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HOW REQUIREMENTS DEVELOPMENT COULD SUPPORT DESIGN OF EFFECTIVE AND RESOURCE-EFFICIENT OFFERINGS

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“Better a diamond with a flaw than a pebble without.”

Confucian scholar from the Ming Dynasty, 1540-1620

ABSTRACT

What a company offers its customers has to fulfil several different needs, desires, constraints, which can originate from multiple different sources that affect the offering throughout its life cycle. All these criteria have to come together and be translated into statements that can support the designer's understanding of the offering's purpose. This translation is done through a requirements development process to provide a controlled process to define statements that describe what the offering is supposed to fulfil.

This research provides insights on key challenges and success factors in requirements development to support the design of effective and resource-efficient offerings. Namely, it identifies crucial sources and aspects to be considered, and a requirements development process demonstrating how to overcome identified challenges. By getting the requirements right from the beginning, sub-optimisation and unnecessary time and risks can be avoided. The consideration of accurate sources and aspects is considered to be one of the most important factors for the successful design of offerings. It is also in the earliest phases of design, that is to say requirements development, where one has the greatest possibility to affect the environmental impact of the offering. What is missing, however, is sufficient and appropriate support in industry on how to do so.

The gap between the three areas of *effectiveness and resource efficiency*, *design of integrated offerings*, and *requirements development* has been investigated. Results are based on findings in the literature and in industry, identified primarily by qualitative studies. In the research, 15 different companies have been included through a number of interviews and discussions.

Key sources and aspects to consider in the requirements development process are identified along with challenges, and success factors that can be utilised to overcome the identified challenges. This research's final results include an adapted requirements development process that considers the earlier-mentioned *sources and aspect*, *challenges*, and *success factors*. Such a requirements development process should support the design of effective and resource-efficient offerings.

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This thesis is a personal victory and a milestone in my life that I never thought would mean so much to me. I have come through this journey as a stronger person and with a truly professional sense of mind. An endless number of hours and about 1,000 cups of coffee later, here I am, already starting to sob before I have even finished this paragraph.

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*To my wonderful grandma who did not have the chance to be a part of this journey,
you are in my heart forever.*

APPENDED PAPERS

The following papers were written during the research and set the foundation for this thesis:

- Paper 1:** Nilsson, S, & Lindahl, M, 2016, A Literature Review to Understand the Requirements Specification's Role when Developing Integrated Product Service Offerings, *Procedia CIRP*, 47, pp. 150-155, doi: 10.1016/j.procir.2016.03.225
- Paper 2:** Wiesner, S, Nilsson, S, & Thoben, K-D, 2017, Integrating requirements engineering for different domains in system development – lessons learnt from industrial SME cases, *Procedia CIRP*, 64, pp. 351-356, doi:10.1016/j.procir.2017.03.013
- Paper 3:** Nilsson, S, Lindahl, M, & Sundin, E, Integrated Product Service Offerings – Challenges in Setting Requirements, Draft (submitted 10th of October 2017 to *Journal of Cleaner Production*)

Contributions in the papers:

Paper 1: The author of this thesis solely carried out this review (Systematic Literature Review 1), and the paper was to about 95% written by her. The co-author supported in the research process and supported with background knowledge in the area, framing and scope.

Paper 2: This paper was prepared in collaboration between the authors, from idea to submission. Each author contributed with cases as well as knowledge from their own expertise. The author of this thesis contributed specifically with the idea to focus on SMEs, and also added the sustainability aspects of providing integrated offerings. The author of this thesis also contributed with one of the use cases (that originated from Interview Study 1), and wrote about 30% of the text in the paper.

Paper 3: The literature review and the company cases were based on results from Systematic Literature Review 2 and Interview Study 1. The author of this thesis wrote the main draft of the manuscript. Co-authors supported the work along its process, and especially with rewriting and reworking when revising the paper after the first submission.

OTHER PUBLICATIONS

Following papers were also written during the research process:

- Paper 4:** Nilsson, S, Jensen, J, Björkman, M, & Sundin, E, 2016, 11 Rules of Design for Manufacturing when producing pre-impregnated carbon fiber-reinforced plastic components – an application at SAAB Aerostructures, SAE Technical Paper 2016-01- 2124, 2016, doi:10.4271/2016-01-2124
- Paper 5:** Sundin, E, Nilsson, S & Björkman, M, Design for Manufacturing and Assembly (DFM/A) methodology concerning products made in composites of Carbon Fiber Reinforced Plastics, Draft (submitted 30th of June 2017 to International Journal of Production Research)

DEFINITIONS AND CONCEPTS

The definitions and concepts that are essential for this research are presented here.

Actor: An individual, group or organization that plays a specified role in interacting with an offering (IIBA, 2015).

Aspect: In this thesis, an aspect implies a statement, for example information, a need or a constraint, before it has been processed in a requirements development process into a requirement.

Circular economy: “A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times...” (Ellen MacArthur Foundation, 2015, p.2).

Effective and resource efficient: In this research, this concept implies *using the right resources the right way*, meaning reducing the amount of needed raw material in order to reduce the total environmental impact, but these resources need to be used carefully. The concept is further discussed by, for example, Abukhader (2008) and Hay et al. (2017).

Environment: “Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships.” (ISO 14001, 2015, p. 2). The surroundings can extend to the local, regional, and global systems. Biodiversity, ecosystems, climate, and so on can be terms used to describe the surrounding.

Design process: In a generic design process, the required activities have to be organised in a meaningful way that forms a clear structure of main phases and specific working steps, so that the work flow can be planned and controlled (Pahl et al., 2006). Examples of phases could be *to identify the need, plan for the design process, develop requirements specifications, develop concepts, and design the offering* (Ullman, 2002).

Integrated Offering (also referred to as offering): An offering is an integrated system consisting of a combination of different subsystems and/or individual elements such as software, services or products, where the elements have been designed to be integrated and optimized from a life cycle perspective in relation to customer value (Meier et al., 2010). Instead of selling physical products, an offering provides functions, service and performance (Sundin et al., 2006).

Life cycle: The progress from raw material to disposal and life cycle phases can include, for example, design, resource extraction, production of materials, manufacturing, use and end-of-life activities (Rebitzer et al., 2004). The life cycle concept is an approach to products, processes and services where all life cycle stages have environmental and economic impacts (Fava and Weston, 1997).

Product: A product can be referred to as any type of element that has a marketable value, but is in this thesis only implies physical items as according to Goedkoop et al. (1999, p.

111), that is “A tangible commodity, manufactured to be sold in large quantities. It is capable of falling onto your toes and of fulfilling a user’s need”.

