).</p> <p>The KAOS methodology is a Goal-Oriented Requirements Engineering approach for eliciting, specifying, and analyzing goals, requirements, scenarios, and responsibility assignments. (Pohl, 2010). KAOS allows combining different levels of expression and reasoning: semi-formal for modeling and structuring goals, qualitative for selection among the alternatives, and formal for more accurate reasoning. The KAOS framework supports conceptual modeling of goals, assumptions, agents, objects, and operations in the system. It also supports linear-time temporal logic for the specification of goals and objects, and state-base specifications for operations.</p> <p>Each construct has a two-level structure:</p> <ol style="list-style-type: none"> 1) the inner formal layer for formal concept definition. 2) the outer graphical layer where the concept is defined together with its attributes and relationships to other concepts. <p>(Dardenne, Van Lamsweerde & Fickas, 1993; Brachman & Levesque, 1985; Van Lamsweerde & Letier, 2004).</p>
The NFR Framework	<p>The NFR framework is used for analyzing and modeling of Non-Functional Requirements. The main goal of using the NFR framework is to decrease the importance of non-functional requirements. (Chung, Nixon, Yu & Mylopoulos, 2012).</p> <p>The framework aims at dealing with the main activities such as capturing and dividing NFRs, identifying possible conflicts in order to design possible alternatives solutions. It also deals with ambiguities, tradeoffs, priorities, and interdependencies among NFRs. It supports decisions with design models, and it evaluates impact of decisions. The NFR framework approach is used systematically for modeling and refining non-functional requirements. It is also used for defining positive and negative influences in different alternatives of the requirements. (Mylopoulos, Chung & Nixon, 1992; Lapouchnian, 2005; Chung, Nixon, Yu & Mylopoulos, 2012).</p>

2.2.8 Object-Oriented Approach for Requirements Engineering

What is Object-Oriented Approach?

The object model defines the principles of abstraction, encapsulation, modularity, hierarchy, typing, concurrency, and persistence. Object-Oriented analysis is a method for analyzing whereby requirements are examined from the perspective of the classes and objects found in the vocabulary of the described need or a problem. (Booch, 2006). The fundamental elements of Object-Oriented analysis and design are class, object, and relationship. (Khanom, 2014).

The basic idea of Object-Oriented approach is to have a system of communicating objects. This can be applied throughout the development process. The coherent representing of objects and notations is one of the attractive features of Object-Oriented development. (Kaindl, 1999).

The Unified Modeling Language (UML) has been considered as the de-facto standard for modeling language in the Requirements Engineering process (Bera & Evermann, 2014). UML attempts to bring together Object-Oriented approaches and therefore it is widely accepted (OMG, 2006; Bera & Evermann, 2014). UML notation consists of several models which together explain the requirements. Each model serves different purposes in different phases of Requirements Engineering. Not all available diagrams are used at the same frequency. It has been estimated that a small subset of diagrams is enough to model a system. (Khanom, 2014). UML class diagrams describe the static structure of a model. The class diagrams are considered to be the most popular UML diagrams used in practice. (Bera & Evermann, 2014). UML use case diagram describes a user's interaction with the system and shows the relationship between the user and the different use cases where the user is involved. The use case diagram identifies different types of users of a system. Use cases are often accompanied by other types of diagrams.

The Table 13 depicts the most common object-oriented models.

TABLE 13 The most common Object-Oriented models

Diagram	Description
Class diagram	Class diagrams are used to document a product at different levels of abstraction. Class diagrams are created and developed further during the Requirements Engineering process and during product implementation phase. Class diagrams are used for documenting the static view of the product in a particular problem space. (Pohl, 2010; Khanom, 2014). Class diagrams are used in a similar way as document entity-relationship models are used for documenting requirements in the data perspective. A class diagram consists of a set of classes and their relationships. (Pohl, 2010).
Use case diagram	Use case diagram contains information about actors and use cases, and relationships between them. An actor represents systems or persons which interact with a system. Each use case describes functional requirements for the implementation. Use case combines main scenarios together with possible related alternative and exceptional scenarios (Khanom, 2014). Scenarios are proposed as another method for capturing requirements, to be used with stakeholders during early activities of Requirements Engineering. Scenarios support production of models which are familiar to users. Scenarios provide detail focused events to support understanding of needs or problems described as requirements. (Sutcliffe, 2003; Carrizo, Dieste, & Juristo, 2014).

The challenge of using Object-Oriented models is that the users need to be trained to use object orientation when modeling different kinds of needs with Object-Oriented analysis and design. (Booch, 2006).

2.2.9 Viewpoint-Oriented Approach for Requirements Engineering

The purpose of a Viewpoint-Oriented approach is to identify all required information for implementation requirements by considering the implementation not only from one but from multiple perspectives. A Viewpoint can be considered as partial information for implementation requirements. When the information gathered from different viewpoints is integrated, it forms a final specification for implementation requirements. Therefore, requirements should be gathered, organized and prioritized from several different viewpoints. The importance of Viewpoint-Oriented Approach has been justified with several arguments depicted in the Table 14.

TABLE 14 Arguments for Viewpoint-Oriented Approach (Pohl, 2010)

Viewpoints	Arguments
Users' viewpoints	There is no typical user defined and the usage of a product is heterogeneous. Therefore, different viewpoints support requirements gathering from different groups of users: end-users, customers, developers and other stakeholders.
Environment viewpoints	It supports different types of information which is relevant when specifying products. Information covers the business domain, product's technical environment and information about the implementation from the developers. All viewpoints are utilized to gather, classify and prioritize the required information.
Requirements Elicitation viewpoints	It supports structuring of Requirements Elicitation phase.
Implementation viewpoints	It supports gathering of different models of the product. Gathered models provide some information for implementation requirements.
Viewpoints for Requirements descriptions	It supports structuring of requirements description and also decreases conflicts between the requirements.

Based on the listed arguments, there are two main viewpoint approaches proposed. (Pohl, 2010)

1. **Viewpoints associated with stakeholders.** Stakeholders can be affected directly or indirectly by the product through different kind of roles such as business owner, developer, maintenance and support.

2. **Viewpoints associated with organizational and domain knowledge.** Organizational viewpoints are humans, processes and practices. Domain knowledge is business environment, local, national and international laws, regulations and standards. This kind of gathered knowledge cannot be associated only with single class of stakeholders. Relevant information must be collected based on several kinds of sources.

When several viewpoints are identified, it is challenging to manage the large amount of information. To solve this problem, it is essential to select the most important viewpoints to be analyzed.

Viewpoints in requirements elicitation

Viewpoints which are used in Requirements Elicitation are mostly outside of the product which will be specified. In this situation, viewpoints represent the sources of product requirements. There are informal descriptions and models of viewpoints available during the elicitation phase. Requirements are written in natural language or described through diagrams and domain-specific notations. (Sommerville & Sawyer, 1997)

Viewpoints in requirements modelling

It is a common practice to define a set of models which describe informal, structured or (less common) mathematically formal notations during the phase whereby requirements specification is detailed. Viewpoint-oriented approach supports identifying, defining and checking the consistency of the models. (Sommerville & Sawyer, 1997).

Several methods which supporting management of viewpoints are depicted in the Table 15. The methods are classified based on two activities in Requirements Engineering process; Requirements Elicitation and Requirements Modeling.

TABLE 15 Methods for managing Viewpoint-Oriented Approach

Method	Description
Jackson System Development (JSD)	Jackson System Development (JSD) supports Requirements modeling. It starts in the phase of the project when requirements are only on a general level. Development starts by describing and modeling the real world, rather than specifying or structuring the features or functions performed by the product. A product described using JSD method performs the

Requirements Modeling	simulation of the real world before any direct attention is given to the function or purpose of the product. The implementation of the product is based on transformation of specification into a set of processes. These processes should be designed in a way that makes it possible to execute them on available software and hardware. (Jackson, 1983).
Structured Analysis and Design Technique (SADT) Requirements Modeling	Structured Analysis and Design Technique (SADT) (Ross, 1977; Ross & Schoman, 1977) method is an analyzing technique where analysis is done from different viewpoints, but it does not include viewpoints as explicit entities in the method. Viewpoints are sources of the data in a data-processing model which is required by the method. (Sommerville & Sawyer, 1997).
Controlled Requirements Expression (CORE.) Requirements Elicitation	CORE method (Mullery, 1979) is based on SADT-like 'data processing' models. The method includes viewpoint identification, analysis (Sommerville & Sawyer, 1997) and specification (US-CERT, 2006). Method describes viewpoints and limitations of different users for the product and its operational environment. Method covers performance and reliability investigation to some extent. (Mullery, 1979). The CORE method supports Requirements Elicitation, Requirements Analysing and Requirements Specification phases. The method represents incremental development of information flows and processing. Each step of viewpoints development provides a support for Requirements Specification. The method identifies possible design limitations. The result of CORE methods is a structured data flow for Requirements Specification. (Finkelstein, 1992; US-CERT, 2006).
Viewpoint-Oriented Requirements Definition (VORD) Requirements Elicitation	<p>The VORD method is used for activities such as viewpoint identification, viewpoint description, cross-viewpoint analysis. The method is used for discovering inconsistencies, removing irrelevant information or conflicts and for developing an object-oriented model based on the viewpoint analysis. VORD supports designing which is specified in any appropriate notation either informal, structured or formal. Multiple specifications, in different notations can be managed and linked. (Sommerville & Sawyer, 1997)</p> <p>VORD viewpoints can be classified under two categories; direct viewpoints and indirect viewpoints.</p> <ol style="list-style-type: none"> 1) Direct viewpoints represent stakeholders or other parties who directly interact with the product (Khanom, 2014) by sending or receiving information. Direct viewpoints also cover sub-systems or linked products interacting with the product being analyzed. (Kotonya, 1999) 2) Indirect viewpoints represent stakeholders or other parties that do not interact directly with the product. (Khanom, 2014). However, these stakeholders have interests in some or all features of the product. Indirect viewpoints may create requirements which constrain the features delivered to direct viewpoints. (Kotonya, 1999)

2.3 Chapter Summary

This chapter reviewed the Requirements Engineering practices in the automotive industry. General definition of Requirements Engineering and relevant terminology were offered in this chapter. The importance and the challenges of the Requirements Engineering were also discussed.

A special attention should be given to the Requirements Engineering process and its practicalities when products are developed in a way that satisfies customers' needs and meets budget constraints and project schedules. The purpose of Requirements Engineering is to document stakeholders' requirements as accurately as possible within the defined quality criteria. Furthermore, the purpose is to identify and solve possible problems or conflicts in the requirements during the process as early as possible. Successful Requirements Engineering can be reached by including relevant stakeholders and by following the core activities of Requirements Engineering: *Requirements Elicitation, Requirements Analysis, Requirements Specification, Requirements Validation and Requirements Verification* and *Requirements Management*. (Pohl & Rupp, 2015).

Requirements Engineer plays a really important role for the successful Requirements Engineering process execution. This person is the primary contact in the Requirements Engineering process and holds valuable domain and process knowledge. (Pohl & Rupp, 2015).

Requirements can be identified from different sources and are important for the success of the product delivery. Multiple perspectives are covered within a definition of the requirements. They ensure the high quality and make sure that the users' expectations of the product are met.

The importance of the Requirements Engineering cannot be emphasized enough. Properly executed Requirements Engineering practices reduce the risk of re-working in the development phase and also minimize the number of errors and fault expectations. This leads to cost accuracy and to securing the development budget as planned.

Challenges of the Requirements Engineering are mostly related to peoples' behavior and expectations towards the product. Customers and users are not able to clearly describe what they need. This leads to occurrence of unrecognized needs in the development phase. However, it is important to emphasize that there are always recognized and unrecognized needs in this phase. This can be avoided by using techniques such as interviews, observations, reading existing documents and prototyping to gather users' needs for the product.

Defining the complete Requirements Engineering process is challenging because the process should be aligned with the company's other processes such

as portfolio management, product development, product management, error management, supplier management and manufacturing. Therefore, the development of sub-level processes under the Requirements Engineering process should not be done separately. All interfacing processes should be identified and considered while developing the certain independent process.

The definition of Model-Based Requirements Engineering was discussed in the second part of the chapter. Models are important elements in many engineering domains. Complex concepts can be explained in a simplified way by utilizing models when irrelevant information cannot be excluded from the explanation. (Brambilla, Cabot & Wimmer, 2012). Using models enables the specification of requirements and it enables communication between them on different abstraction levels.

The research study discussed three different approaches to Model-Based Requirements Engineering: Goal-Oriented Approach, Object-Oriented Approach and Viewpoint-Oriented Approach. Each of these approaches is discussed by introducing common definitions and concrete methods.

Each of these approaches has its own notation language. This creates challenges in a communication within and between the organizations. The language must be understood in a same way by everyone. All parties need to agree on the formalities of the language. Therefore, employees' culture aspects and experiences should be taken into account when agreeing on the formalities.

The Model-Based Requirements Engineering approach supports complexity by taking into consideration all means of abstraction. It also supports increased efficiency in the development of software or engineering in overall. Several empirical studies have showed benefits of Model-Based approach e.g., increased productivity (Hutchinson, Whittle, Rouncefield & Kristoffersen, 2011) and improved quality (Agner, Soares, Stadzisz, & Simão, 2013). Therefore, Model-Based Requirements Engineering should be considered as a candidate solution to address the challenges in the automotive Requirements Engineering. (Liebel, 2018).

3 RESEARCH METHODS

This chapter discusses research study methodology, research design and implementation. The study was divided into three phases. The research methodology of each study phase is presented.

3.1 Research Design

The research study was divided into three different sequential phases to make the structure of the study unambiguous for the reader, easy to implement and clear to communicate. The definition of research design by Yin (2014):

“Every type of empirical research study has an implicit, if not explicit, research design. In the most elementary sense, the design is the logical sequence that connects the empirical data to a study’s initial research questions and, ultimately, to its conclusions.” (Yin, 2014).

This research study followed the sequential research phase design, as depicted in the Figure 10.

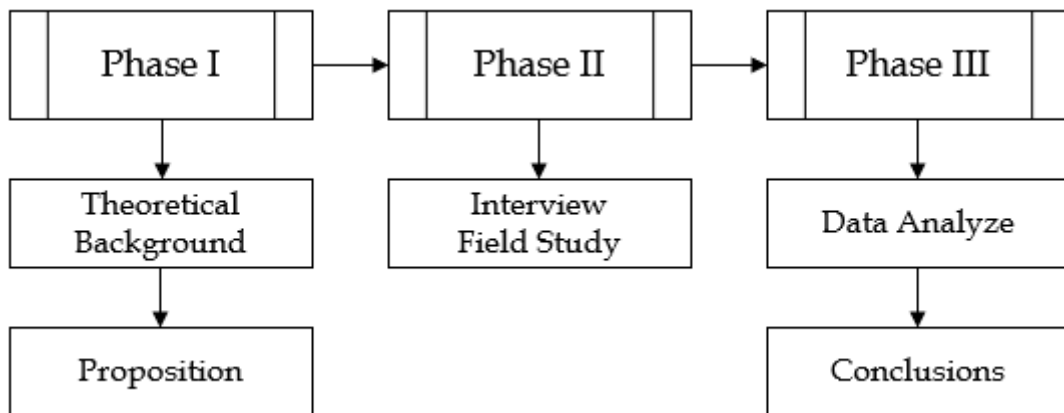


FIGURE 10 The three phases of the research study

The first phase of the research study consisted of creating the Proposition through the literature review. A condensation of the literature review resulted in identified Proposition which was the baseline for interview questions in the second phase. The first phase primarily aimed to answer the following research question:

RQ1: What is the (Model-Based) Requirements Engineering in the Automotive industry?

The second phase covered an interview field study in which the practitioners and relevant business representatives from different automotive companies participated. The Proposition was addressed in the interview questions. The second phase aimed to answer the remaining research question:

RQ2: What are the organizational challenges on different levels of organizations in the automotive companies which apply (Model-Based) Requirements Engineering process and practices?