Service: Services are activities or benefits, tangible or intangible, which are offered for sale or provided in connection with products (Regan, 1963).

Software: “Computer programs, procedures, and possibly associated documentation and data pertaining to the operation of a computer system” (ISO/IEC/IEEE 24765, 2010, p. 329).

Source: Defined in ISO/IEC/IEEE 24765 (2010) as “an item or activity having a potential for a consequence”. In this research, this means that the source is the origin of aspects that later are translated into requirements.

Sustainable development: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 41).

Requirement: “A statement that translates or expresses a need and its associated constraints and conditions” (ISO/IEC/IEEE 15288, 2015, p. 8).

Requirements attributes: Each requirement contains the main requirement statement, and additional information can be added with so-called *Requirements attributes* (Hull et al., 2011).

Requirements development: A set of activities that involve collecting the needs and constraints of relevant actors and translating them into requirements, and documenting them in a specification describing what the offering is supposed to fulfil (Wiesner et al., 2015).

Tool: An instrument that enables the performance of a certain task (Reinhart et al., 2014).

Traceability: Traceability ensures that it is clear where the requirement came from, what requirements are related to it, and what requirements were derived from it (Hull et al., 2011).

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1. INTRODUCTION

This chapter introduces the research subject, with background challenges for manufacturing companies and how utilizing requirements development to support the design of effective and resource-efficient integrated offerings can approach these challenges. The objective and research questions used to investigate this subject are also presented. The chapter ends with a description of the research's delimitations and an overview of the thesis's content.

1.1 BACKGROUND

Manufacturing companies are continuously working on staying competitive in the market. The challenge, however, is to keep up with rapid technological change (Chang et al., 2013). Within this challenge, time to market has been a struggle since even before the 21st century, as stated by, for example, Smith and Reinertsen (1998), and is still no less important. Another challenge for companies is to identify an appropriate balance between both quality and cost-effective businesses (Kossiakoff et al., 2011). Pressure also comes from, for example, the United Nations within the Sustainable Development Goals for 2030, where one goal is to *ensure sustainable consumption and production patterns* (United Nations, 2015). This goal includes, among others, the *efficient use of natural resources and reduces waste generation through prevention, reduction, recycling and reuse*, which directly imply moving towards a circular economy, that is *"one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times..."* (Ellen MacArthur Foundation, 2015, p.2). To enhance, for example, the reuse of a more durable product will reduce breakdowns and both enable reuse and prevent unnecessary waste. Breakdowns and waste are thus becoming important topics, where effectiveness and resource efficiency are highly relevant (European Commission, 2014). As regulations push manufacturing companies to consider aspects of sustainability in their operations, they must meet challenges with new prerequisites and still find ways to create revenue within these boundaries.

1.2 EFFECTIVE AND RESOURCE-EFFICIENT OFFERINGS

The challenges mentioned above (for example, keeping up with rapid technology changes, time to market, balancing quality and cost, and reducing the need for raw materials) are met by manufacturing companies through developing holistic solutions, that is, offering customers more than just an individual product. A product can be referred to as any type of element that has a marketable value, but hereafter in this thesis it will only imply the physical item, in accordance with the definition by Goedkoop et al. (1999). An offering is an integrated system consisting of a combination of different subsystems and/or individual elements such as software, services or products, where the elements have been designed to be integrated and optimized from a life cycle perspective in relation to customer value (Meier et al., 2010). Instead of only selling physical products, an offering provides functions, service and performance (Sundin et al., 2006).

As offerings are designed as holistic solutions, it is often considered that offerings are a way toward more effective and resource-efficient solutions with less impact on the environment¹ (see, for example, Tukker and Tischner (2006) and (Lindahl et al., 2014)). In this research, the

¹ Environment in this research follows the definition from ISO 14001 (2015, p. 2) *"Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships"*.

term *effective and resource-efficient* refers to *using the right resources the right way*, and means reducing the amount of needed raw material in order to reduce the total environmental impact, but these resources need to be used carefully (Abukhader, 2008, Hay et al., 2017).

1.3 DESIGN OF INTEGRATED OFFERINGS

The design of integrated offerings requires collaboration between several disciplines, for instance mechanical engineering, computer science and service engineering, in order to be successful in integrating the offering's different elements to together fulfil a common purpose (Lindahl and Sundin, 2012). When designing an offering, there is the implication of a change in what is expected from the included elements compared to when they are designed individually. In a generic design process, the required activities have to be organised in a meaningful way that forms a clear structure of main phases and specific working steps, so that the work flow can be planned and controlled (Pahl et al., 2006). Examples of phases could be identifying need, planning for the design process, developing requirements specifications, developing concepts, and designing the offering (Ullman, 2002).

1.4 REQUIREMENTS DEVELOPMENT

A part of the design process is to develop the requirements specification (Ullman, 2002). According to ISO/IEC/IEEE 15288 (2015, p.8), a requirement is defined as "A statement that translates or expresses a need and its associated constraints and conditions". This translation of needs and constraints is conducted in an activity commonly called requirements development (Ulrich and Eppinger, 2011). Anything before that translation is referred to as an aspect; examples include information, needs and constraints. Requirements development, therefore, consists of a set of activities that involve collecting the needs and constraints of relevant actors and translating them into a specification describing what the offering is supposed to fulfil (Wiesner et al., 2015).

The translation referred to in the definition is done through a requirements development process. This process becomes complex when designing integrated offerings with requirements originating from several different sources that provide a huge amount of aspects that need to be considered (Vasanth et al., 2012). As defined in ISO/IEC/IEEE 24765 (2010), a source is "an item or activity having a potential for a consequence". In this research, this means that the source is the origin of aspects that later are translated into requirements. As illustrated in Figure 1, the early stages of the design process have a high impact on the final performance of the designed offering (Lindahl, 2005, Lindahl and Sundin, 2012, Ullman, 2002); something sometimes referred to as the design paradox. One could actually reduce the offering's total design time by spending more time on developing the requirements and truly putting an effort on understanding the involved actors' needs, desires, demands, constraints, and so on (Lindahl and Sundin, 2012).

Figure 1 – Illustration of the design paradox (Lindahl and Sundin, 2012).