The data was discussed in the third phase and the conclusions were made based on this analysis. This was reflected in the Proposition. The overall and more detailed structure of the thesis research study is depicted as the Figure 11.

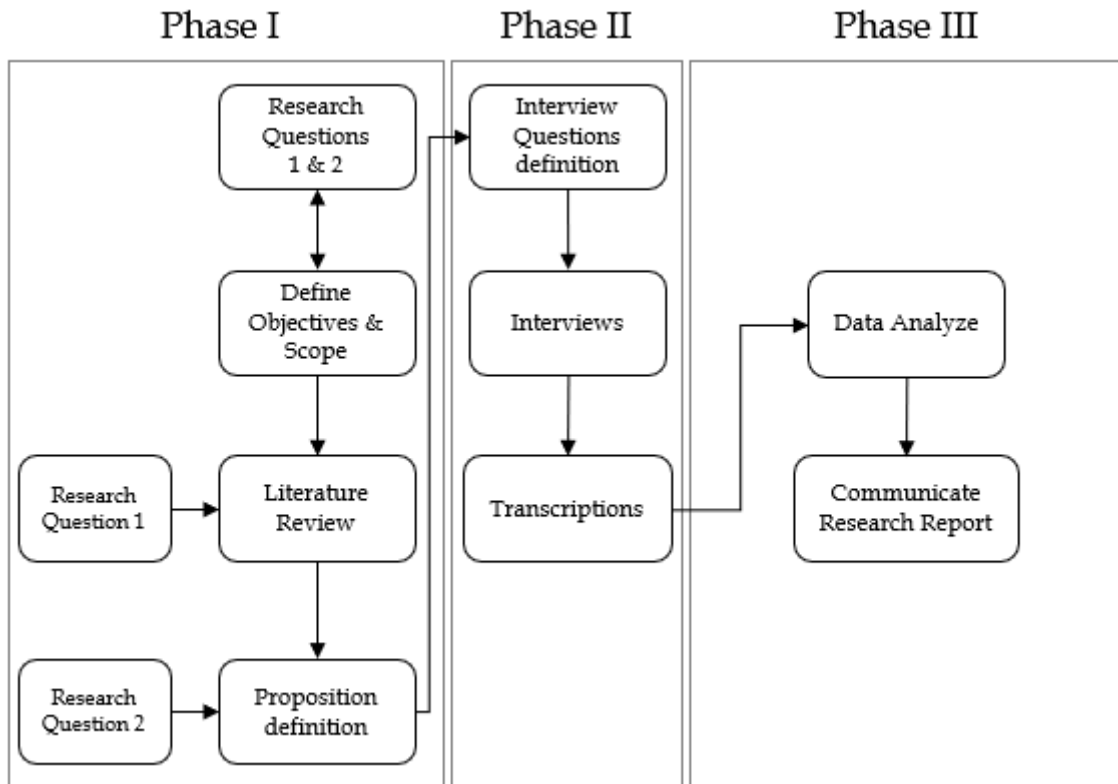


FIGURE 11 The three phases of the research study in detail

3.2 Phase I – Literature Review

The first phase covered the literature review which implements a theoretical background for following the field research study activities in the automotive companies.

The goal of the literature review is to provide an overview of the research area. The literature review summarizes the previously conducted research on the topic in the field and creates a knowledge base and quantifies the amount of evidence to enable the success of the project. (Rowley & Slack, 2004; Petersen et al., 2008). It becomes possible to identify gaps in the field where further research is beneficial. Screening the articles was followed by the method based on *Systematic mapping process*. (Petersen et al., 2008).

The systematic mapping process was chosen to support the literature review phase. The reason for choosing the systematic mapping process was to explore the existing studies related to Requirements Engineering in general and the existing studies related to Model-Based Requirements Engineering in particular. The outcome of the systematic mapping was to support identifying and mapping research area related to Model-Based Requirements Engineering and possible research gaps. The identified gaps in the research area are discussed in *Further Research* chapter in the end of this report. The overall systematic mapping process consists of five process steps with their outcomes. The process description is depicted in the Figure 12.

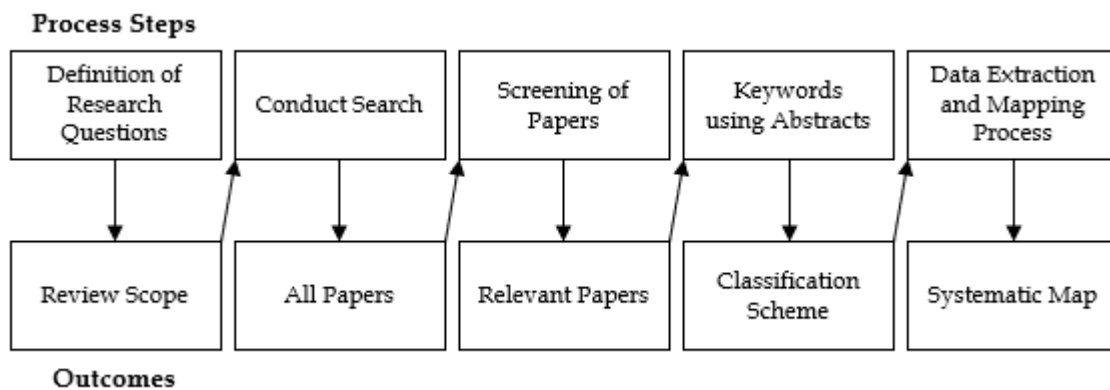


FIGURE 12 Systematic Mapping Process (Petersen et. al, 2008)

The first step in the systematic mapping process was to define the research questions. The research questions were defined before the literature review. The goal of the literature review was to provide an overview and understanding of the current status of (Model-Based) Requirements Engineering in the automotive industry. Therefore, the specific research question for the literature review was:

RQ1: What is the (Model-Based) Requirements Engineering in the Automotive industry?

The second step was to search for the relevant articles and books from previous studies related to the topic. A pre-defined search protocol implemented concrete methods that were used to execute the literature retrieval. Pre-defining the protocol decreases the possibility of researcher's bias. (Petersen et al., 2008).

The key question when starting a literature review is how to find literature which is relevant for the research study. Rowley and Slack (2004) identified four main search strategies for finding the relevant literature. Their findings are depicted in the Table 16.

TABLE 16 Four main search strategies (Rowley & Slack, 2004)

Research Strategy	Description
<i>Brief search</i>	Retrieves a few documents crudely and quickly
<i>Building Blocks</i>	Takes the concepts in search statement and extends them by using synonyms and related terms
<i>Citation Pearl Growing</i>	Starts from one or a few documents and uses any suitable terms in those documents to retrieve other documents.
<i>Successive Fraction</i>	Approach that can be used to reduce a large or too large set of documents. Searching within an already retrieved set of documents can be used to eliminate less relevant or useful documents

When searching articles from different databases, the used search strings were:

- *"requirement development" OR "requirements development"*
- *"requirement engineering" OR "requirements engineering"*
- *"requirement management" OR "requirements management"*
- *"model-based requirement" OR "model-based requirements"*
- *"model-driven requirement" OR "model-driven requirements"*

In order to be able to find relevant articles for the research, the Brief search approach was used to have a small amount of documents as a starting point. When the number of documents was increasing, Successive Fraction approach was used to eliminate clear articles which did not have common ground with the research topic.

After designing and testing the search protocol, the scientific electronical databases were chosen for the searches. Searches in this research study were made on eight scientific article databases such as (1) IEEE Xplore Digital Library, (2) European Journal of Information Systems, (3) Information Systems Journal, (4) Information Systems Research, (5) Information and Software Technology, (6) Journal of the Association for Information Systems, (7) Journal of Information

Technology and (8) The Journal of Strategic Information Systems. (9) Google Scholar was also used as one article source.

After searching the articles from the scientific databases, the next phase was doing a screening of the articles. The irrelevant articles were excluded from the research study. Screening the relevant articles was done according to the process suggested by Dybå and Dingsøy (2008). First, the screening was done based on the titles of the papers. Papers which were identified as irrelevant based on the titles were excluded. There were cases, where it was difficult to decide whether the article was relevant for the research study based on the article title. In these cases, research study marked the article for further reading. The next step was to read the abstracts from the papers which had passed the previous phase. Additional exclusion criteria were used while screening the articles. The decision was to exclude the articles which (1) did not have a full text available, (2) articles which were not written in English, (3) articles which did not have common ground with the automotive or ICT domains and (4) articles which were duplicates. The next step was reading the abstracts of the papers which had passed the four exclusion criteria. After this, the relevant papers were included in a further screening. This step consisted of reading the conclusion paragraph from each article and deciding if the article was relevant to be included in the research study. (Dybå & Dingsøy, 2008).

After finding the relevant papers, the next step was the keywording of the abstracts in the mapping study process. Petersen et al. (2008) define the process which supports the keywording. They advised that the keywording should be done in two steps. The first step is to read abstracts of the articles and identify keywords and possible concepts which reflect the context of the paper. The second step is to create higher level of understanding of the context and the research study discussed in the articles. Higher level understanding can be reached based on the keywords. (Petersen et al., 2008).

However, in this phase the process followed by the research study differs from the originally described Systematic Mapping Process (Petersen et al., 2008). This research study modified predefined process and made it more suitable for this research study. If the article was considered as suitable after reading the abstract and the conclusion chapters, the whole article was read. Keywording abstract was not used in this research study and notes were written while reading the articles.

The written notes covered the topics which were discussed in the article, and it was noted which chapter in the article was relevant for the research study. As the work on this research study was progressing, new suitable articles appeared and some of them were included in the study. Moreover, all articles were processed in the research study report. All articles were processed by following the described process.

The outcome of this step was to have notes for each article read and these notes were used for writing chapters of the research study report. The searching and selection process of the articles is depicted in the Figure 13.

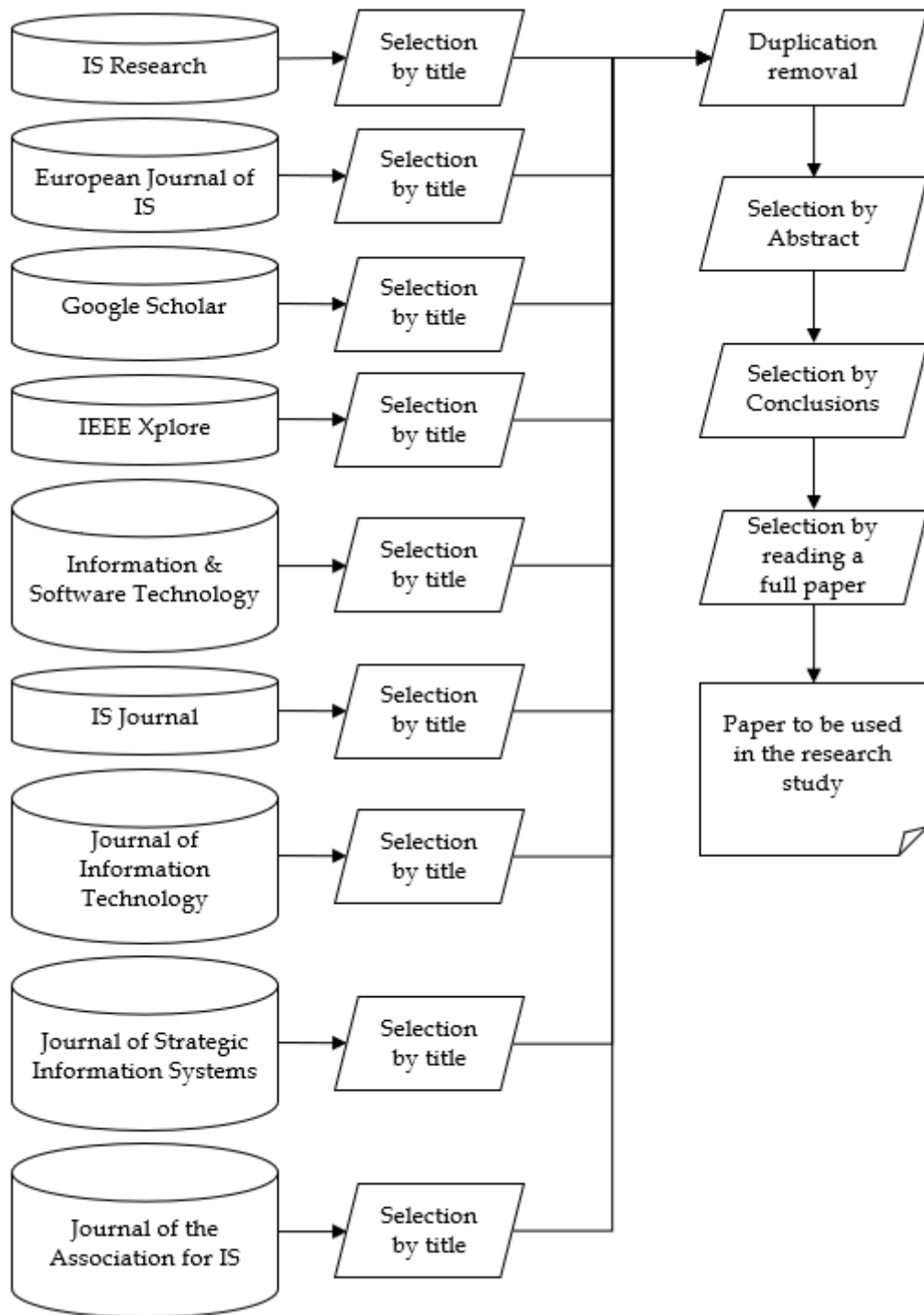


FIGURE 13 Searching and selection process of the articles (Yli-Huumo, Ko et al., 2016)

Specific data extraction table was designed to collect the relevant information from the read articles. This is depicted in the Table 17.

TABLE 17 Data extraction from the literature (Yli-Huumo, Ko et al., 2016)

ID #	Data Item	Description of the data
D1	Unique article identified	Unique identifier for each study
D2	Title	Title of the article
D3	Authors	Name of the author(s)
D4	Journal	Name of the journal
D5	Conference	Name of the conference
D6	Date	Date of publication
D7	File	Identifier of the file name on the hard drive
D8	Classification	Classification of the article (Requirements Engineering in Automotive Industry, Requirements Engineering in Software Engineering Industry, Information Systems Science, Positive Case Study, System Development, Organization Management)
D9	Comments	Free text comments

Data items D1 to D7 contain the basic information of the articles. These items included e.g. the title of the paper, the name(s) of the author(s), the name of journal or the name of the conference where the article was published, the date of publication and an identifier of the article as a file name. Two remaining data items (D8-D9) were written after reading the articles. Those data items included classification of the paper defined by research study itself and free text comments such as study goals and major findings of each article. The data was first recorded in a paper form and later transferred to proper Word and Excel documents. These practices helped in using the data more efficiently.

The result of the literature review phase was described Proposition. The Proposition worked as a baseline for defining the questions for the interviews. All interview questions are linked with Proposition.

3.3 Phase II – Interview Study

Interviews are the most common strategy for collecting qualitative data. The purpose of making an interview is to collect data that will enable examination of certain phenomena or a matter on the field. The different qualitative interviewing strategies are the result of diverse perspectives in a wide variation of interviewing approaches. (DiCicco-Bloom & Crabtree, 2006).

Interviews are used to provide better understanding of the research object. The purpose depends on research questions and on a disciplinary perspective of the researcher. Some research methods are designed to test hypotheses and they use structured interviewing format where interview questions and data analyzing methods are standardized. Thus, other research methods aim to understand meaning and perception in order to have wider understanding of a phenomenon or matter. This research method requires a qualitative interviewing where an interviewee is about to share rich descriptions of phenomena while leaving the interpretation and analysis to researchers. (DiCicco-Bloom & Crabtree, 2006).

The interview methods can be divided into two categories: (1) Structured interviews and (2) unstructured interviews. The methods are depicted in the Table 18.