The integration and collaboration with relevant actors is seen, according to Vasantha et al. (2012) and Mont (2002) as an important aspect of designing a successful offering. On the same note, it is also crucial to understand the underlying needs throughout the life cycle (Sage and Rouse, 1999). Therefore, it is essential to have a suitable requirements development process that can capture all involved actors' needs and related aspects. An apparent challenge here is the process of integrating the perspectives of different domains into a common view. In order to ensure consistency and compatibility in the requirements, a continual interaction between requirements development and the elements to be designed is inevitable (Hull et al., 2011). Lindahl et al. (2007) highlight the importance of handling and balancing various types of requirements, and not only, for example, environmental or customer-driven aspects. Mont (2002) has also found the relationship between the provider of the offering and suppliers to the offering's elements to be essential when designing an offering in order to have a sustainable production and consumption system. In a review of methodologies for designing offerings, Vasantha et al. (2012) found that *working with requirements* and *actors' involvement* are two of the areas with the weakest maturity among different characteristics for designing an offering.

1.5 THE RESEARCH GAP

As requirements are supposed to describe what the offering is to fulfil (Hull et al., 2011), it should be possible to affect the amount of resources necessary in the offering through what requirements are defined in the requirements development process. Figure 2 illustrates that it is in the earliest phases where one has the greatest possibility to affect the environmental impact of the offering, even though the final impact does not become evident until much later in the design process (British Standards Institution, 2017). Song (2017) confirms in a status review of the topic "requirements management for integrated offerings" that environmental aspects are often neglected in the design process, as only one of the methods/tools identified in the review included it.

Figure 2 – Relation between environmental impact and when it is possible to influence (British Standards Institution, 2017).

To sum up the background of this research, there is a gap between *effectiveness and resource efficiency, design of integrated offerings, and requirements development*. It is important to work with requirements to achieve more effective and resource-efficient offerings, as it is in the earliest phases of design where one has the greatest chance to impact the offering's environmental impact. There are also challenges in working with requirements to actually be able to do this, due to, for example, the complexity in designing integrated offerings.

Requirements are key to ensure that the offering actually becomes effective and resource-efficient from a sustainable life cycle point of view (Becker et al., 2016). If the goal regarding how the offering should be effective and resource-efficient is not clear from the beginning, unnecessary time and costs might be added throughout the offering's design process.

1.6 OBJECTIVE AND RESEARCH QUESTIONS

Based on the described background, an objective and three research questions have been developed to set the frame for this thesis. The main objective of this thesis is to *investigate how the requirements development process could be improved in order to better support the design of effective and resource-efficient integrated offerings*. This objective implies that requirements should facilitate the realisation of effective and resource-efficient offerings that are sustainable and satisfy involved actors affected throughout the life cycle.

1.6.1 RESEARCH QUESTIONS

In order to reach the objective of this research, the following three research questions have been defined:

RQ1. What types of sources and aspects should be considered in the requirements development process in the design of effective and resource-efficient offerings?

The first concern in this research is to determine what types of sources and aspects should be considered in the requirements development process in the design of effective and resource-

efficient offerings. This primarily includes investigating what types of sources are addressed and what types of aspects are extracted and considered, in both the literature and in industry. This will be further discussed in the following RQs, and more specifically how these are embodied in the requirements development process and how it could be done. Identifying what types of sources (both internal and external, for example, customers, end users, company management, suppliers, and institutes) that influence effectiveness and resource efficiency is important in order to understand who and what should be considered and included in the requirements development process. In the same way as with the sources, it is also important to understand what types of aspects (for example, materials, maintenance, and economics) are considered in order to know what should be considered and included in the requirements development process.

RQ2. What challenges exist in the requirements development process when designing effective and resource-efficient offerings?

RQ2 is based on insights into how requirements are currently developed when designing effective and resource-efficient offerings. Understanding the situation of manufacturing companies today, and from there identify what challenges that exist, which will provide the foundation for RQ3. RQ2 will also add knowledge on prerequisites for the companies to be able to design effective and resource-efficient offerings.

RQ3. How could the requirements development process be improved to support the design of more effective and resource-efficient offerings?

Given by results from RQ2, opportunities for improvement found in the industry are to be identified, such as missing support in certain steps of the requirements development processes. This is to identify success factors and how these could be applied in the requirements development process to better support the design of more effective and resource-efficient offerings.

Taken together, these three RQs should provide a good insight into the challenges and possibilities that exist in the requirements development process to emphasize effectiveness and resource-efficiency when designing integrated offerings.

1.7 DELIMITATIONS

The focus in this thesis lies on companies moving from traditional product development and manufacturing towards providing integrated offerings consisting of, for example, software, services and products. This research has therefore delimited what companies are included in the interview studies, primarily focusing on manufacturing companies, which are further described in 3.1 Research Context. Only a few of the companies come from a background of service or software engineering. Knowledge contributed from these companies, therefore, has to be utilized and analysed accordingly. Generalisations have to be made carefully, and input from other influences might affect the results, even though it is not part of the

published papers but rather is included in the results in order to obtain a high level of abstraction.

1.8 THESIS OUTLINE

The structure of the thesis is as follows: Chapter 2 introduces the theoretical framework, describing concepts, subjects and terminology used. Chapter 3 is the research methodology chapter, which portrays the overall picture of what activities have been executed to obtain the answers to the research questions in the thesis. There is also a reflection on ethical perspectives in the performed research. In Chapter 4, the appended papers are summarised. For each paper, aim and method, conclusions, and author contributions are described.

Chapters 5-7 are oriented for each research question, presenting results from the different studies performed according to topics related to the research questions and main findings. The results in each chapter are discussed and concluded.

The thesis continues with Chapter 8, which includes conclusions describing the original knowledge this thesis contributes to the research field and the industry. To finalize Chapter 8 and the entire thesis, suggestions for future research are presented based on findings in the research.

2. FRAME OF REFERENCE

This chapter presents the theoretical foundation for the thesis. It focuses on describing the relevant terminology and concepts of three main areas: effectiveness and resource efficiency, design of integrated offerings, and requirements development. This provides a frame for related research areas and the author's perception of the research questions.

2.1 EFFECTIVENESS AND RESOURCE EFFICIENCY

In this section, relevant concepts and terms related to effectiveness and resource efficiency are described and clarified. In this research, the term environment is defined according to ISO 14001 (2015, p. 2) as “Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships”.

2.1.1 SUSTAINABILITY AND THE CIRCULAR ECONOMY

Sustainable development was defined by WCED (1987, p. 41) as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, and has been adopted by the United Nations as a guiding principle for economic, environmental and social development. Trying to balance these three areas is challenging as they build on very different types of values that are not comparable, for example, biodiversity vs. costs or profit vs. equity (Mieg, 2012).

As mentioned in the introduction, the term *effective and resource efficient* is defined in this research as *using the right resources the right way* and refers to reducing the amount of needed raw material in order to reduce the total environmental impact, but these resources need to be used carefully. This can partly be solved by circular material flows, for example, reuse, remanufacture and recycle (see Figure 3).

Figure 3 – Illustration of the circular economy, based on the Ellen MacArthur Foundation (2015).