TABLE 18 Differences in the interview methods

The interview methods	Description
Structured interview	Structured interviews are called intensive interviews or in-depth interviews and only predefined, closed-end, questions are discussed. (Yin, 2014).
Unstructured interview	Unstructured interviews are commonly organized with a set of predefined open-ended questions where other possible questions are emerging from the dialogue between interviewer and interviewees. Unstructured interviews are conducted once for an individual or group and it can take between 30 minutes to even several hours to complete this kind of an interview. (DiCicco-Bloom & Crabtree, 2006).

The purpose of the qualitative research interview is to contribute to knowledge which can be conceptual and theoretical. The knowledge is based on the meanings that life experiences hold for the interviewees. (DiCicco-Bloom & Crabtree, 2006).

3.3.1 Backgrounds of interviews

The material for the research study was gathered from the literature and it was supplemented with several semi-structured interviews for the data collection. The interviews were conducted with the automotive industry representatives in Europe. The research study interviewed 22 persons from 6 countries, with experience of working in 11 automotive companies. Countries where the companies operate are Austria, Finland, Germany, Norway, Sweden and the United Kingdom.

The interview questions consisted of 6 demographic questions and 18 topic questions targeting the answer research questions through defined Proposition. Qualitative interviews were arranged to understand what the status quo is and how today's state of practice reflects the literature-based Proposition.

All interviewees were selected through personal contacts in each company. Interviews were focused on roles such as Product Engineer, Product Manager and Project Manager. These roles were seen as the most appropriate since they are usually related to requirements or Requirements Engineering tasks in the automotive industry. The backgrounds of the interviewees are summarized in Chapter 4 together with other results. All interviews were transcribed verbatim. In the transcriptions, names of companies and interviewees were anonymized, and the transcribed documents were sent out to the interviewees for a review.

It is important to note that the research study investigated organizational challenges in organizations which use model-based Requirements Engineering practices. The interviews were also conducted in organizations which do not follow model-based practices in their daily operations. The interview time ranged between 65 and 155 minutes.

3.3.2 Defining the interview questions

Identifying the problems based on the literature

During the literature review process, the research study identified and gathered multiple problems concerning the Requirements Engineering process and practices in the automotive industry.

All identified problems were divided into multiple problem categories. Each problem category contains one or many literature-based problems in Requirements Engineering. The naming of the problem categories is defined by the research study in a way that the naming describes and generalizes unequivocally the actual problems within the category. It was noticed that certain problem could be suitable for multiple problem categories. All problem categories with identified problems are depicted in Appendix 1.

Setting up Propositions and interview questions

After the problems were gathered and categorized, the problem categories were merged into wider entities. Wider problem category was the baseline for the Proposition. Definition of the Proposition is described in sub-chapter 5.2 Implication to Research. The Proposition was the baseline for the definition of the actual topic questions for the interview. The interview questions were defined in cooperation with domain experts who have several years experience in the research work in the automotive industry. This process has been depicted in the Figure 14.

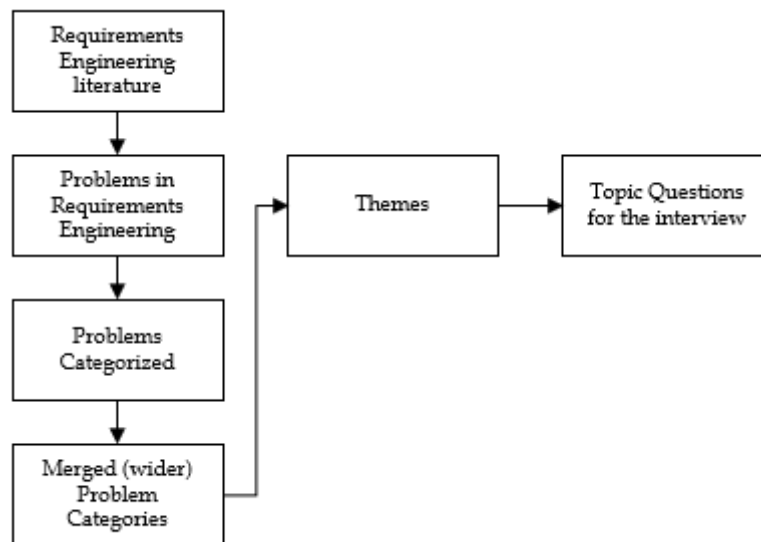


FIGURE 14 Process for setting interview questions

The linking between the interview questions and the Proposition was discussed and agreed while the interview questions were defined. Another key point to remember is that the interview questions were connected to actual literature-based problems.

3.3.3 The interview session

The interview session was divided into four parts (from A to D). This was designed to support efficiency and also to increase understanding of the phase of the interview session between the interviewer and the interviewee.

Part A covered the introduction of the interview flow. The interviewer shortly presented the topic and the research questions, and the interviewer pointed out that the interview is anonymous. The interviewer asked for permission to record the interview in order to facilitate the data analysis. The interviewer also pointed out that the interviewee will receive the transcribed interview once it is available and may review it and/or object to some of the stated points. In this case, the interviewer may not use these parts of the data. Finally, the interviewer pointed out that the final data analysis for each company will be discussed with the interviewees, if desired.

Part B contained the demographic questions. There were six questions which covered the interviewee's current and previous roles and how long he/she has worked in the current role. The interviewee was also asked to shortly describe his/her work. The interviewee's working experience and the level of education were discussed.

Part C covered the actual topic questions. There were 18 open-ended interview questions with some sub-questions underneath. The interviewer also asked focused questions based on the given answers. These focused questions might not be included in the original set of questions. The precise interview questions are introduced in Appendix 2.

In part D, the interviewer thanked the interviewee for the participation and asked for recommendation for other possible interviewees. The interviewer encouraged the interviewee to come back with any comments or questions. The interviewer gave contact details to the interviewee for possible further contacts.

3.3.4 Transcriptions

Writing transcriptions from the interview recordings might be more common than making conclusions based on recordings. Making conclusions directly from recorded materials is efficient in research studies when there are only few interviewees and when the interview does last long.

There are no unambiguous instructions for the granularity of transcriptions. It depends on the research study and its research method. When transcriptions are in the electronic form, it supports data handling and analyzing in later phases.

Writing a detailed transcription word by word takes time. Many researchers think that writing a transcription is the most time-consuming phase in the research study. When making a decision about the granularity of writing a transcription, the researcher must consider that each word and later each coding marking extends the time which is used for data analyzing. It is

estimated that one hour of spoken material requires 3 to 6 hours to be transcribed (this significantly depends on the skills of the person who does the transcription). It is good when the researcher can write the transcription in a format that support designed data analyzing. (Hirsjärvi & Hurme, 2008).

It was possible to arrange 22 one-to-one interviews. One interview took approximately 1½ hours and the interview time range was between 65 and 155 minutes. The recorded material was transcribed into 389 pages.

3.4 Phase III – Thematical Data Analyzing Method

This sub-chapter discusses the definition of thematical data analyzing method which was used to analyze gathered interview data.

Codes are labels which have a symbolic meaning to describe the gathered data. They are attached to data chunks which can vary in size, and are in a form of straightforward, descriptive label, evocative or complex one (e.g. a metaphor). The code is usually defined by a word or a short phrase which symbolically assigns and captures a summative, salient, and the essence of the data for a portion of language-based or visual data. Coding presents a deep analysis and interpretation of the data's meaning and reflects the phenomenon of the real world. Therefore, coding is analysis. (Miles, Huberman & Saldana, 2014).

The coding of the data can be divided into two major phases: First Cycle coding and Second Cycle coding as depicted in the Figure 15. In the First Cycle coding, the codes were assigned to the data chunks. This coding summarizes segments of the data. In the Second Cycle coding, the codes were generally grouped into summarize into bigger categories, themes or constructs. (Miles, Huberman & Saldana, 2014).

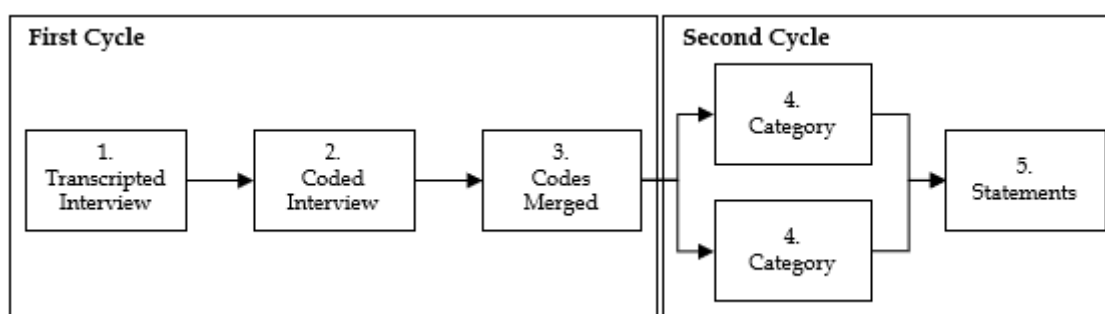


FIGURE 15 Data Analysis Procedure

3.4.1 First Cycle coding

Both *Descriptive Coding* and *In Vivo Coding* were used parallel in the first cycle of the coding. This was seen as supportive coding method for later data analyzing because of the high amount of gathered interview data.

The *Descriptive Coding* means that labels are assigned to the data to describe and summarize a word or a short phrase. This is the ground for analysis of qualitative data. Assigned labels provide an inventory for topics for further indexing and categorization of the data. Descriptive coding is an

appropriate method for data analysis in social environments. (Miles, Huberman & Saldana, 2014).

In Vivo Coding is the one of most well-known methods for qualitative coding and analysis. The coding method represents using words or short phrases from the interviewee's own language in the data record. In Vivo coding is appropriate for qualitative studies which honor and prioritize the participant's own language and voice. (Miles, Huberman & Saldana, 2014).

The steps of the First Cycle coding in the research study

The data analysis started with writing transcriptions based on the recorded interviews. (Step 1 in the Figure 15). That step is discussed in sub-chapter 3.3.4 Transcriptions.

The interviews were coded in a way that one or many descriptive or In Vivo codes were added to interviewees' statements. The length of the statements varied from few words to short phrases. Coding were implemented on Themes basis. The answers to each interview question which were linked to a certain Theme were coded at once. (Step 2 in the Figure 15).

After finishing the coding for Theme, all duplicate or similarities in codes were merged to be more descriptive on the higher level of the abstraction. The purpose of merging the codes was to decrease the number of unique codes to make codes handling more efficient. (Step 3 in Figure 15).

3.4.2 Second Cycle coding

First Cycle coding generates individual code labels which are assigned to their respective data chunks. These First Cycle codes are transformed into more abstractive pattern codes in the Second Cycle coding. (Miles, Huberman & Saldana, 2014).

Pattern codes are explanatory, and they identify themes, or inferential codes, (ones that identify an emergent theme), format or explanation of the phenomenon in the data. Pattern codes are merged codes from the First Cycle coding. One Pattern code gathers together a lot of data from First Cycle coding, increases the abstraction level of the data while turning it into more meaningful units for the analysis. Pattern codes are a sort of meta-code. (Miles, Huberman & Saldana, 2014). In the research study, data categorization was used as terminology to illustrate one type of Pattern coding.

The steps of the Second Cycle coding in the research study

After the First Cycle coding had been implemented, all the created codes were filtered according to the scope of the research study. Filtered codes were reviewed and then patterns and similarities in the codes were identified, which were merged under one categorization. Pattern coding created multiple categories under each Theme as depicted in the Table 20. The aim was that one

First Cycle code fits only into one category. These categories were used to extract statements which were relevant for the Theme. (Step 4 in the Figure 15). As a result of the categorization, six major categories under the Theme were identified. Three of six categorizes were focused to describe identified challenges and other three of six categorizes identified solution proposals for existing challenges. This way of managing the codes supports further data analysis by making it as simple as possible. This means that all statements under one category can be seen and studied efficiently. (Step 5 in the Figure 15).

3.5 Chapter Summary

The chapter discussed how the research study was implemented. The design of the research study was divided into three different sequential phases: the literature review, the interview study and the thematical data analyzing method. These phases were discussed in this chapter.

The literature review followed the steps of systematic mapping process that was slightly modified for this research study. The actual process steps are described in detail. It is explained how the articles were gathered and analyzed during the literature review.

The chapter also discussed the process of the implementation of the interview study and how the interviews were transcribed into the data which can be analyzed.

Thematical data analyzing discussed how the collected and transcript data was analyzed, which steps were taken during the analyzing phase and what were the outcomes of the analyzing phase.

4 FINDINGS

This chapter discusses the research findings. First the chapter presents the demographic backgrounds of the interviewees and then all identified Themes based on interview data are discussed.

4.1 Summary of Interviewees

For the empirical part of the research study, 22 persons from 11 different automotive companies were interviewed. The interviewees were from six European countries. There were eight interviewees from Finland, seven interviewees from Germany and two interviewees from Austria, Sweden and the UK each. There was one interviewee from Norway. The Figure 16 depicts the number of interviewees per country.

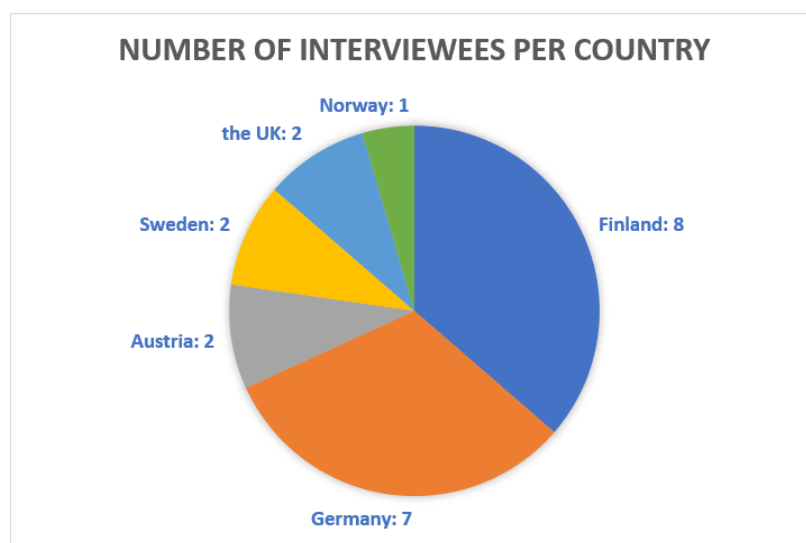


FIGURE 16 The number of interviewees per country

The Figure 17 depicts the level of education of all interviewees. There were 14 participants who hold the Master's degree and four who hold the Bachelor's degree. Only one participant has the PhD degree. Most of participants have degree in Engineering, Electronics or Computer Science. Three interviewees did not mention their level of education.

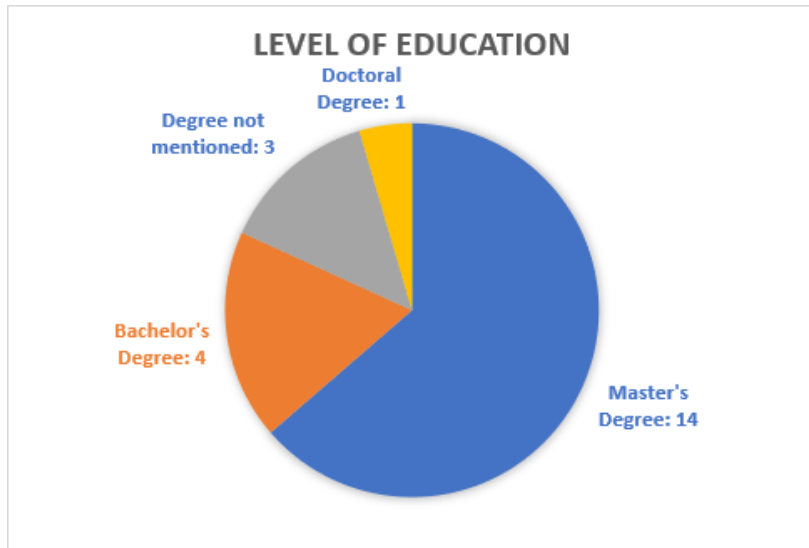


FIGURE 17 The level of education of the interviewees

The Figure 18 depicts that the average work experience in a current role is approximately over four years (52 months). The most experienced interviewee has worked 20 years and the least experienced interviewee has worked eight months in the current role.

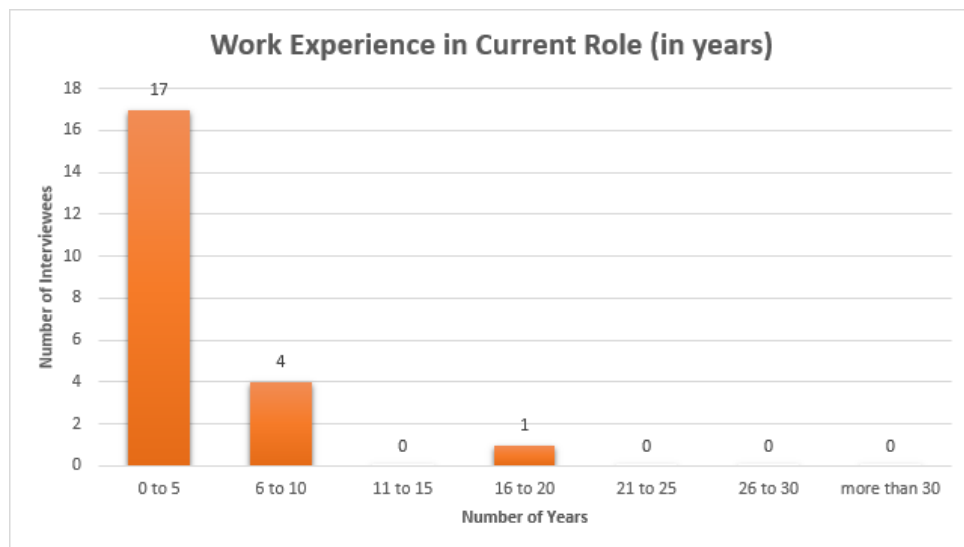


FIGURE 18 The work experience in current role (in years)

The current role of most of the interviewees is managerial. There were 13 interviewees with the word *Manager* or *Management* in their job title. Eight interviewees have the word *Engineer* in their job title. There was one person who had *Product Owner* as a title and one who had *Head of Research & Development*. Beside the current role, all the interviewees have worked earlier in at least in one role, such as *Software Developer*, *System Engineer*, *Testing Engineer* or *Project Manager*.

Total work experience is in average 20 years. The minimum working experience was 10 years (three interviewees). All other interviewees had more than 10 years of working experience. There were three interviewees with the experience of 30 or more years. This is depicted in the Figure 19.

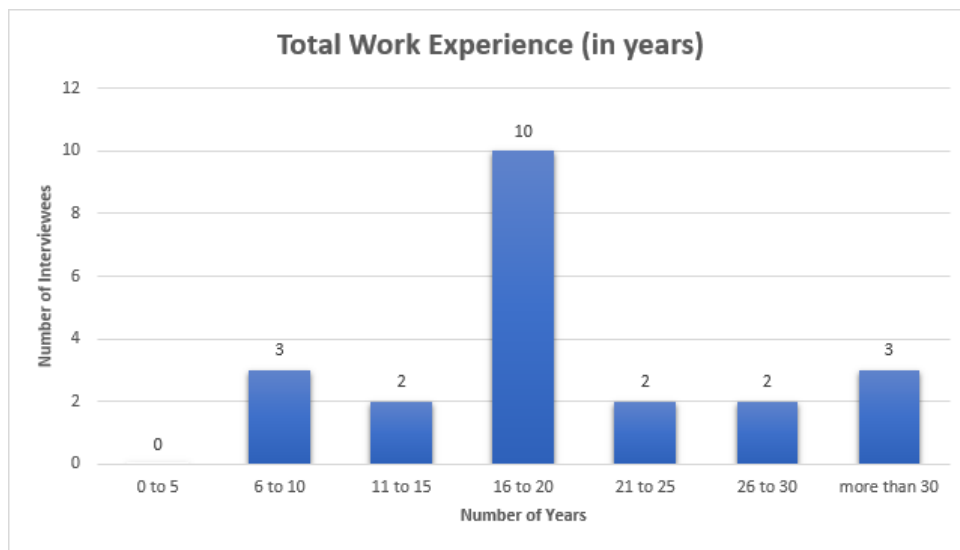


FIGURE 19 Total work experience (in years)

4.2 The Findings of the Proposition – Lack of time as an obstacle to understand requirements

The Proposition is divided into three Themes as depicted in the Table 19:
(1) *Communication & Co-Operation*, (2) *Organizational Culture* and (3) *People Skills*.

TABLE 19 Identified Themes based on the Second Cycle coding

Theme	Short description of the Theme
Communication & Co-Operation	All factors which have an impact to Requirements Engineering concerning the communication and co-operation inside the company and in a co-operation with external companies.
Organizational Culture	All factors which describe organizational culture and have an impact to Requirements Engineering.
People Skills	All factors where people skills and expertise are relevant for Requirements Engineering.

These Themes are also divided into challenges and proposed solutions. These categorization values came to prominence and are conducted based on the interview data during the analyzing phase. These are not intended as universal means for describing all possible challenges and solutions in the state of practice. They are meant to outline different approaches towards identified problems and solutions. This is depicted in the Table 20.

TABLE 20 The Themes for the analysis of the Proposition

	(1) Communications & Co-Operation	(2) Organizational Culture	(3) People Skills
CHALLENGES	C 1	C 2	C 3
SOLUTIONS	S 1	S 2	S 3

The Figure 20 depicts the amount of time reserved for Requirements Engineering activities based on all available working hours. Most of the participants (14 interviewees) mentioned that less than 25% of all available working hours can be allocated for Requirements Engineering activities. But only 3 of 22 participants were able to allocate more than 76% of their working hours to Requirements Engineering.

Time Allocation for Requirements Engineering

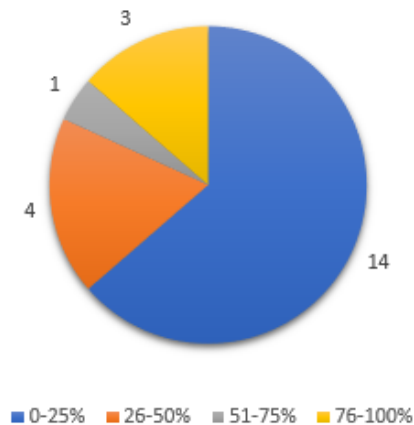


FIGURE 20 The Time Allocation for Requirements Engineering

The findings on this Theme are discussed in the following way: firstly, the identified challenges were described per category and then the solutions are proposed for each category.

4.2.1 Findings in Communication & Co-Operation (C 1 & S 1) Theme

Challenges in Communication (C 1)

Project Manager has an important role of managing conversation and taking it forward. All industry domains and even companies within the domain have their own slang wordings, abbreviations, views and opinions on organizing development process. The challenge is to find a common way of managing the development process. This is done in order to have clear understanding of the needs and to be able to transform them into high-quality requirements. Therefore, Requirements Engineer must have detailed information and a broad perspective of the issue.

All interviewees indicate that the most efficient way to communicate is a face-to-face discussion. When face-to-face discussions are not possible to organize, sharing a document is mentioned as the next best way to communicate. It is recognized that this is not as effective as direct discussions because communication via shared documents is more time consuming.

Another negative aspect of communication via shared documents is that there is no possibility to read a body language of participants.

The fact that car manufacturers and their suppliers have their own technical language can be problematic. Even within the same industry, different companies often use different terminology. Defining a common terminology among the companies is time-consuming.

Korean and Japanese car manufacturers normally write requirements in their native languages. Communication between them is managed through specific contact centers and Requirements Engineers do not have a direct communication channel with the representatives of car manufacturers. All messages are translated from their native language to English (and vice versa) by the contact centers. Therefore, Contact Centers have to understand comments and questions before they can do translations. When people do not use their native language, there is an increased risk of misunderstandings and it takes more time to verify if the message is understood correctly. Verifying correctness of a comment or a question is very important because otherwise it can create misunderstandings and delays in phases of a project. This is one of the reasons why the requirement is not understood correctly. In this case, Requirements Engineer has to contact a person who had a direct discussion with the representative of car manufacturer. This kind of communication behavior creates chains of messaging, and this chain usually fails at some point. Messaging in chains always takes time and creates grounds for miscommunication and misunderstandings. But in some extreme cases, when it is not a question of understanding or translation, meetings with teleconferences are arranged. In these cases, companies invite Specialists from all areas of product development, and they try to discuss it in English. They mainly communicate and share their ideas in a written form.

Requirements Engineers use whiteboard designs and available documents to verify if the information is clear. On the other hand, modern modeling tools and languages such as UML are rarely used in Requirements Engineering process. Models are preferred in development of the product. The Requirements Engineers think that using models would not only bring efficiency to the process but would also decrease misunderstandings in communication. However, the problem is that using models is time-consuming.

The most common problem is how to manage time, or more specifically how to arrange enough time to do Requirements Engineering practices properly. Establishing a required level of understanding is crucial, especially in the beginning of all projects. When there is no special terminology defined then all wording should be discussed and agreed. All of this requires time.

Cultural differences also create certain communication challenges among companies. It takes time to find a common way to communicate because English language is not de facto language in the automotive industry. Automotive business in Asian countries like China is growing constantly but the knowledge of the English language and capability to operate in English is

still falling behind. Therefore, translation services are used to support communication and requirements settings between the companies in Asia and the rest of the world. Translation between the Chinese and English language creates conflicts in a form of misunderstandings. Solving these conflicts are costly because they require time and re-development activities.

There are different practices how companies apply global standards, and therefore some companies created their own standards beside the global standards. Furthermore, legislation variations in different countries create additional challenges for companies' standards and procedures. This has side effects on the way requirements are communicated and understood between the companies. Using different kind of standards which have not been standardized globally increases challenges in communication.

Solutions or proposed activities for improving Communication (S 1)

All interviewees emphasized the importance of direct and open communication during the whole lifecycle of the development project. Face-to-face meetings are pointed out as the most efficient way to communicate because they allow certain level of flexibility.

Meetings are held to pass and to clarify the information. The customers in all levels of supply chain are deeply involved in the product development process. Therefore, they have interests to participate actively in communication in order to secure their interests in the product development.

The kick-off of development project is an important event for the success of the project. People get together to familiarize themselves with the project, its scope, schedule, budget, and expected outcomes or deliverables. In the kick-off events people will get to know each other which will make cooperation easier. The kick-off events are always organized in a form of face-to-face events.

In the face-to-face meetings, there are possibilities to demonstrate ideas, exchange opinions and viewpoints. Participants can share PowerPoint presentations, draw sketches on whiteboard and illustrate their viewpoints by using any other tools. Presenting with the tools makes topics more concrete and it makes it easier to make a requirement out of it. Moreover, reading emotions and body language is easier when all participants are present in a same room. Understanding emotions and body language supports understanding of the message and possible corrections can be done immediately. In the situations when people cannot meet face-to-face (i.e. due to geographical distance) video conferences are organized.

One form of face-to-face meeting are workshops which are organized for discussing a certain topic or to solve a certain problem. Workshops are organized for activities such as discussing project management topics, agreeing processes and setting practicalities related to the project.

Interviewees mentioned that they usually prepare for the meetings by defining a set of questions in advance or by coming up with a list for action points and open items. The most expected outcome of workshop is documentation which supports the project development.

Meetings are arranged for completing formal activities such as document reviewing within the company or among two or more companies. After the formal review, the documents are signed off. This means that all counterparts agreed on the documents' content. This enables progressing in the product development process.

It is mentioned that workshops are held in order to understand the business perspective or to understand things from a business model approach. The scope of the workshop could be to have the look at the end customer perspective. Workshops are seen as a good way to start that. It could also be interviewing session with the key stakeholder if the project requires that. There are also highly technical workshops where scenarios and use cases are defined, and key parts of the technical solution are identified. Workshops enable the possibility to gain a common viewpoint on the topic fast and to integrate all participants. Face-to-face meetings should be held at the beginning of every project. There are project milestones where workshops should be held as face-to-face so as to support the co-operation between all parties. Instant and flexible face-to-face communication e.g. in the office decreases the need of calling up meetings or workshops.

When face-to-face meetings are not possible, interviewees mentioned a few alternative ways to organize them: Skype or Webex teleconferences, regular phone calls or emails. Emails are only used just for exchanging information. They are not used for wide discussions. There are regular meetings during the projects. These are agreed in a project plan at the beginning of the project or during the project. There are also meetings agreed to be held in certain phases of the project like in milestone checkpoints or similar. Regular meetings are organized weekly or biweekly with beforehand fixed agenda and with a possibility for ad-hoc discussion topics.

The automotive industry is heavily standardized field of industry. There are standards which define requirements and also work as a guidance for the product development.

Companies' Legal Departments drive the legal requirements which work as a voice of legislation and they set the framework for the product development from the legislation perspective. Legislation depends on the markets where the product is meant to be sold. Therefore, there is a variety of legislation requirements for the product development. When it comes to standards and IPRs or patents, there are experts who cross-check existing patents against requirements and planned implementations. This brings multiple viewpoints to the requirements. Therefore, both standards and legislation requirements should be considered during the Requirements Engineering process and especially during the requirements specification phase.

Requirements do not often reflect the whole picture which is why there is always need for internal discussions. There are multiple discussions where people who have different roles and competencies analyse requirements at each

level. For instance, an architect does the first pass with some kind of architectural team of roles from different technology groups. After this, they make sure that the technology lead of technical requirements brought the team's knowledge into analyzing and understanding the complexity and potential architectural implementation of the requirement. It is a continuous analysis together with key stakeholder and every role which is relevant. This is putting the knowledge down to the different teams. These discussions are required to minimize assumptions and also to have a similar and shared understanding among all parties who are involved in the implementation.

All interviewees highlighted the importance of internal discussions between the meetings with customers and other parties. The forms of internal discussions vary from short informal meetings and multiorganizational workshops. There are different kind of methods described as internal discussions e.g. some teams keep lists of open issues which are discussed in those meetings. Also, different kind of review practices were mentioned in all interviews. Companies have established systematically approaches for reviewing documents which are submitted by the customer or described together in the meetings with the customer. In practice this means that there is one or a few persons who read the customer documents first in order to have a common understanding about the impact of the requirement on the organization. Requirements are studied internally in teams with all relevant Practitioners are involved. There is an active dialogue between teams and experts.

One solution which was proposed is known as a parent-child requirement. The one defining the parent-requirement has to review the child-requirement. This is seen as the simplest practice because it can be ensured that no information will be lost in the process of deriving the child requirement.

Challenges in Co-Operation (C 1)

Understanding customer's business, its value proposition and understanding the pains points in the current needs, enables success in the requirements gathering. When requirements are identified, they should be written down and shared for the review with other participants within the company or in a cooperation with partners. The practices how requirements are formalized vary between the companies. Some are more strict in following formalities than others. Formalities can be seen using of dedicated documents templates or information systems. Unformal ways of documenting requirements are using PowerPoint documents or some other generic solution.

When totally new technology should be developed, or a customer has totally new concept, there is no possibility to set requirements properly at the first place. No one has an understanding to define a comprehensive set of requirements.

There are always conflicts in understanding the requirements. When there are problems with understanding the requirements, several meetings should be organized in order to discuss the issues. On the other hand, in the automotive industry the customers are deeply involved in the verification of the product, and in most cases, customers perform the validation of the product by themselves. Therefore, a major misunderstanding in the requirement specification can lead to a completely different function from what was required. In the case like this, product development organization and customer will solve it together during the verification phase. When requirement is completely comprehensible, the possibility for misunderstandings is decreased.

Reviewing requirements might represent a challenge for managers. Managers want a simplified list of activities that should be represented in one PowerPoint slide. For instance, Product Developers and/or Requirements Engineers can have 5 000 requirements specified beforehand. Managers are just interested in implementation of 2 000 requirements which they originally asked for. This leads to situations where Managers may say:

“Sorry, can you go back because this one doesn’t make any sense...Oh right, we didn’t really review it, that’s why it didn’t make any sense...”. (Quote from the interviewee).