One of the Ellen MacArthur Foundation (2015, p. 7) principles is to “Optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles”. This implies that what is illustrated in Figure 3 as a smaller loop and tighter system will preserve materials with, for example, less risk of downgrading the material by reuse rather than recycle (Hosoda, 2012). Waste does not exist in a circular

economy, and is intentionally designed out (Ellen MacArthur Foundation, 2015). Reducing the amount of required products and materials is even more efficient than reuse and remanufacturing, for example, by designing the offering accordingly (Allwood, 2012), or through manufacturing techniques (Herrmann et al., 2014), or by using economic models such as the sharing economy (Prothero et al., 2011).

2.1.2 LIFE CYCLE

Several different life cycle models can be considered in industry, but often they are fairly similar. Two different conflicting definitions generally exist (Östlin et al., 2009), and in this thesis are denoted as the economic life cycle and the material life cycle. The economic life cycle describes the evolution of a product, measured by its sales over time, and consists of phases such as introduction, growth, maturity, and decline (Cox Jr, 1967). Here, the material life cycle refers to the progress from raw material to disposal, and the phases can then include, for example, design, resource extraction, production of materials, manufacturing, use and end-of-life activities (Rebitzer et al., 2004). As this thesis focuses on effectiveness and resource efficiency, the term life cycle, used throughout this thesis, implies the material life cycle.

The concept of life cycle is an approach to products, processes and services where all life cycle stages have environmental and economic impacts (Fava and Weston, 1997). Applying a life cycle perspective implies consideration of the environmental effects of activities, products, and services that an organisation can control or influence (ISO 14004, 2016). It is important to have a full life cycle perspective for each element and the system as a whole in order to avoid sub-optimisation of any specific life cycle phase that may result in a higher environmental impact (Sundin, 2009).

A life cycle can be described as the concept of a product's life, and includes the life cycle phases as well as the loops between them. Complex structures can be a challenge in evaluating the system reliability (Frangopol, 2011). This challenge becomes especially evident for products that are, for example, remanufactured or repaired: Where does the life cycle actually start and end?

An offering can have several different life cycles, both for each individual element and for the offering as a whole. As can be observed in Figure 4, there is an example of two different life cycle perspectives that has to be considered for the offering. The first perspective in Figure 4 is the *product life cycle* in the offering, while the second is the *customer relationship life cycle* - that is, the relating system and other elements that create a relationship between the provider and the customer, for example, installation or maintenance activities. The provider must understand both these cycles in order to exploit the full potential in providing integrated offerings (Tan et al., 2006).

Figure 4 – The two life cycle perspectives for integrated offerings, based on Tan et al. (2006).

Comparing the life cycle of integrated offerings with traditional products, the value of the offering moves beyond the product itself, making the customer's activities a part of the value creation; note that the provider needs to interact with the customer throughout all of the life cycle phases (Tan et al., 2006).

2.2 DESIGN OF INTEGRATED OFFERINGS

An offering consists of several elements that have to be jointly designed in order to create successful integrated offerings (Mont, 2002). With these elements coming from different engineering domains, the design space requires a wider knowledge and understanding when designing the integrated offering compared to the individual elements on their own (Akasaka et al., 2012). Commonly, an offering consists of a combination of software, services and products, defined here as follows:

- **Software.** "Computer programs, procedures, and possibly associated documentation and data pertaining to the operation of a computer system" (ISO/IEC/IEEE 24765, 2010, p. 329).
- **Service.** Services are activities or benefits, tangible or intangible, which are offered for sale or provided in connection with products (Regan, 1963).
- **Product.** A product can be referred to as any type of element that has a marketable value, but in this thesis it only implies physical items, as according to Goedkoop et al. (1999, p. 111), that is "A tangible commodity, manufactured to be sold in large quantities. It is capable of falling onto your toes and of fulfilling a user's need".

Figure 5 shows how, metaphorically, the design object gets a higher value when a product and a service collaborate in fulfilling customer needs (Sakao and Shimomura, 2007).

Figure 5 – Illustration of the combined value of products and services and the importance of co-design, based on Sakao and Shimomura (2007).

Compared to traditional, individually-offered products or services, an offering may need to be specifically designed and delivered in order to actually become more effective and resource efficient (Vezzoli et al., 2015). The different life cycle phases provide many different and varied aspects that should be considered, which make the offering's design process both complicated and complex (Kurtz and Snowden, 2003). The entire life cycle, therefore, needs to be considered early in the offering's design process (Pigosso et al., 2010).

Offerings can be developed though, for example, systems engineering, which is defined by ISO/IEC/IEEE 15288 (2015, p.10) as *"An interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution and to support that solution throughout its life"*. Looking into this definition a little bit more in detail, the solution is in this case the offerings. The stakeholder is in this research referred to, with a wider term, as an actor, implying an individual, group or organization that plays a specified role in interacting with an offering (IIBA, 2015). The transformation from needs, expectations and constraints into solutions is executed in a structured design process. In a generic design process, the required activities have to be organised in a meaningful way that forms a clear structure of main phases and specific working steps, so that the work flow can be planned and controlled (Pahl et al., 2006).

A wide range of design processes, methods and tools has been developed, some with a narrow focus on specific steps in the process, and others with the entire design process in mind (Vasantha et al., 2012). Established engineering design approaches, for example by Andreasen and Hein (2000), have a successful model for integrated product design, which works in a similar way to how an integrated offering should be designed, that is in a collaborative manner among several domains and departments. Approaches specialised for designing integrated offerings, however, are lacking broad acceptance in industry (Vezzoli et al., 2015).

In this research, a tool implies an instrument that enables the performance of a certain task (Reinhart et al., 2014). A tool, therefore, can be used at certain points within, for example, the offering's design process, or in the requirements development process.

2.2.1 SUSTAINABILITY AND INTEGRATED OFFERINGS

The offering supplied to the customer often implies that instead of buying the actual product, the customer pays for the function (Tukker, 2015). This transfers the responsibility of care for the offering to the provider instead of the customer, and moves the focus from consuming products to getting results from them. Therefore, an offering is often seen as a way toward a more effective and resource-efficient solution with less environmental impact, as discussed, for example, by Tukker and Tischner (2006). Providing offerings has the possibility to be one way towards a more effective and resource-efficient society, but if the environment is not considered properly in a holistic perspective of the offering it could have a higher impact on the environment than traditional product sales (Lindahl et al., 2014). An integrated offering can also be more sustainable if the products used in the offering are, for example, reused, remanufactured, or recycled, thereby reducing the need for extracting new raw materials (Sundin and Bras, 2005).