Lack of reviewing requirements leads to implementation of the ways of working where managers do not need to look at the details. The problem occurs because managers often overlook details and at the same time, they are not precise enough when giving instructions about requirements. This is an expensive problem, but this is also an opportunity for improvements in a process-wise and cost-efficiency wise.

Planning a roadmap for future projects and later products, it requires tens of companies to be involved, such as different supplier companies in the supply chain and also car manufactures. This requires having almost 100 face-to-face meetings so as to verify common understanding of the roles and deliverables of all companies in the supply chain.

Solutions or proposed activities for improving Co-Operation (S 1)

Companies are set up small and shorten projects to clarify customer’s needs and requirements for the product. These projects happen before the actual product development project takes place. Operating in this way, the companies can optimize their resources to right projects at the right time. They can also follow the costs much easier when projects are shortened and less resourced.

Companies working in their own premises and using their own information systems for managing the requirements, can be seen as an obstacle for the efficient communication and information sharing.

Not every requirement will be discussed face-to-face with the customer. When product developers do not understand the customer request, the content

of the requirement, or in case when the requirements cannot fulfill the demand, there should be a possibility to set a status *to be clarified*. Each requirement which is not understood or cannot provide the required functionality should be discussed with the customer.

Therefore, companies have started to share with customers their internal information systems where they manage the requirements. This enables that both parties, customers and Product Developers, have the same information available almost in real time. Product Developers are able to submit questions towards customers and they have a visibility when a customer has provided the answer.

When using the shared information systems, process flow is equal to both customer and product developers. This brings efficiency in managing requirements and improves the visibility of the status of the requirements. This enables more reliable possibilities to measure the efficiency of the Requirements Engineering process and make adjustments to it. Some interviewees mentioned that exporting the status of the requirements from the information system works as an agenda for co-operative meetings with customers. The most mentioned information systems were JIRA, DOORS and MKS. Using the shared information systems minimize the need for meetings, reduces delays in the product development, improves the quality and minimizes the number of error reports and the late re-development.

One interviewee mentioned that they have developed a certain Requirements Engineering framework to support requirements quality. When a new requirement document is created, there are certain constraints of this framework. These constraints promote the quality of the requirement itself and the process. In practice this means that they have documented standards on how to write requirements which can meet quality targets. They use checklists to maintain the quality of the requirements as high as possible.

Customers of the project receive documents for the review. These reviewed documents are used as a baseline in the next meeting and there are several roles such as Tech Lead, Unit Leads and Product Managers, who participate in these meetings. This is seen as a collective form of operation where as many persons as possible review the documents and cover the gaps in many abstraction levels of requirements. This supports the designing phase of the implementation.

Some product development companies have built up their organizational structures to be align with product architecture or with customer's own organizational structure. This is called *customer-aligned level structure approach*, e.g. "...so, from the top, from vehicle level to over powertrain, over sub-system, over component and over software..." (Quote from the interviewee). This kind of operational model supports the discussions during the project when all participants can adjust themselves to the right abstraction level.

Customers' understanding of their own needs varies between thousands of pages of documentation where everything is explained in very detail level. Most of German car manufactures, who already have a long history of developing cars, are able to create such amount of requirement documentation. On the other end are newcomers from Asian countries. They have a vision of the product based on what they want to do with a high pile of money. Concepting is seen as a working solution for customers who cannot identify their needs clearly and therefore cannot define their requirements.

Product presentations are described on the certain level of abstraction. The level of abstraction is defined based on the discussions with the customer. This abstraction level sets a baseline for the forthcoming requirements specification activities and supports the later understanding of requirements specification. The other goal of the discussions is to gain the understanding of customers' own requirements and possible requirements of customers' own customers' requirements. The chain of the requirements can go deep in the supply chain where several companies are involved.

Concept cars are the ones, which are shown in the car exhibitions. Car can be driveable and it can include all required technology for that. These concept cars are used as a baseline for the product development process. When there are no documentation available of the concept car or the quality of the documentation is low then the car should be broken down to pieces to study the requirements further, and to produce required documentation for the product development.

An example of legal requirement could be that a cone of front lights should be shown on a certain part of the road. The cone of the lights cannot be described only as a written text. It must be modelled as 3D model. The 3D models of design and measurements of existing objects are used to support concepting and illustration. Therefore, also so-called concept cars are used to illustrate requirements.

Product concept creation and developing prototypes is seen as an alternative solution to gain the understanding about the requirements. Creating a concept and multiple concepts is used to illustrate the understanding which is received based on the requirements. Reference products such as cars from other manufactures can be used as concepts for the project.

"Everyone understands, when you are sitting into some Bentley – WOW all the materials are correct with the highest quality. All tolerances are correct, and everything is in the state of the art. This is something what I want! Then we just need to start studying how Bentley has managed to do everything right. Learnings from this will be brought to our development project." (Quote from the interviewee).

Concept creation also supports customers' own understanding about the requirements and possible outcome of the implementation. When illustrating the product with concepts, the customer can submit more relevant

requirements for the product development. It might happen that the concept will become an actual product. Concepts are valued based on different criteria like weight, price, needed time for product development, features for end users, etc. These are measurement values for these variables, they support the evaluation of the concept, and later the validation of the requirements and verification of the product.

When development work concerns functional safety, the modeling of requirements has an important role. The modeling is used in order to see if beforehand specified requirements will actually work. The modeling also gains the understanding with the customer and therefore can be used as a communication method.

Scenario descriptions, Use Case descriptions, block diagrams and message flow diagrams are the methods to understand the customer expectation or how a user would think of certain functionality. It is important to have similar modeling language used and common understanding of symbols in the modeling language.

Understanding the requirements of different companies in the supply chain supports all involved companies' current product development projects. It also supports the planning and roadmapping of future product development projects and product planning.

"At the end of the day either, we get this information somehow from the customer or we have to assume something. Then we have to get the confirmation from the customer that this assumption correct. But to be honest, if there is some information missing that has a significant effect on your design, then you are in each case – 'I'm sorry but you are in troubles because there is no way to find out information that you cannot know'. So, either you make assumptions but even then, you are in troubles because assumptions are only assumptions and not a fact. If you do not even have an assumption, then you have a serious problem." (Quote from the interviewee).

4.2.2 Findings in Organizational Culture (C 2 & S 2) Theme

Challenges in Organizational Culture (C 2)

Car manufactures located in Japan and Korea usually write their requirements in their own language. Therefore, their requirements must be translated in English. This creates situations where suppliers are not able to understand the requirements correctly and also some details might change due to poor translation process. Time needed for requirements processing is increased when direct communication practices are established between the originator of the requirements and experts on supplier side. Direct communication usually means face-2-face communication where a representation of the supplier is located in car manufacturers' premises. This causes delays in the requirements

elicitation and specification phases. It is considered as a threat when cultural aspects are not recognized or managed. This usually becomes obvious when it is difficult to find common understanding about open topics and discussions. Some of the obstacles in finding mutual understanding are different terminology, legislations and standards used in the companies. When there is no common understanding, conflicts might arise or there could be delays in project work. In cases like this, constructive dialogue among companies is necessary. However, this requires more time. This should be taken into account when planning project activities.

Car manufacturers do not share all the details about the requirements with their suppliers. This means that the supplier will receive just specific pieces of information as the requirement without having a concrete picture of the overall functionality. This is a sign of lack of trust that suppliers might leak information to the competitors of car manufacturer, and to give competitors advantages to other companies. This leads to situations where suppliers have their own internal requirements specified based on assumptions. This often leads to compromised product quality because the supplier does the implementation based on inadequate information and without proper understanding of the needs.

At the beginning of the project, the number of participants who define the project scope and customer requirements is set to minimum. This is seen as an efficient way to make high level agreements about the project. However, when companies face changes in personnels, there are always challenging situations. Different persons have different opinions about requirements, and what is important or what is not important in the project. They might have different missions or visions about the goal of the project. In addition to this, they might want to lead the project in different direction of what was originally discussed and planned. This creates quality problems in the expected deliveries and also causes misunderstandings in the organisations about what is expected by the customer.

Suppliers might work in their own premises or they might be located on-site on customers' premises. Selected key experts from the customer company might be also located on the supplier's own premises. This is usually discussed in an early phase of the project. Decision on the location of the project members can be affected by the project goals, its schedule and also available technology or know-how. Key experts being located in other companies's premises is seen as an advantage when relevant resources are easily available and accessible. Silent knowledge is also seen as a threat for the project success. When all relevant persons are located in optimal locations reduces information sharing and decreases silent knowledge. This is considered as one of the success factors in completed projects.

Solutions or proposed activities for improving Organizational Culture (S 2)

Companies nowadays want to create open communication culture. When there are disagreements between supplier and car manufacturers, It is recommended to discuss issues internally before discussing them with the customer.

There is always mistrust between big car manufacturers and their suppliers. It is suggested that trust can be improved through Requirements Engineering. Supplier should create its own internal requirements. Those internal requirements will be linked to customers' own (external) requirements. Also, internal requirements should be written in a way that they express customer's needs on generic level. When requirements are on generic level, there is a lower risk that important information from car manufacturers own requirements will be leak out. This practice will also provide visibility to customer's side that implementation requirements (internal) are identified and also secured for information leaking. When the actual implementation is done, dedicated tailored requirements report will be delivered.

4.2.3 Findings in People Skills (C 3 & S 3) Theme

Challenges in People Skills (C 3)

It has happened that a person who does not have enough experience in the domain wrote the requirement on behalf of the car manufacturer. It is seen as problematic to intervene in cases like this. The detection of such problem is easy but communicating it can be difficult. Moreover, customer's expectations can make this problem much harder to confront. This leads to poor quality requirements which have negative effects on many aspects of the project. These problems mostly exists on newcomers car manufacturers.

Solutions or proposed activities for improving People Skills (S 3)

In most of the interviewed companies there is a person who has a role of *Tech Lead* or *Technology Leader*. The role is responsible for writing technical specifications as internal implementation requirements. These requirements contain detailed description of what should be implemented and what is expected outcome. Writing of requirements specification is usually done in a cooperation with major customer/customers. The source of requirements specification are multiple discussions with the customers. The written requirements specification makes the earlier discussions concrete. When the requirements specification is done, it is reviewed by the customers, and also internally by multiple persons in different roles. Approved specification is used as a baseline for later discussions between the supplier and the customers. The requirements specifications are discussed on multiple levels in the organization

from multiple perspectives. This increases the quality of the requirements specification and later reduces irrelevant implementation work and errors.

It is important to have in mind that requirements do not always cover all perspectives. That is why it is suggested to communicate regularly with customers. However, one must be prepared in advance before talking to a customer. The interviewed Requirements Engineer mentioned that own judgement skills are relevant in his role.

“... I read these requirements, I make my own assumption how it could work, I discuss with the experts what they have understood from the customer, I also look at our current implementation and make my mind up what are already in place and where do we have differences so that's how I work.” (Quote from the interviewee).

Previous experiences with the product are relevant for understanding different aspects of the product itself and its development process. This helps Requirements Engineers and Product Developers to contribute requirements specification work and related discussions on that.

Companies are aware of challenges in communication and therefore they value the expertise of other companies such as such as supplier or car manufacturer companies. In a problematic situation they usually try to get in touch with the technical experts from the counterpart of the supply chain. It is important to have the technical experts discussing the issue. Furthermore, it is seen as beneficial that a requirements writer directly communicates with the person who is responsible for the certain implementation.

All the interviewees emphasized the importance of the customers. Customers should be heard, and the company should be in touch with them during whole lifecycle of the project.

5 DISCUSSION

This chapter discusses and reflects on findings of the research study based on the academic literature and the interviews in selected automotive companies. This chapter provides answers to research questions and described Proposition, and it provides the implications to both the research and the practices. In this chapter, the results of the field study are discussed and summarized.

5.1 Reflection on Research Questions

The research study was set up to answer two research questions:

1. *RQ1: What is the (Model-Based) Requirements Engineering in the Automotive industry?*
2. *RQ2: What are the organizational challenges on different levels of organizations in the automotive companies which apply (Model-Based) Requirements Engineering process and practices?*

In order to answer these questions, the scope of the literature review was defined. The goal was to study current understanding of Requirements Engineering in general. In addition to this, the meaning of Model-Based Requirements Engineering for the automotive industry was introduced. Secondly, qualitative interviews were conducted in the selected automotive companies in Europe. In this chapter, the qualitative results will be discussed. The discussion will first focus to understand what is the definition of (Model-Based) Requirements Engineering in the automotive industry and secondly, what kind of challenges the automotive companies face in the area of Model-Based Requirements Engineering.

5.1.1 RQ1: What is the (Model-Based) Requirements Engineering in the Automotive industry?

Theoretical background was created based on the literature review and it was made in order to provide understanding about what Requirements Engineering is and what are its constraints. The literature review was conducted based on academic articles and books about Requirements Engineering. Books were written by scientists who hold long experience in studying the Requirements Engineering area. Nine different scientific article databases were utilized for finding the relevant academic articles.

The literature review was divided into two major parts; Requirements Engineering and Model-Based Requirements Engineering. First part provided a comprehensive overview about Requirement Engineering applied to the context of the automotive industry. Second part provided a comprehensive overview of Model-Based Requirements Engineering practices. These major parts are discussed to provide the answer to the first research question.

Requirements Engineering practices should be applied to the whole project planning, because the principles of Requirements Engineering are not only limited to the software and hardware development projects. The literature recognizes different definitions for the requirement. (Kotonya & Sommerville, 2000; ISO/IEC/IEEE 24765, 2017). It can be concluded that the definition of the requirement is not unambiguous and may vary in different contexts.

It was identified that requirements have three main sources: existing documentation, stakeholders and other systems in operations. Stakeholders can be either individuals, groups or organizations which have interests in the outcomes of the project. (Hofmann & Lehner, 2001; ISO/IEC/IEEE 24765, 2017).

During the literature review, at least three different definitions of Requirements Engineering were notified. (Zave, 1997; ISO/IEC/IEEE 29148, 2011; Khanom, 2014). Using a simple definition for Requirements Engineering that covers all aspects of it was a challenging and ambitious task. The Requirements Engineering process was divided into two major processes: Requirements Development and Requirements Management. (Hofmann & Lehner, 2001; Cheng & Atlee, 2007; Khanom, 2014). These processes should be conducted during the whole project life-cycle because new requirements could be identified and because existing requirements are often refined during any phases of the project.

Two main types of requirements were identified: customer requirements and implementation requirements. (Wiegiers & Beatty, 2013). The source of customer requirements describes needs of stakeholders. (Wiegiers & Beatty, 2013). However, this type of requirements can be also used when the source of the requirement is already existing documentation or when the source are existing systems in the operation. There are implementation requirements that describe what should be implemented to fulfill the needs in customer requirements. Both of these requirements include Functional and Non-

Functional requirements. (Pohl & Rupp, 2015). This type of classification is based on the content of the requirement. Functional requirements describe functionality needed for the system. Non-Functional requirements define quality, material or design aspects of the implementation or the system. (Pohl & Rupp, 2015).

Requirements Engineering activities are an important factor for the success of projects. That is why the relevant contribution of Requirements Engineering should not be underestimated. There are evidences that problems in projects can be avoided when more attention is given to Requirements Engineering. (Boehm & Basili, 2001; El Emam & Koru, 2008; Pohl, 2010; Wieggers & Beatty, 2013; Khanom, 2014). Identifying the requirements from previously mentioned sources is challenging. All the requirements cannot be promptly defined, which is why interaction with stakeholders is needed. The paradox occurs because stakeholders are not able to identify their needs until they see or interact with possible implementations or results. (Cheng & Atlee, 2007; Sommerville, 2011). Furthermore, defining Requirements Engineering process as an end-2-end process is not feasible. Therefore, it is also challenging to manage other affected or interfacing processes and organizations due to complexity of business models. (Houdek & Pohl, 2000). Organizations which are involved in the Requirements Engineering process and its activities may be company's own internal organizations or organizations from a supplier company.

The models are used to illustrate different phenomena in many scientific contexts, and they are used to simplify the reality from multiple viewpoints. (Brambilla, Cabot & Wimmer, 2012; Pohl & Rupp, 2015). This approach is used to generalize presented information. Models can be represented in graphical form as sketches or as diagrams among textual requirements or requirements lists, and they illustrate requirements on different granularity levels. (Brambilla, Cabot & Wimmer, 2012; Fowler, 2015; Pohl & Rupp, 2015). Due to increasing speed of the technology development and due to increasing complexity of the systems, the automotive industry needs methods to manage complexity and quality of systems development. The models has seen as a solution for these challenges. (Xiaojian, Xuqin et al., 2010; Sikora, Tenbergen & Pohl, 2011).

Model-Based Requirements Engineering is a parallel approach with natural textual requirements where different models are used to fulfill identified gaps. This is done so as to describe and manage requirements and their context. The intention is to utilize the modeling in all phases of Requirements Engineering. This enables possibilities to translate requirements from model to another model. Models can also be used as a base for source codes. Modeling of requirements graphically is supported by a notation language in Model-Based Requirements Engineering. (Mohagheghi, Gilani, Stefanescu, et al., 2013).

The benefits of Model-Based Requirements Engineering were comprehensively described in the Table 9 by dividing them into 11 categories which cover multiple viewpoints.

The challenges of using Model-Based Requirements Engineering is how to describe requirements in a consistent and manageable way. (Xiaojian, Xuqin et al., 2010). Another challenge is how the models on different abstraction levels can be integrated so that they still form a consistent and complete understanding of the requirement, and also about the product. Modeling and analyzing the requirements is challenging because automotive software has tight interactions with other systems and because the software is distributed to cars over networks. (Xiaojian, Xuqin et al., 2010; Kirstan & Zimmermann, 2010). Safety-critical aspect should always be taken into consideration when it comes to timing behavior and other relevant non-functional properties.

Model-Based Requirements Engineering is dependent on vendors of the development tools. The quality of produced software is dependent on possible bugs in used tools. Therefore, some developers are skeptical about tools' code generators when safety-critical aspects and efficient code are not considered. (Xiaojian, Xuqin et al., 2010; Kirstan & Zimmermann, 2010). Despite that, Model-Based Requirements Engineering is the most used method for describing and analyzing requirements at different abstraction levels in the automotive industry. This shows that companies rely on Model-Based approach in their product development processes.

The literature review concluded that the Requirements Engineering supports the product development during the whole life-cycle of the development process. The Requirements Engineering is seen as a process which is tightly attached to all product development activities, and therefore the value and efficiency of Requirements Engineering should not be underestimated. When Requirements Engineering is considered as a major asset for product development, and there are required resources allocated to all the phases of it. Requirements Engineering brings efficiency to companies' daily activities by decreasing development and operational costs in various levels of organizations. It also also increases process efficiency and reduces irrelevant activities in the product development.

5.1.2 RQ2: What are the organizational challenges on different levels of organizations in the automotive companies which apply (Model-Based) Requirements Engineering process and practices?

The qualitative interview study was conducted to answer the second research question. Answering the research question was divided into three major themes which were identified based on the interview data: *Communication & Co-Operation*, *Organizational Culture* and *People Skills*. This is depicted in the Figure 21.



FIGURE 21 Organizational Challenges in the Automotive industry

Each theme was divided into *Challenges* in the current mode of operation. In addition to this, *Improvement Proposals* or *Solutions* were also identified to solve these organizational challenges. Each theme consists of multiple sub-themes. Themes with their sub-themes are depicted in the Appendix 3. In order to answer the second research question, the data and identified themes are discussed theme by theme. Both *Challenges* and *Proposed Improvement Proposals* or *Solutions* are discussed under a certain theme.

The domain of the Requirements Engineering is a challenging part of the product development. Practitioners should be able to understand principles of the product development and the way it is organized from the process-wise and from the organizational-wise perspective. It is important to understand how Requirements Engineering influences project management, development costs, and the strategy of the company. Therefore, the practitioners should have a lot of experience in related activities to be able to work successfully in the domain of the Requirements Engineerings.

Interview data shows that most of the practitioners have reached a managerial position by previously working for a long time in developer and/or engineering positions. Furthermore, Project Manager positions are seen as an advantage for working in Requirements Engineering activities. These previous developer and engineer positions have provided them understanding about product development activities and about relations to organizational and other interfacing processes. What is more, they gained knowledge about how these processes construct the holistic understanding of the product development.

Communication & Co-Operation

Product development is also a matter of communication on multiple levels in the organizations. (Bjarnason, Wnuk & Regnell, 2011). Sales representatives discuss with customers. Product developments discuss internally in the company or between the companies, Project Managers discuss with several practitioners in the company and between the companies. There are needs for clear, unambiguous and simple ways to communicate.

Requirements Engineering is based on beforehand defined processes (Sommerville, 2013) where practitioners interact by utilizing different kind of communication methods. The basic form of managing Requirements is using Excel documents. Using the Excel is manual work with minor possibilities for automation. There are no clear possibilities to define process flows with proper rules. Excel is available for all companies and it requires less effort than deploying the proper information systems into the use.

Companies use dedicated information systems which are designed to support process flows of the Requirements Engineering. In this case, the communication happens through the Requirements documents in the system. Information on the documents contains natural plain text or illustrations in forms of pictures and models. Companies have started to share their Requirements Engineering information systems with their cooperation companies such as customers and suppliers. This increases the information sharing between the companies and makes processes work more efficiently when the information is available to all relevant companies with minor delays.

Communication within automotive companies and between the companies in a supply chain is challenging to manage due to different kind of variables. These variables are language, geographical distances and cultural backgrounds. All these variables have an impact on the communication. Language can be divided into written and spoken languages where the used terminology plays an important role. Companies have their own terminology defined when they communicate internally. (Karlsson, Dahlstedt, Regnell et al., 2007). However, interviews showed that there are cases when the company-specific terminology is also used with cooperative companies. This causes problems to communicate clearly and unequivocally.

Not all companies use English as their operating language. These companies are mostly originated in the Asian countries. In this case, the

communication should be organized through companies which offer translation services. These translation companies are not specialized in the terminology used in the automotive industry. It takes a lot of time to translate messages and later to verify that messages are translated properly. This is a time-consuming and costly process where the benefits are questionable.

Companies have realized the existence of these challenges and started to improve their ways of operating to make communication more efficient. Face-to-face meetings are seen as the most efficient way to communicate. Face-2-face meetings provide a safe environment for discussing complex and sensitive topics efficiently. This is the most commonly used form of meeting in internal meetings, and also meetings with external participants. The purpose of the communication is to transfer a message between two or several recipients. The form of the communication is not just about talking or writing. It contains an illustration of the topic. Models are used to illustrate different levels of abstraction in the system development during the product development process. (Bera & Evermann, 2014; Pohl & Rupp, 2015). However, the models are not commonly used in Requirements Engineering, and it is seen that this should be changed in the future (Liebel, Tichy, Knauss et al., 2016).

Using models is seen as one of the solutions which can minimize problems in communication. Models illustrate technical topics in a concrete way and contribute in having common understanding of the topic. (Kirstan & Zimmermann, 2010; Sikora, Tenbergen & Pohl, 2011; Mohagheghi, Gilani, Stefanescu, et al., 2013; Pohl & Rupp, 2015). All discussion participants are able to verify their understanding based on the model. Modeling requirements are considered as a factor that helps in gaining similar understanding which later decreases conflicts. This brings benefits in requirements reviewing and requirements validation. (Mohagheghi, Gilani, Stefanescu, et al., 2013). Later in the product development process, modeled requirements are used to verify the delivered product against the requirements specification. This decreases development costs and brings cost-efficiency which has a positive impact on the company's business results. (Kirstan & Zimmermann, 2010).

Organizational Culture

Product development is multi-organizational activity in the automotive industry. One company cannot implement end-2-end solutions at once, and there is a need for cooperation with other companies. The industry networks, and one company can work as a supplier for several companies. This creates a risk of information leakage to competitors of a customer company. Car manufacturers and also companies on the top of the supply chain have created a mode of operation where they do not share all the information with their suppliers. This has created a culture of mistrust where companies cannot implement their products efficiently when they do not have all the required information. This has led to the situation where supplier companies should guess what customer really needs. This creates irrelevant costs in a sense of

time and resources. This has led to the situation where products are created incrementally utilizing several prototypes.

Personnel are the key asset in product development, but there are always changes in this area. When companies face changes in personnels, it always have an impact on the project, its mission, its scope, its schedule and its budget. This creates problems during the whole lifecycle of the project, starting from the requirements gathering, through the the product delivery and till the ramp-down of the project.

Silent knowledge is seen as a threat for all companies. Interviewees mentioned that minimizing the silent knowledge brings efficiency to the product development activities. Therefore, the companies have started to decrease the risk by re-locating their employees to their partners' premises. An employee of supplier can be re-located to customer's premises – and an employee of the customer company can be re-located to its supplier's premises. This is done in order to improve the efficiency of communication and sharing knowledge between the companies. This decreases amount of silent knowledge and project can be executed more efficiently.

It can be concluded that the Requirements Engineering plays a major role in decreasing the silent knowledge based on the given information. When a systematic approach is applied in the organizations by deploying a proper process and information system, information is gathered by the process and stored to the relevant systems. Requirements Engineering is also seen as increasing the trust between the companies when the process and information systems create a transparency and possibility to follow-up the activities in both ends of the supply chain.

People Skills

Gathering customer's needs and expectations of the product should be done before they can be analysed, specified and prioritized for later processing. (Summerville, 2013). This requires that the practitioners have good communication skills. Active communication with the customer, other possible stakeholders and also with colleagues is surely required. It is not possible to write a perfect requirement at once because the customer is not able to know or to express his/her needs at once. Therefore, it is required to have a regular communication with the customer, and it is recommended to make prototypes or models to illustrate the requirements (if possible). When requirements become more concrete to the customers, they can identify more of their needs. Product development always requires cooperation with other companies.

One company is not able to implement all requirements by itself. Cooperation requires communication skills and knowledge about the content. Those are difficult tasks for people who do not have enough experience about the content. The lack of experience manifests in having requirements with poor quality. This leads to the risk of re-working and it also increases costs. (Boehm & Basili, 2001; Pohl, 2010). Because of this, companies allocate the responsibilities of Requirements Engineering to the persons who hold several

years of working experience in the industry and have a comprehensive understanding about the content and its dependencies to other projects or products.

5.2 Implications to Research

This sub-chapter defines the Proposition which was used as a background for interview questions. The definition of the Proposition is derived from the literature review. The sub-chapter ends with description of the implication to research where this study is reflected existing research studies of the area, and what new information this study has produced.

5.2.1 Definition of the Proposition: The lack of time and insufficient discussions are obstacles to understand requirements

Product Developer or Requirements Engineer does not have enough time to study and to understand the actual needs or problems described as a requirement. Lack of joint discussions between all relevant stakeholders also affects the product development process.

There are two basic expectations from all development processes. A complete and explicit set of requirements from users should be derived. Need and desires which are not identified should be determined as quickly as possible.

Product Developer or Requirements Engineer usually does not have enough time to study and to understand properly customer's needs or problems which are described as requirements. As a result, the provided implementation commonly does not fulfill customer's expectations concerning the content or the quality. Lack of proper studying on the development side can lead into increasing number of late change requests. When time is invested in studying the requirements, product quality is improved, and customer's satisfaction is greater. In addition to this, proper deliverables are enabled when the the right level of quality is achieved at the right time.

Cheng and Atlee (2007) claim that although a lot of attention is given to the core of Requirements Engineering, the method for handling requirements is not successful enough because it is still based on intuition. They also argue that development needs can only be identified by the Practitioners with no experience in software engineering when they have an insight into the final result or when they interact with it.

Requirements Engineers must have enough knowledge about products in the company's product portfolio, but emerging technologies create complexity to the products. This happens because the more products there are, the more difficult it is to handle the Requirements Engineering processes. Therefore,

uncertainty is unavoidable. When product or process related knowledge is divided among several persons, it is difficult to arrange efficient discussions within a short notice. Sharing, discussing, managing and agreeing on the same information with many persons separately has a negative impact on the work efficiency.

All of these factors lead into pressure of delayed project schedule, increased risk of late delivery and exceeding the estimated project budget. These factors may also decrease quality of the product.

(Liebel, Tichy, et al., 2016; Broy, Krüger, et al., 2007; Bjarnason, Wnuk & Regnell, 2011; Filipovikj, Nyberg & Rodriguez-Navas, 2014; Karlsson, Dahlstedt, Regnell, et al., 2007; Weber & Weisbrod, 2003; Braun, Broy, et al., 2010; Houdek & Pohl, 2000; Pernstål, Magazinius & Gorschek, 2012; Brambilla, Cabot & Wimmer, 2012; Sommerville, 2011; Cheng & Atlee, 2007)

5.2.2 Implications to Research

The study extends the knowledge from previously done research studies (Bjarnason et al., 2011; Karlsson et al., 2007; Liebel et al., 2016; Pernstål et al., 2012), and provides deeper understanding concerning the organizational challenges in Requirements Engineering in the automotive industry. This study extends and deepens understanding about challenges in the automotive organizations concerning the Requirements Engineering. Several studies are conducted in this area, but they are more focused on identifying challenges and less on proposing solutions to the identified challenges. This study focuses on challenge identification and on making proposals for existing challenges.

The identified challenges are more organizational and social in their nature than technology oriented. According to this study, challenges and solutions are more focused on people than on technology improving. This study verifies the results from several research studies (Bjarnason et al., 2011; Karlsson et al., 2007; Liebel et al., 2016; Pernstål et al., 2012) which say that having a clear and structured communication is challenging in Requirements Engineering. Messages between customers and suppliers are misunderstood or overlooked. Therefore, when it comes project schedules and budgets and when it comes to functionality and quality of deliverables, customers' expectations cannot be met.

Bjarnason (2011) identified four main factors which may cause interruptions in communication: (1) scale, (2) common views, (3) temporal aspects and (4) decision structures. The scale is defined as a size and complexity of the product development project. It is also confirmed in this study that these factors increases challenges in communication. It is found that there are multiple gaps in communication between customers or other possible stakeholders, Requirement Engineers and actual Product Developers. Gaps in communication have an impact on requirements' content and later on quality of

the deliverables. These increase costs in product development and later in product.

Mutual understanding about the scope of the project, roles and their responsibilities, and about the content of the requirements is essential for the efficient product development projects. Misunderstandings and even lack of understanding of these creates challenges in communication. There were cases when Requirements Engineers or Product Developers were not involved in the discussions where decisions were made which affected the requirements and project schedules. This finding is aligned with Bjarnason's (2011) study.

Temporal aspect was defined in a way that it focuses on the lack of continuity in requirements awareness through the project life-cycle. Lack of requirements awareness causes gaps in communication. (Bjarnason et al., 2011). There are similar findings in this study where requirements are discussed between customer and a supplier company. Challenges occur in cases when there is no common language available and therefore, translation services are used. This can create a situation where requirements are misunderstood, or parts of the requirements are missing due to a poor translation. When this happens, decision and implementation plans cannot be properly done. However, this study does not show that Developers would start to create their own requirements to fill the gaps due to faulty translations, and therefore this cannot be verified.

This study shows that companies put an effort into decision structures, which is the way they want to improve their communication practices. Companies often arrange kick-off events when projects starts. One of the purposes of the kick-off events is to clear up the visions and goals, and also to agree on high level requirements of the product development project. This is seen as an improvement according to previously done research studies. (Bjarnason et al., 2011).

This study confirms the findings from some previous researches (Bjarnason et al., 2011; Karlsson et al., 2007; Liebel et al., 2016; Pernstål et al., 2012) according to which gaps in communication can create a series of multiple serious and expensive consequences such as wasted effort or quality issues (i.e. not meeting the customer's expectations). This is noticeable first in a context of requirement and later in a context of delivered products. Gaps in communication can also be realized as overscoping of the development project and later as irrelevant work in requirements. This study aims to identify potential organizational challenges.