Becker et al. (2015) highlight some important aspects to consider when designing sustainable integrated offerings:

- **Interdisciplinarity.** Sustainability requires attention to concepts from other disciplines and must work across disciplines.
- **Multilevel.** There is a requirement to consider at least two levels of the design: the offering under design and its sustainability, and the wider system of which it will be a part.
- **Multiple timescales.** There is a requirement for long-term thinking to address the timescales in which sustainability effects occur.
- **Isn't zero-sum.** Changing an offering's design to consider long-term effects does not automatically imply making disadvantages now.

The offering needs to consider sustainability in the entire life cycle of the offering. An example of misuse of effectiveness and resource efficiency can be to use a toxic paint on a boat that will require fewer resources (only has to be painted every other year instead of each year, as does non-toxic paint), but still has a high environmental impact on the surrounding ecosystem.

2.3 REQUIREMENTS DEVELOPMENT

Requirements development is a set of activities (for example, elicitation and documentation) that involve collecting the needs and constraints of relevant actors and translating them into a specification describing what the offering is supposed to fulfil (Wiesner et al., 2015).

There are several different recommended requirements development processes; in Paper 3 (Appendix 3), three well-known requirements development processes are summarised and represented in Box 1.

Box 1 – Summation of three well-known requirements development processes directly cited from the theory section in Paper 3 (Appendix 3).

Ulrich and Eppinger (2011) describe three main steps in their requirements development process: *identify customer needs*, *establish target specification*, and *set final specification*. The first two focus on setting a target for what the offering is expected to perform. The final specification, in turn, is made when the offering is complete and specifies what the offering can perform. When establishing the target specification, different aspects are gathered (for example, from interviews or surveys) and interpreted into customer needs. These needs are then translated into metrics that are used in the target specification.

Kossiakoff et al. (2011) have four steps in their requirements development process: *requirements elicitation*, *requirements analysis*, *requirements validation*, and *requirements documentation*. The elicitation process relies heavily on input from relevant actors. Information gathered in elicitation is later analysed for various attributes and characteristics, for example feasibility or verifiability. The requirements are validated sequentially to identify if they could achieve the user's needs and objectives. Finally, the requirements are documented.

The requirements development process according to Kotonya and Sommerville (1998) consists of *domain understanding and elicitation*, *evaluation and negotiation*, *specification and documentation*, and *quality assurance*. These are illustrated as a spiral in their model to emphasize an iterative process. In the first step, relevant information is collected as an *informal statement of requirements*, and subsequently is processed into *agreed requirements*. The requirements are documented as a *draft requirements document*, and after quality assurance (for example, validation) result in either *consolidated requirements* or an iteration of the process.

All requirements development processes described in Box 1 include, in some manner, the four main activities: *requirements elicitation*, *requirements analysis*, *requirements documentation*, and *requirements validation*. These activities are not always specified with these exact denominations, but all the requirements development processes, described in Box 1, contain activities with similar purpose and content as these four main activities. The purpose and content of each main activity is further elaborated in the following sections.

Figure 6 illustrates that requirements development is a step with its own activities within the offering's design process.

Figure 6 – Requirements development activities in relation to the offering design process, based on the aggregated main activities by Ulrich and Eppinger (2011), Kossiakoff et al. (2011), and Kotonya and Sommerville (1998) and the design process by Ullman (2002).

2.3.1 REQUIREMENTS ELICITATION

In the requirements elicitation, relevant sources and aspects are identified and determined (Wiesner et al., 2015). In ISO/IEC/IEEE 24765 (2010), a source is defined as “an item or activity having a potential for a consequence”. In this research, this means that the source is the origin of aspects that later are translated into requirements. For effective acquisition, the elicitation is commenced by identifying relevant sources (Lamsweerde, 2009). Relevant sources can be, for example, an actor (such as an individual, group or organization (IIBA, 2015)) that plays a specified role, or other items or activities that may have a potential consequence when interacting with an offering. It is important to consider the right sources, and to include all types of appropriate knowledge based on the source’s representative roles, stakes and interest (Lamsweerde, 2009). Identifying all sources for a system can be very challenging (Wiesner et al., 2015).

Several different methods or tools can be used to extract information from the identified sources (Sutcliffe, 2002), such as interviews, questionnaires, observations, and documentation analysis. Good communication is key for collecting and understanding the source’s aspects (Lamsweerde, 2009, Sutcliffe, 2002). Some examples of challenges are:

- **Ambiguity.** The inability to accurately explain what the source does or wants (Sutcliffe, 2002).
- **Use of language.** Using different types of terminology, for example coming from different backgrounds or cultures (Lamsweerde, 2009).
- **Social factors.** Attitudes and opinions may be unreliable, as they can be influenced by other sources without even being noticed (Sutcliffe, 2002).

2.3.2 REQUIREMENTS ANALYSIS

Requirements analysis should identify conflicts, overlaps, omissions and inconsistencies among the elicited aspects (Sommerville and Sawyer, 1997). Commonly, requirements are divided into three different varieties (Robertson and Robertson, 2015):

- **Functional requirement.** Express something that the offering must do or provide; for example, the offering has to withstand a defined impact.
- **Non-functional requirement.** Some property or quality that the offering must possess; for example, the offering has to be easy to maintain.
- **Constraint.** Can be a limitation or restriction on the offering's design; for example, a component cannot exceed a defined size.

Non-functional requirements are sometimes hard to work with, as they may seem vague and incomplete (Robertson and Robertson, 2015).

Requirements can be defined on different levels of the offering (Hull et al., 2011). An example of levels in an offering is shown in Figure 7, where the entire offering's functions and constraints are defined on, for example, the system level, the individual elements functions are defined at a subsystem level, and each component of the elements is defined at component level.

Figure 7 – Example of levels in an offering (Hull et al., 2011).

During analysis it is important to bear in mind the *emergent properties* of a system. Hull et al. (2011, p. 4) had the following to say about emergent properties: “... the usefulness of a system does not depend on any particular parts of the system, but emerges from the way in which its components interact”. Requirements for emergent properties must be defined with a top-down approach; they cannot be obtained by specifying requirements for individual elements and then hoping that the desired properties will exist in the integration (Hull et al., 2011). One must also consider the possibility of the complete system exhibiting emergent properties that were not considered as a part of its design and, in some cases, that may be undesirable in the final offering (Hull et al., 2011).

When translating aspects into defined requirements, several characteristics should be considered; some examples include (INCOSE, 2015):

- **Implementation independent.** A proper requirement should address the offering as a *black box* only specifying *what* the offering should fulfil, not *how* it should be done.