Four important findings are identified in this study: *Communication, Co-Operation, Organizational Culture* and *People Skills*. Each of these four findings can be considered as a starting point for research hypotheses for later research studies. These four aspects should be studied further in order to improve Requirements Engineering processes and related practices.

This study extends the findings from previously conducted research study (Liebel et al., 2016) where the challenges concerning the communication and organizational structure are studied within two companies in the automotive industry. Liebel's study also states that list of possible solutions should be investigated in order to improve the communication in organizations. Describing identified challenges can provide better understanding of the situations in which challenges occur. Additionally, identified solutions work pro-actively to minimize faults which can happen in organizations, and provide options to improve daily operations in Requirements Engineering.

The findings of this study show that there are certain patterns in organizations such as challenges in communication with customers, decreasing the silent knowledge with re-location possibilities, gaining the trust between companies in a same supply chain and required level of expertise for successful Requirements Engineering process. Additionally, a requirement can affect multiple technology areas within the company. It is important that organization structure is designed to support cooperation across technology areas in different phases of Requirements Engineering and later product development. And, therefore, there should not be silos in the organization. It is expected that the organization structure supports formal and informal communication between the involved teams or other organizational structures.

Pernstål et al. (2012) looks at *people*, *tools* and *process* categories. Their study claims that knowledge and experience gained in earlier projects must be seized, shared and reused. This kind of practice will help in having clearly defined roles and responsibilities in the product development interface. Moreover, this will improve the understanding of each other's work.

This research study agrees with the findings of Pernstål et al. (2012) that the knowledge should be shared within the company and also among the companies in the supply chain. Therefore, companies have started to pay attention about re-location of its employees. It is important to share knowledge and best practices from previous projects within organizations. These activities help in building trust among companies.

Pernstål et al. (2012) claim that when it comes to the category of process, in both companies he worked with, engineers have a tendency to delay the engineering of operation they are responsible for because they want to have a clear idea of concepts and designs of the software-intensive systems.

This study confirms claims done by Pernstål et al. (2012) that Requirement Engineers and Developers want to receive well defined requirements. Models are seen as an improvement for presenting concepts and designs in a more clear way.

Speaking about categories of tools, Pernstål et al. (2012) say that the main problem occurs within Requirements Engineering. According to that, there are difficulties related to identifying and handling requirements. Nevertheless, even when they are identified properly, the procedures and tools which should

support Requirements Engineering activities are not specified and clearly defined. Therefore, it is hard to give specific advice to practitioners because previous key studies offer very few solutions to the issue discussed.

The increased understanding about organizational challenges in Requirements Engineering and proposed solutions provide new information to researchers. Daily practices should be explored widely in scope of Requirements Engineering in the automotive industry. This would help in tackling recognized challenges and Requirements Engineering could be performed more efficiently. Lastly, it would enable cost-efficient development projects which could meet customer's expectations.

5.3 Implications to Practice

The findings have multiple implications both theoretical and in the practice. This chapter deals with the theoretical aspects related to the industry. Moreover, it will be presented how the findings can be put into practice. The aim of the study is to enable the automotive companies to enrich their Requirements Engineering practices internally and when cooperating with other companies.

The study explored multiple challenges in Requirements Engineering practicalities when operating internally or with other companies in the automotive industry. There are several challenges with a negative effect on the Requirements Engineering practices. These can even prevent using models in the Requirements Engineering. Some of the interviewees did not have previous knowledge about using models in Requirements Engineering activities. Interviewees who were aware of the modeling, mostly considered it as a tight part of the product development. There was also a fallacy that models were mostly used in software development. There was no proper knowledge about the model-based approach, therefore the awareness of the benefits of using models in Requirements Engineering was low.

In the theoretical part, backgrounds of model-based approaches and their meaning in the Requirements Engineering context were discussed. Furthermore, benefits and challenges of using Model-Based Requirements Engineering were presented. Benefits were covered by introducing eleven different perspectives. At the end of theoretical part, three model-based approaches were discussed: *Goal-Oriented*, *Object-Oriented* and *Viewpoint-Oriented approaches*. The basic properties from all of these approaches were discussed together with the methods of each approach. This theoretical aspect increases the awareness of model-based approaches in the automotive companies. Using the models in Requirements Engineering brings value to practitioners and also to Requirements Engineering in the all phases of the product development.

Beyond the theoretical contribution, the study proposed possible solutions to improve the mode of operation and to tackle the organizational challenges in

the industry. Emphasizing the solutions in findings has a positive implication to the Requirements Engineering practices in the industry.

All the participants emphasized communication as the most critical aspect in the Requirements Engineering. They also emphasized the importance of putting an effort in making it efficient. This is because the Requirements Engineering mainly consists of communication. There are many ways to improve communication in companies. Considering the re-location of the employees efficiently to the customer's premises or supplier's premises improves the formal and non-formal communication. When the communication runs smoothly, the amount of hidden knowledge is decreased. All this improves the product development and all aspects of it.

Communication improvement can be implemented both on the process-wise, and also on the information systems wise level. Improving the communication means that information flows efficiently between all the companies and internally in the company. The Requirements Engineering processes and related information systems can be integrated in a way that they stretch over the organizational boundaries. In these situations, communication is improved when the information is correct, available and up to date for all the participants in the product development. Utilizing different information systems such as Fault Management, Test Management or Documentation Management, and integrating them into the Requirements Engineering process also improves the communication.

Improving the communication from the organizational perspective can be designed and implemented in multiple ways. Companies' organizational structures are designed to support their strategic goals. These goals usually have a strong dependency on the product development.

The organization structure can be designed to be aligned with a product architecture. This means that there are organizational teams whose responsibility is to design and develop specific components for the product. The deliverables from the teams are integrated into a product which is delivered to the customer.

Other dimension for the organization is the structure which is aligned with customer's own organizational structure. This improves the proper communication across the companies when teams in the companies are able to efficiently find a counterpart of the product development from the other company.

The companies in the automotive industry operate as customer-supplier supply chain. The study identified that there could be four-leveled structures in the supply chain. One supplier company can have multiple customers, and one customer company can have multiple supplier companies. There is a network of supply chain such as suppliers of suppliers. When there is a supplier on the higher level in the structure, it is a customer for lower level suppliers. These

customer and supplier companies on the markets are competitors to each other. Therefore, the atmosphere is skeptical and there is often mistrust between the companies. Requirements Engineering process can be implemented and deployed in a way that it builds the trust between the companies. The process can be implemented in a way that all companies in the supply chain can verify the information which is available to the companies which are involved in the process. One technical solution for this is to implement so called parent-child documentation structure for requirements. It means that the parent requirement is a customer requirement. It reflects the customer's perspective of the need. The parent requirement is divided into one or several child requirements. The child requirement reflects the supplier's perspective on how the customer requirement will be implemented by the supplier, and when it will be done. When following the progress of the child requirements, the customer is able to gather the overall view of the progress of the requirements' implementation. Transparency of available information and ability to track the activities in the process can increase the trust between the companies.

It was seen as a challenge in many cases that sales people who negotiate the project contract and the scope of the project (including high-level requirements), are the ones who do not develop actual solutions to fulfill customers' needs. This is a risk for the deliverables agreed with the customer. It also creates risks concerning project schedule and budget. Therefore, it was proposed that companies should involve more roles into negotiations in an early phase. People who hold technical knowledge about the product development, existing product portfolio and expected product delivery should be involved. The internal communication is improved both in the customer and supplier companies during the whole project lifecycle when customer's requirements are gathered and specified in a quality way.

Finally, the interviewees expressed their interests to understand more concretely the benefits and practices of modeling in Requirements Engineering context. This would support the practitioners to utilize and to apply the gained knowledge in their daily practices. This should motivate researchers to continue to study modeling in Requirements Engineering, and it should support practitioners to improve daily Requirements Engineering practice. This will pay off as an improved Requirements Engineering practices. It enables efficient product development projects which have a better predictability in terms of the budget and schedules. Predictability also secures development of products which cover the needs of the customers with the highest quality and with lower development costs.

6 CONCLUSIONS AND FUTURE RESEARCH

This chapter concludes and summarizes the study. In this chapter, the summary of the study is discussed with the summary of the contribution. Also, the limitations of the study are discussed from the multiple angles. The chapter ends with proposals for possible future research topics for the area.

6.1 Summary of the Study

This research study provides an overview focusing on the organizational challenges in the Requirements Engineering process area in the automotive companies. The aim of the study is to increase the knowledge about the organizational challenges related to the model-based approach in the Requirements Engineering process.

The Introduction chapter is followed by the Theoretical Background chapter in which the narrative outlining is started. The chapter consists of two parts. The first part describes the Requirements Engineering process from the general perspective. The importance of Requirements Engineering for the product development is highlighted in the paper. It is also emphasized that when Requirements Engineering processes fail, there are negative consequences which manifest in increased project costs or delayed schedules. Those are caused by the failures in content of requirements when the requirement's specification is overlooked and does not meet consistency, completeness and correctness quality criteria.

Challenges concerning the Requirements Engineering are twofold; there is identifying customers' needs and specifying them in a form of requirements. This is seen as a challenge from the content perspective. From the process-wise perspective, defining the comprehensive Requirements Engineering process is challenging or even impossible to do. Therefore, it is proposed that the

Requirements Engineering process should be a chunk of processes instead of a single end-2-end Requirements Engineering process.

Model-Based Requirements Engineering approach is described in the second part of the chapter. It started by discussing the definition of models and the backgrounds of the Model-Based Requirements Engineering. After this, the actual Model-Based Requirements Engineering is described.

The benefits of using Model-Based Requirements Engineering is discussed from eleven perspectives. The perspectives were gathered from multiple academic studies so as to provide a wider view of the topic.

The main challenges in model-based approach can be divided into two perspectives, challenges concerning both modeling and analyzing the requirements and challenges which are created by the operational environment. This sets challenges for the suitable modeling notation language. There are also other challenges which are related to available modeling tools when they are not reliably supporting code generating for the functions of safety-critical behavior.

Situations or expectations when the Model-Based approach should be considered are covered from four perspectives. The perspectives cover how the models can be utilized in different phases of the Requirements Engineering process and they cover the benefits of using models in that certain phase. Combining a natural text with models in requirements creates advantages. The natural text clarifies and supplements the description of the model.

Three different model-based approaches are described: *Goal-Oriented*, *Object-Oriented* and *Viewpoint-Oriented*, since it is important to have knowledge about different modeling approaches. Those approaches are chosen due to their generality and coverage for the requirements specification phase.

The empirical research methods are discussed in the Chapter 3. The research study is structured in a way that there are three phases and the research activities in each of these phases are discussed. The phases were discussed in a chronological order. This is done in order to have clear structure of the study.

It is explained how the literature was selected and how it was reviewed. The actual research data was gathered by arranging several unstructured interviews in multiple automotive companies across the Europe. The process of the defining the interview questions through the literature-based Proposition is also represented.

The interview session is divided into four parts which cover introduction, demographic questions, actual topic questions and session closing. After the interviews, the recorded data was transcribed into 389 pages.

Thematical Data Analyzing method is used for analyzing the transcribed data. The data analyzing is done in two cycles which provide better visibility of the gathered data.

The Findings based on the data are discussed in the Chapter 4. Based on the Thematical Data Analyzing method, the Findings are divided into three categories: *Communication & Co-Operation*, *Organizational Culture* and *People*

Skills. All these main categories include sub-categories such as *Challenges* and *Solutions Proposals* which describe identified challenges and also solution proposals for the challenges.

The research study has two research questions. The questions are answered in the Chapter 5. This chapter also discusses the implications to the previous research studies and to the daily practices in the automotive industry.

Summarization of the research study and conclusions are presented in the final chapter. The limitations of the study are discussed from the five validity perspectives. The chapter ends by making propositions for the further research topics in the field.

6.2 Summary of the Contribution

The research contains two research questions concerning the Requirements Engineering practices in the automotive industry. The answer to the first research question was found in the literature review. The literature review introduced two theoretical aspects of Requirements Engineering. The first part of the literature review discusses Requirements Engineering in general. The second part of the literature review focuses on the Model-Based Requirements Engineering.

The literature review introduces three different definitions for Requirements Engineering. The Requirements Engineering process can be divided into two major sub-processes: Requirements Development and Requirements Management. Those sub-processes are described as process charts.

There are three main sources for the requirements: (1) existing documentation, (2) stakeholders and (3) other systems in operation. The sources are discussed in detail. Requirements can be classified under two main types: customer requirements and implementation requirements. The classification is based on the content of the requirement.

The importance of the Requirements Engineering should not be underestimated. It has impact on project schedule, budget, scope and quality. If Requirements Engineering activities are properly managed, there are better chances that project costs will be decreased.

Models are beneficial for improving Requirements Engineering. Models can graphically fulfill the requirements which are normally written as natural textual language. The benefits of using models in the Requirements Engineering are comprehensively discussed from multiple aspects.

Challenges of model-based approach are related to the abstraction level of requirements definition. When a clear definition of the content of the requirements is given, challenges related to the product development are decreased. Requirements should be consistent and manageable in the end. The model-based approach is dependent on the development tools and their

vendors. It is notified that there is suspiciousness in the industry when it comes to development tools.

The answer to the second research questions was studied by organizing 22 semi-structured interviews in 11 different automotive companies in Europe. The findings are categorized under three main themes: (1) Communication & Co-Operation, (2) Organizational Culture and (3) People Skills. All the findings describe challenges in the companies own organizations or in a co-operation with external companies as called as suppliers.

The implications to research set a literature-based definition of the Proposition which is used to define the interview questions for the field study. The Proposition is two-sided and argues that product developer or Requirement Engineer do not have enough time to study the content of the requirement as thoroughly as it is needed. The other argument is that there are problems in communication within the relevant parties who should be involved in the product development process.

The study extends the knowledge from the previously conducted research studies concerning the challenges in the Requirements Engineering in the automotive industry. This study also reflects its findings on multiple previously completed research studies.

The study has multiple implications to practice. From the theoretical aspect, the study discusses benefits of model-based approach. It was notified during the interviews that practitioners were not aware of the benefits of model-based approach when specifying the content of the requirements. In addition, different kind of approaches for model-based Requirements Engineering were not recognized in the companies. The study discusses three different ways of using model-based approach: (1) Goal-Oriented, (2) Object-Oriented and (3) Viewpoint-Oriented. These are beneficial to companies which want to get more involved in Model-Based Requirements Engineering.

The study discusses proposals for improving the situation in the companies and how to solve the challenges. Studying these issues is pivotal for improving companies' operations in the area of the Requirements Engineering. This will make processes more efficient and it will reduce costs when it comes to high-quality content of the requirements.

6.3 Limitations

This sub-chapter discusses five different aspects of the research study limitations. The limitations are classified into construct, internal, external validity, reliability and conclusions validity as discussed in Yin (2014).

6.3.1 Construct Validity

Construct validity reflects the accuracy of the analyzed measures which are generalizable to the concepts being studied. This means that the constructs which were used in the research study, such as terminology, abbreviations and their definitions, are interpreted in the same way by the researchers and the interviewees. Construct validity describes that the data collection was done in a neutral manner. This means that the interviewees were not influenced by the presence of the researcher and the interview questions were not asked in a way that induces a certain answer. (Yin, 2014).

The interview guide was designed by the researcher and discussed together with the supervisor and the practitioner from the Virtual Vehicle Research Center. They hold several years of experience in the research studies in the automotive industry.

The data was collected by arranging 22 interviews. The interviewees were selected from 11 different automotive companies in six European countries. This is done in order to avoid mono-operation bias.

In hypothesis guessing, the interviewees might try to guess what the researcher is aiming for and then answer accordingly, but this cannot be ruled out completely. An effort was put in order to formulate questions in a neutral way so as to avoid leading the interviewee to answer in a desirable way. Ambiguities in terms and definitions were reduced by reviewing and refining the interview questions. This was done to ensure the clarity of the interview questions and also to remove suggestive questions. The interview questions were improved based on received feedback from the pilot interview in order to minimize this threat. Finally, the recorded data from the interviews were treated completely anonymously in order to avoid biased answers due to evaluation apprehension.

The interviewees were contacted through the personal contacts in the automotive companies and they participated on a voluntary basis. At the end of most of the interview sessions, some interviewees proposed other persons to be contacted to participate in the study. Interviewees were granted the anonymity and the option to review and comment their transcribed interview before the analyzing phase was started.

6.3.2 Internal Validity

When causal relations are analyzed, internal validity reflects whether all relations are examined or whether there are unknown factors or variables which might affect the outcome. It is impossible to study all contextual factors and variables in a qualitative study, even when the context is a large automotive industry. (Yin, 2014).

Numerous measures were used to defend the internal validity of the study. The data Triangulation was used throughout the data collection and data analysis. Multiple roles in several companies were covered by the research study in order to have an extensive approach to the problems and to offer suitable solutions.

In order to ensure internal validity during the data collection process, all the interviews were implemented by following agreed interview guide. Due to the nature of the semi-structured interviews, there were multiple follow-up questions which were asked depending on the discussions and interviewees' answers.

Selection threats could not be excluded because there were few companies where one contact person proposed potential interviewees. To address this, the participation in the interviews was fully voluntary. In addition to this, all interviewed persons had a possibility to nominate persons who could be contacted and asked if they were interested in participating in the research study.

The maturity of the Requirements Engineering processes and other practices varied between the companies. It is considered as a validity threat when problems and solutions cannot be identified due to unmaturing processes and practices. This issue could be addressed in a follow-up study.

6.3.3 External Validity

External validity discusses the generalizability of the research study findings. (Yin, 2014). The companies which participated in the research study operate in the automotive industry which can be classified as a major sub-domain of the embedded systems domain. The demographic data of all interviewees was collected in order to confirm this aspect. The participants with different backgrounds in the automotive industry were targeted for this research study. The samples covered the participants who work in Europe, and some of them work in companies which operate worldwide. Therefore, the research study states that this does not limit the validity of the results and it is possible to generalize them to other research studies outside of Europe.

External validity also discusses the level of degree to which the results of the research study can be generalized to a wider context. In general, the external validity in case studies is low. It cannot be said that the presented problems and proposed solutions are general in the automotive industry or even in a wider context in the embedded systems domain.

The fact is that most of the participants from different companies were able to identify similar problems and also were able to propose similar solutions. This shows that the companies face similar problems regularly and also recognize them as relevant. This is an indicator that the findings of the research study are to some extent generalizable.

The research study states that the findings are generalizable in the areas of automotive industry in terms of constraints and the scope. Those areas might be heavily regulated systems engineering domains which have a strong business operations of value creation between car manufacturers and a chain of suppliers. They might face similar problems and probably have found similar solutions in their engineering practices.

6.3.4 Reliability

Reliability discusses how findings of the research study are dependent on the researchers who conducted it. The question is if another researcher replicates the study, will the outcome be same as in the original study. (Yin, 2014).

When it comes to the case study design, these aspects must be reviewed: research study design, data collection instrument and interview design. The reliability of measures was increased by organizing a pilot interview with two persons. The interview questions were improved and later reviewed by three researchers. Subjective judgment was avoided by transcribing the recorded interviews word by word.

The two-cycling coding method for transcribed interviews used in data analysis was advised by the thesis supervisor. The research study tried to address subjectivity by comparing identified findings within the literature. These actions should reduce reliability threats. However, a certain degree of subjectivity cannot be avoided when it comes to the abstraction and categorization of the coding.

6.3.5 Conclusions Validity

Conclusion validity discusses the ability to draw correct conclusions from the studied data. (Yin, 2014). There were four researchers involved in the whole case study design, covering interview design. Their participation and expertise was supposed to reduce the risk of manipulating the participants. The interview questions are published to enable the replications and assessment of the validity of the research study. The research study did not have any purpose to aim for specific results.

6.4 Further Research Topics

Awareness of Model-Based Engineering practices varies among the practitioners in the automotive companies. During the research study, it was notified that many supplier companies were not aware of the existence of Model-Based Engineering practices or did not use them, even though their customers might be using the approach for their Requirement Engineering activities. The same companies mostly follow an old-fashioned waterfall model to lead their product development process. In those companies, Requirements Engineering process was mostly based on documents which are written in natural languages. Therefore, it should be studied how to make companies be aware of the Model-Based Engineering and its possibilities to support product development in the automotive industry.

The companies which follow Model-Based Engineering practices to support their Requirements Engineering, often limit the use of modeling to informal or semiformal notations. Using formal models in a wise way improves requirements elicitation and requirements specification phases. This supports verification activities both in requirements and product verification phases and later reduces development costs. It was stated by practitioners during the interviews that the amount of modeling is unclear in different phases of Requirements Engineering. Therefore, the future work should introduce in a systematic way how models should be used. A possible research area is the way awareness of Model-Based Engineering practices can be improved in the automotive industry covering many different artefacts, abstraction levels in different organization levels. Furthermore, the way the theory of Model-Based Engineering use is built, and the way Model-Based Engineering can be deployed to the industry are seen as advantages.

According to the interviews, both electrical and mechanical engineers have an important role in the product development process. The way their needs for the Requirements Engineering process can be more focused in a context of Model-Based Engineering depends on the organizational-wide research studies where both Model-Based Engineering and Requirements Engineering approaches are covered in a sense of organizational-wide mode of operation.

It was notified during the literature review that current studies concerning the area are shattered. Therefore, the systematic mapping approach for publications concerning the Model-Based Requirements Engineering should be studied. This will help later research studies in gaining better overview of the research area and its current gaps.

The research study shows that the viewpoints of product developers and line managers differ during the Requirements Engineering process. Product developers can have more realistic views on required time, resources and

details for specifying the implementation. However, managers have more accurate understanding related to budget, agreements with customers and project schedule. Both viewpoints should be studied to create a wider understanding on the organizational obstacles in the Requirements Engineering. Similar organizational challenges can also exist in other domains of embedded systems development and not only in the automotive industry.

Bjarnason et al. (2011) and Liebel et al. (2018) studied challenges in a communication of Requirements Engineering. According to them, there is a need to continue the work on building a theory on the influence of organizational challenges in the Requirements Engineering. This can be seen as a factor for improving the efficiency of Requirements Engineering process.

The studies concerning Requirements Engineering are more focused on proposing new techniques or guidelines. The replication of previous studies in different industries should be implemented in practice where actual practitioners are involved as participants, not just research subjects. Practitioners have more insights into the industry and therefore they should be involved more in both problem identification and solution proposal phases.

Currently, V-model is highly used in the automotive industry as a de facto model for the product development process. Actually V-model is slightly modified development model-based on the traditional Waterfall model. The focus is moving from cars development towards software development. This is caused by the increasing speed of development cycle and also provided services by a car. Therefore, the automotive companies have interests to move their way of operating towards the way ICT industry has been operating for years. That is why the automotive industry have shown their interests to move towards Agile ways of working. For this reason, the automotive companies have started to study the meaning of Agile practices deployment in daily operations. This fundamental change creates interesting research opportunities, such as how Agile based the mode of operation can be deployed into use in the automotive industry. What kind of challenges exists in the area of Requirements Engineering? A comparison of these should be studied between the automotive industry and ICT domain.

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APPENDIX 1 CATEGORIZED PROBLEMS IN REQUIREMENTS ENGINEERING LITERATURE

Problem Category	Identified problems from the literature
Changing World	<p>Long lead-times in Requirements Development phase with a changing technology demands are increasing a number of later change requests.</p> <p>Product developer does not have enough time to study and to understand a context of requirement properly.</p>
Content of Requirements	<p>It increases complexity and therefore challenges in the organizations when requirements are written as natural language text.</p> <p>Using different abstraction levels of the information, it increases misunderstandings of requirements' content within the organizations.</p>
Co-operation with external companies - Communication aspect	<p>It is challenging to find a competent person to talk with between a company and external supplier company in a manner of Requirements Engineering processes</p> <p>It is challenging to arrange a proper discussion and feedback possibilities between the company and external supplier company in a manner of Requirements Engineering processes.</p>
Co-operation with external companies - Process aspect	<p>Requirements Engineering with external supplier companies can cause problem situations both in process-wise and organizational efficiency wise.</p> <p>Late change requests for requirements can cause problem situations both in Requirements Engineering process-wise and organizational efficiency wise.</p>
Customer involvement	<p>Customer does not have enough time to study and to understand his needs and actual problems behind of the requirement.</p>

Information Systems	<p>There are insufficient tools support available for executing Requirements Engineering processes in the organizations.</p> <p>There is a legacy software available and used for executing Requirements Engineering processes in the organizations</p> <p>Communication about requirements with external supplier companies is not supported in used Information Systems in Requirements Engineering process.</p> <p>Exchanging Requirements Engineering process related information (such as life-cycle statuses) is not supported in used Information Systems in Requirements Engineering process.</p>
Internal Communication	<p>Communication has a crucial role in the organization efficiency. Gaps in communication can cause a number of problems, e.g. delays in project schedules, insufficient quality of the outcome of Requirement Engineering processes.</p> <p>It is not instructed and trained enough how Model-Based approach should be applied in Requirements Engineering processes.</p> <p>Both unclear vision and unclear goals in the organization's strategy increases challenges in Requirements Engineering processes.</p> <p>It is challenging to arrange a proper discussion and feedback possibilities within a company in a manner of Requirements Engineering processes.</p>
Mode of Operation	<p>Engineering staff proceeds more in ad-hoc manner than in a structured process way.</p> <p>When many internal stakeholders are involved in Requirements Engineering, it can cause problem situations both in a process-wise and organizational efficiency wise.</p>
Organization structure	<p>Organization structure and internal communication practices are not designed to support Model-Based approach in Requirements Engineering processes.</p> <p>It is challenging to find a competent person to talk with within a company in a manner of Requirements Engineering processes.</p>

Portfolio Management / Product Management (externally)	There are gaps in understanding between a company and external supplier company, how implementation fits into overall product, service or delivery.
Portfolio Management / Product Management (internally)	There are gaps in understanding within a company, how implementation fits into overall product, service or delivery.
Requirements Engineering process	<p>All defined roles and their responsibilities do not cover overall Requirement Engineering processes in the organization.</p> <p>Waste level in bureaucracy with rigid Requirements Engineering processes and practices, decreases organizational efficiency in many aspects</p>
Training	<p>It is not instructed and trained enough how Model-Based approach should be applied in Requirements Engineering processes.</p> <p>Employees in the organization do not have a proper understanding of required roles and their related responsibilities in Requirements Engineering processes.</p> <p>Employees in the organization do not have a proper understanding of required tasks and related activities in Requirements Engineering processes.</p> <p>It is challenging to find a competent person to talk with within a company in a manner of Requirements Engineering processes.</p> <p>The automotive companies often use some kind of Model-Based approach, but they are not usually aware of it.</p>

APPENDIX 2 INTERVIEW QUESTIONS

Part A, Introduction:

- The interviewer shortly presents the topic and the research questions (2-3 min)
- The interviewer points out that the interview is anonymous.
- The interviewer asks for permission to record the interview, in order to facilitate data analysis later on.
- The interviewer also points out that the interviewee will receive the transcribed interview once it is available and may review it and/or object to some of the stated points. In this case, the interviewers may not use these parts of the data.
- Finally, the interviewer points out that the final data analysis for each company will be discussed with the contact person at the respective company and possibly with the interviewees as well, if desired.

Part B, Demographic Questions:

1. In which role do you work at [Company]?
2. Could you shortly introduce your work at [Company]?
3. How long have you worked in your role?
4. In which other roles have you worked before?
5. How much working experience do you have in years?
6. What is your level of education?

Part C, Topic Questions:

1. Could you shortly describe your role in Requirements Engineering at [Company]?
2. What kind of other roles and responsibilities there are in Requirements Engineering practices?
3. How would you describe a role and responsibilities of Requirements Engineer?
4. What kind of activities there are in Requirements Engineering practices?
5. How do you make sure that you have understood correctly the needs or problems described as a requirement?
 - a.SUB: What kind of practices or techniques do you actually use to analyze the needs or problems?
 - b.SUB: How important discussions are organized with customers?
6. What kind of practicalities do you have to support communication and decision-making for Requirements Engineering practices? (E.g. discussion forums, idea sharing workshops)

7. How all important discussions, concerning Requirements Engineering practices, are organized?
8. Which practices are advised by [Company] concerning Requirements Engineering?
9. How do you follow advised and trained Requirements Engineering practices?
 - a. SUB: Do you think that advised practices are useful?
 - b. SUB: How should they be improved?
10. What kind of trainings are available for you when you are working with requirements?
 - a. SUB: What kind of Requirements Engineering trainings you have already participated?
 - b. SUB: What kind of other Requirements Engineering trainings there are available?
11. How is your workload balanced between Requirements Engineering related topics and other work topics?
12. Which practices in Requirements Engineering do you apply to ensure a good quality for the product?
13. How the end product is described/illustrated to you when planning an implementation or solution?
14. How do you make sure that you have understood correctly how the implementation serves overall product?
15. How do you make sure that all stakeholders are heard within product development process?
 - a. SUB: How important discussions are organized with stakeholders?
16. Which practices in product development process do you apply to ensure a good quality for the product?
17. How important discussions are organized, which are relevant for effective product development process?
18. How Requirements Engineering practices are aligned with product development process on daily basis?

Part D, Finish:

- The interviewer thanks for the participation.
- The interviewer asks the who else could be interviewed for the research?

The interviewer encourages the interviewee to come back with any comments or questions after the interview, if they may arise. Interviewer gives a contact details to the interviewee.

APPENDIX 3 THEMES BASED ON THE INTERVIEWS

This Table depicts identified Themes in the 1st and 2nd cycle, based on the interview data conducted during the Thematical Data Analyzing phase.

Identified Themes on the 1st Cycle	Identified Themes on the 2nd Cycle
Challenge: Communication using Excel files	Challenges: Communication & Co-Operation
Challenge: Conflicts in understanding the requirements	
Challenge: Co-operation within a customer	
Challenge: Foresight of the future	
Challenge: Internal communication	
Challenge: No modeling for Requirements	
Challenge: Reviewing of Requirements	
Challenge: Risks of misunderstanding due to used languages	
Challenge: Roadmapping	
Challenge: Terminology	
Solution: Active follow-up	Solutions: Communication & Co-Operation
Solution: Agreeing requirements with a customer	
Solution: Communication in English	
Solution: Concept creation for possible products	
Solution: Confirming assumptions	
Solution: Co-operation process with customer	
Solution: Documents reviewing	
Solution: Documents sharing	
Solution: Formal Requirement documents	
Solution: Initial Use Cases	
Solution: Internal discussions	
Solution: Iterative software updates	
Solution: Meeting practices	
Solution: Modeling Requirements	
Solution: Multi-organizational co-operation	
Solution: Own documentation	
Solution: Presentation practices	
Solution: Prototyping with a customer	
Solution: Reference products	
Solution: Responsibilities with customer	
Solution: Reviewing practices	
Solution: Shared documentation with customer	
Solution: Software design descriptions	
Solution: Tight co-operation with a customer	
Solution: Understanding a customer's business	

Solution: Verifying understanding with a customer	
Solution: Working in customer's premises	
Challenge: Cultural differences	Challenges: Organizational Culture
Challenge: Lack of trust between parties	
Challenge: Personnel changes	
Challenge: Silent knowledge	
Solution: Lack of trust between parties	Solutions: Organizational Culture
Solution: Open communication culture	
Solution: The value of customer	
Challenge: Conflict with customer	Challenges: People Skills
Challenge: Missing expertise in writing a requirement	
Solution: Own judgement	Solutions: People Skills
Solution: Previous experiences	
Solution: Right level of expertise for discussions	