- **Necessary.** Redundant requirements covering other requirements or a combination of requirements is a sign that a requirement is unnecessary and should not be included.
- **Feasibility.** Requirements should be realizable in terms of risk, budget, time, and technology.
- **Singular.** Each requirement should only include one function or constraint.
- **Unambiguity.** Domain properties, requirements, and assumptions are formulated so that they can only be interpreted in one way.
- **Verifiable.** Each requirement has to be able to be verified by a single method, for example, inspection, analysis, demonstration or test. This also allows for alternatives to be evaluated against them.

A second round of elicitation can be necessary if misunderstandings and questions appear during the analysis (Wiesner et al., 2015). The decisions of which requirements should or should not be included in the specification is an important part of requirements analysis (Hood, 2008).

A commonly used tool in the requirements development process of designing integrated offerings is Quality Function Deployment, commonly referred to as QFD. This tool translates customers' needs, called *voice of the customer*, into quantitative parameters called *engineering characteristics* (Ullman, 2002). By putting the voice of the customer in the rows of a matrix and the engineering characteristics in the columns, a mark can be set in a cell to showcase that a voice of the customer correlates to an engineering characteristic. This matrix can be further be elaborated on to build a *house of quality* (Hauser and Clausing, 1988).

2.3.3 REQUIREMENTS SPECIFICATION

The requirements specification should document a complete description of the offering's desired functions and constraints (Wiesner et al., 2015). The documentation should be revised and elaborated on as the design of the offering evolves (Kossiakoff et al., 2011). It is essential to have a tool for documenting the requirements properly; in small projects a simple word processor can do, but for more complex offerings it is recommended to use appropriate software (Jiang et al., 2005).

Requirements Attributes

A requirement cannot be sufficiently defined with only a textual statement - it needs for example classification and status information tied to it as well (Hull et al., 2011). Each requirement contains the main requirement statement, and additional information can be added with so-called *requirements attributes*. The statement is defined by the characteristics mentioned above in Section 2.3.2, Requirements Analysis. Some suggestions on requirements attributes are (Hull et al., 2011, INCOSE, 2015):

- **Type.** Useful since it allows the requirements database to be viewed in different ways.
- **Priority.** Each requirement provides some design space.
- **Source.** The originator (for example, person, organisation, document, or process).
- **Risk.** Contributes to the overall system risk.

- **Rationale.** The reason for the existence of the requirement (can either be written as a statement or an attribute).
- **History.** Changes that are made to the requirement.
- **Relationship to other requirements.** Relationship with other requirements.
- **Other information.** Each requirement should be stored with the date of establishment, the status (proposed, reviewed, accepted, rejected), and comments.

Traceability

Requirements cannot be developed or managed effectively without traceability (Wiesner et al., 2015). Traceability ensures that it is clear where the requirement came from, what requirements are related to it, and what requirements were derived from it (Hull et al., 2011). Clear traceability allows several benefits: greater confidence in meeting objectives, ability to assess the impact of change, improved accountability of subordinate organisations, ability to track progress, and ability to balance cost against benefit (Hull et al., 2011).

INCOSE (2015) suggests seven different types of traces that can be included in the requirements specification:

- **Trace to parent.** A child requirement derived or decomposed from another requirement must be able to be traced back to the parent requirement.
- **Trace to source.** Each requirement needs to be able to be traced to its original source, as it recognises where the requirement originated from and/or how it appeared.
- **Trace to interface definition.** Requirements regarding interface between elements need to be able to be traced to where the interface and interaction with surrounding elements is defined.
- **Trace to peer requirements.** Requirements at the same level that relate to each other need to be traced between each other, for example, if in conflict or if co-dependent.
- **Trace to verification method.** A statement containing how the requirement is to be verified.
- **Trace to verification requirement(s).** Can be used in addition to stating the verification method to set explicit requirements for how the verification should be executed.
- **Trace to verification results.** In order to know how well a requirement has been fulfilled, it should be traced to its verification results.

2.3.4 REQUIREMENTS VALIDATION

Validation is the last stage of requirements development, with the purpose to make sure that requirements represent the offering desired by the actors (Kotonya and Sommerville, 1998). This requires direct involvement of the actors to review the requirements (Cheng and Atlee, 2007). Several different techniques can be used for validating requirements, for example, brainstorming, storyboarding, prototyping, and different reviews from experts or end users (Chemuturi and Gilb, 2013). This process has a tendency to not be given enough time, which will result in unnecessary rework more costly than if validation would have been given sufficient attention (Kotonya and Sommerville, 1998).

3. METHODOLOGY

In this chapter, the methodological research approach of the thesis is presented. The chapter begins by describing the research context, and then presents an outline of the research design and specific methods for data collection. The author's contributions are described under each section of methods for data collection. The chapter ends with reflections on the research approach and a discussion on choices made throughout the process.

3.1 RESEARCH CONTEXT

This research is a part of a four-year research program called *Mistra REES – Resource-Efficient and Effective Solutions*, which is based on circular economy thinking (Mistra REES, 2017). Activities and goals in this research program have had great influence on the research in this thesis.

The Mistra REES program started in September 2015 and is run by a consortium of Swedish universities, large and small companies and some societal actors. The program's vision is to advance the transition of the Swedish manufacturing industry towards a circular and sustainable economy. The main areas of interest in the program lie within product and service design, business models, and policies. These will be looked at separately, but also by studying the interrelations between them.

Some of the objectives for the research program are to create and consolidate contextual knowledge on REES in collaboration with academic, industrial and societal partners; to develop principles, methods and guidelines for the design of REES (products and services); to generate business models for REES; and to create policies and policy packages enabling and driving towards REES. It is also of importance to understand the interrelations between product and service design, business models, and policies and policy packages, and to explore opportunities for effective interplay between them. This should all be done to facilitate mutual learning between academic, industrial and societal actors about the transition of Sweden's manufacturing industry towards more REES.

3.1.1 RESEARCH PROJECT – PRODUCT AND SERVICE DESIGN SUPPORT FOR REES

It is within a research project called *Product and Service Design Support for REES* that this research's contribution is situated. This research project is one out of seven projects that is included in the Mistra REES program (Mistra REES, 2017).

The research project is focused on product and service design support for REES in the early design phases, and is conducted by three PhD students and three senior researchers. The project has been broken down into three different research topics, one for each PhD student: *requirement specification*, *conceptual design*, and *analysis and evaluation*. The first of these topics, *requirement specification*, concerns the research in this thesis. The research project consists of four work packages: 1. *Identify the current situation*, 2. *Derive requirements for a new design method*, 3. *Develop a design method*, and 4. *Evaluate and refine the developed method*; an overview of the activities can be seen in Figure 8. The first two work packages are the main sources of knowledge that are presented in this thesis. Figure 8 also illustrates that the main focus of the thesis lies on early phases in the offering's design phases, and that detailed design is out of its scope. It also shows that the three individual research topics work in parallel in the research process, and that all work packages contribute to all research topics. Jointly performed activities primarily include collection of raw data, where the individual PhD students have performed sequential analysis activities for their own respective topic.

Overlaps between the research topics are coordinated within the research project by the project leader. The program manager coordinates overlaps with the other projects within Mistra REES. Overlapping results are published as articles, books, project reports, and so on.

Figure 8 – Schematics of the research project’s content.

The first work package (in Figure 8, Identifying the current use of design methods) consists of a background literature study of what has been done in the academic world (further described in Section 3.5.2, Systematic Literature Review 2) and performing interviews with relevant involved partners with help of the method actors system maps (further described in Section 3.6.1, Interview Study 1). These results create the foundation for what design methods are used for in industry today, and describe the user’s experiences.

In the second work package (in Figure 8, Deriving requirements for design method) the aim is to identify what a method is expected to fulfil to match the needs of the industry, both in, for example, the way it is used or what the outcome should be. This information will also be extracted from interviews with relevant involved partners and from earlier studies on requirements for successful methodology.

3.2 OVERALL RESEARCH DESIGN

There are different perspectives and traditions for approaching the collection and analysis of data (Bell and Nilsson, 2006). Quantitative research, simply described, has a focus on measuring and statistical analysis to achieve quantifiable and generalizable conclusions (Bell and Nilsson, 2006). Qualitative research, on the other hand, aims to investigate how the world is experienced (Bell and Nilsson, 2006). This thesis relies on qualitative research approaches, as they are in line with the defined purpose and research questions.

The methodology of this research is based on the design research methodology presented by Blessing and Chakrabarti (2010). Their methodology is based on four stages: *Research Clarification*, *Descriptive Study 1*, *Prescriptive Study*, and *Descriptive Study 2*. As this research is primarily focused on understanding the current situation and on getting an idea of what

support could be relevant, only the first three stages are executed. How this research is adapted to the methodology of Blessing and Chakrabarti (2010) is further described in the following paragraphs.

The first stage, Research clarification, has been approached by analysing literature via reviews. This has been an iterative process, where retakes and additions have been included as the research has developed and the need for additional knowledge has been required. One example is that some authors doing research in similar fields were identified in the systematic literature review, and subsequently were further investigated to identify additional related publications.

In the second stage, Descriptive study I, interviews were conducted. This has also been an iterative process: for example, companies were contacted to answer additional questions and to verify and validate information, and a second interview study was also carried out.

The literature reviews and interview studies have given input to each other with knowledge in the areas of interest. The literature has raised issues that were asked for at the companies, and companies raised issues that were further investigated in the literature.

For the third stage, Prescriptive study, learnings from the earlier two stages are synthesised, resulting in ideas of what a support should contain and consider. This will require further development before one can move into the Descriptive study II, and will be left for future research.

3.3 CASE STUDIES

Case studies can be used for *explorative*, *descriptive* and *explanatory* research (Yin, 2009). In this thesis, descriptive research is the main orientation. Descriptive research is good for the quest of description and explanation versus prediction, which is based on reason and action (Merriam, 1994). Qualitative case studies are well suited for insight, discovery and interpretation rather than testing hypotheses (Merriam, 1994). When setting the unit of analysis for the research, it should relate to the defined research questions (Yin, 2009). The research questions are probably too vague or too numerous if the unit of analysis does not favour one unit of analysis over another (Yin, 2009).

Case studies can be performed as single or multiple case studies (Yin, 2009). Single case studies are often representing a *critical case*, *extreme or unique case*, or *revelatory case* (Yin, 2009). Multiple case studies are often considered more robust, as they are more compelling but at the same time also more time consuming (Yin, 2009). Each case has to be chosen carefully so it either predicts similar results or contrasting results for predictable reasons (Yin, 2009).

Companies Included

This research is a multiple case study, and focus has been on companies with a strong background in product design and manufacturing that are moving toward integrated

offerings containing a mixture, for example, of software, services, and products. In total, 15 different companies (listed in Table 1) have been included in the empirical studies.

Table 1 – List of the 15 included companies (those with an * are partners in the Mistra REES program).

Large companies	Small and medium-sized enterprises
1. Attends Healthcare AB *	7. AIDIMME
2. Ericsson AB *	8. FRATELLI PIACENZA
3. Siemens Industrial Turbomachinery AB	9. FTI Engineering Network GmbH
4. Toyota Material Handling AB	10. HTC Sweden AB *
5. Volvo cars AB *	11. Inrego AB *
6. Volvo group AB *	12. Polyplank AB *
	13. Qlean Scandinavia AB *
	14. Ståthöga MA Teknik AB *
	15. TIVOLY – NECO

All companies have contributed with knowledge and insights in the research subject, but the main results are taken from companies that are included in the papers appended to this thesis. This means five of the small and medium-sized enterprises (SMEs) and three larger companies among the companies listed in Table 1. Which companies these are in particular in each study are not mentioned due to confidentiality. The studies including larger companies were primarily performed as a part of the research program Mistra REES that focuses on the Swedish manufacturing industry, so all the large companies are based in Sweden. One of the studies including the SMEs was done in collaboration with *Bremer Institut für Produktion und Logistik GmbH at the University of Bremen*, and therefore SMEs from different parts of Europe have been included. Most of the included companies have markets all over the world, not only within their country of origin.

3.4 RESEARCH DESIGN FOR RESEARCH QUESTIONS

Each of the three research questions have been approached with a theoretical and empirical foundation. Table 2 is a summation of how the methods for data collection and the appended papers contribute to each research question.

Table 2 – Overview of how methods and papers have contributed to answer the individual research questions.

Research questions	Method for data collection					Papers		
	Literature reviews			Interview studies		X – major focus x – moderate focus		
	Systematic review 1	Systematic review 2	In-depth review	Interview study 1	Interview study 2	1	2	3
RQ1	X	X	x	X		X		X
RQ2	x	X	x	X	x	X	X	X
RQ3		x	x	X	x	x	x	X

In the literature, specific tools, methods, processes, and so on were primarily pursued to understand what type of support is currently available and what type of support they focus on, for example the specific life cycle phase or actors. When identifying case studies applying methods or tools it was noted what type of industrial context it had, primarily to identify what type of verification the different methods developed had in the industry.

To get opinions and gauge apprehensions from a population (in this case, manufacturing companies), interviews are a recommended method (Ejvegård, 2003). Focus has been on getting experienced practitioners to share their understandings and knowledge in the area, both for how it is working today and their experiences with challenges and solutions for the future.

3.5 LITERATURE REVIEWS

Performing a literature review is to go through things that have already been written in order to be aware of what is already known, and how this is done can vary in both format and style (Jesson et al., 2012). A traditional literature review implies an interpretation of summarised previous works contributing with an additional dimension (Blumberg et al., 2014). A systematic literature review, in contrast, is according to Jesson et al. (2012) a method to systematically plan and execute the literature review.

3.5.1 SYSTEMATIC LITERATURE REVIEW 1

This literature review was performed solely by the author of this thesis and focused on getting an insight on current research regarding requirements on a general level in the area of designing integrated offerings. It was performed in a systematic way in order to ensure reproducibility and that the study was explicit. Scopus and Web of Science were used as databases, and resulted in 354 hits where, after excluding non-English papers written before 2000 and removing duplicates, 201 papers remained. It was decided to only look at articles from during or after 2000, as the review focused on current research.

After manually going through titles and abstracts, 22 papers were included in the final review. Each paper was summarised in a word file pointing out *methods mentioned*, *sources considered*, *sustainability aspects taken into consideration*, *industrial implementation* (or other case studies), and *other comments*. These topics were chosen together with a senior researcher to fit together with the aim of Paper 1 (Nilsson and Lindahl, 2016). Exact terms used and a more detailed description about the approach can be found in Paper 1 (Nilsson and Lindahl, 2016).

3.5.2 SYSTEMATIC LITERATURE REVIEW 2

This literature review was performed jointly within the research project. It was performed in a similar approach to Systematic Literature Review 1, primarily focusing on finding high-impact research. The execution was therefore designed thereafter, with a wider set of search terms and only using the Web of Science as a database. The Web of Science database was

chosen as it contains high-impact literature sources. The exact terms used can be found in Paper 3 (Appendix 3).

In total, the search identified 1,338 publications, that when delimited to English as the language, and only including journal articles and peer-reviewed papers as the document type, resulted in 585 papers. As this review focused on finding high-impact research, this was the reason for limiting the results to journal articles and peer-reviewed papers. The publications were sorted into four categories, corresponding with the research topics in the research project: *requirements specification*, *conceptual design*, *analysis and evaluation*, and *other*. The sorting was performed so that each PhD student in the project was given about 200 papers to manually go through, looking at the titles and abstracts of each individual paper. As the first round of sorting included all research topics and the PhD students did not want to reject papers by mistake that could be of interest for the other topics, only a small number of papers were rejected in this step. Therefore, after the first round of sorting each PhD student responsible for their individual research topic did a second round of sorting within that topic. This resulted in about 50 papers with relevance to the requirements category.

The author of this thesis did the analysis of the papers in the requirements category. In order to analyse the content in the identified literature, relevant information and quotes were added to an excel spreadsheet according to the subtopics of *elicitation*, *considered environmental aspects*, *prioritization*, *communication* and *tools*. These subtopics were chosen in a research group discussion as a part of the research project.

3.5.3 IN-DEPTH, FOCUSED LITERATURE REVIEW

In addition to the systematic literature review, supplementary literature was required to gain sufficient knowledge in the research area. Literature about requirements development in general and within relevant engineering domains has been consulted to be able to understand the context, limitations and possibilities for the object of study. Following reference chains from relevant literature has also been a way to identify relevant literature as well as to look into specific authors in adjacent research. The author of this thesis solely performed this in-depth review.

3.6 INTERVIEWS

Interviews are one way to collect data in case studies that can be utilised to track "... a chain of evidence, that is, explicit links between the questions asked, the data collected, and the conclusions drawn" (Yin, 2009, p. 78). An interview is a qualitative method for data collection that is done through oral communication (Bell and Nilsson, 2006). It can be based on a structured, semi-structured, or unstructured setup (Kvale, 1996). In both a structured and semi-structured interview, the interviewer should have prepared questions, in a desired order, and a preliminary answer to those questions (Bell and Nilsson, 2006). An unstructured interview, on the other hand, is based on a defined topic and consists of a regular

conversation about that topic, and the interviewee is given more space to answer what is important to her or him (Bell and Nilsson, 2006).

To ease the analysis of the interviews, it is important that they are well-documented (Bell and Nilsson, 2006). A normal approach is to have audio recording during the interview, and then transcribe the conversation at its conclusion (Bell and Nilsson, 2006). The audio recording enables the interviewer to focus completely on the conversation, thus enabling the transcription to support possible quotes and conclusions drawn from the interviews (Kvale, 1996). Several different approaches exist for analysing interviews. To facilitate the process, computer-aided tools can be used to structure transcribed texts by, for example, using coding or searching for key words (Kvale, 1996). Coding can be used, for example, to reduce long statements to simpler categories like *yes* or *no* to denote the presence of a phenomenon (Kvale, 1996).

3.6.1 INTERVIEW STUDY 1

This study was performed jointly by the members in the research project with the purpose to gain a wider understanding of how offerings are and could be designed to become effective and resource efficient in industry. With this rather explorative purpose, a breadth of interviewees and interview topics was necessary. Twenty-four interviews were performed at eight different companies during the spring of 2016. As this study was performed jointly within the research project, the interviews included all three research topics, namely: *requirements specification*, *conceptual design*, and *evaluation and analysis*. In this thesis, the results from subjects relevant to the requirements specification are included, but the execution and analysis are described according to the general procedure. The author of this thesis participated in 16 of the 24 interviews, but results from all the interviews are considered in this thesis.

Execution

The selection of interviewees was made depending on the different companies. A short description of the expected knowledge of the interviewees was given to a contact person at each company, and their expertise of internal knowledge was utilized to identify the most suitable interviewees. At the SMEs, key personnel within the company were identified and chosen. The goal was to interview at least two people at each company to avoid getting a one-sided picture. At the larger companies, employees from different areas were prioritised to get a deep insight into different sides of the company. It is important to get the right person, one who matches with the purpose of the interview (Kvale, 1996).

For each interview, two interviewers and one interviewee were present. One of the interviewers had an active role in asking questions, while the other had the more passive role of keeping notes and asking sub-questions when necessary. In this way, notes could be taken during the interview without disturbing the interviewer, and when interesting subjects were detected, notes could be taken immediately, which is preferable since the longer after something is noticed, the harder it is to remember (Ejvegård, 2003).

The interviews were semi-structured, in accordance with Kvale (1996). As a start for the interviews, the interviewer discussed the purpose of both the research project and the interview to set a starting point for the interviewee. The questions were then divided into an introduction part with questions about the interviewees' experiences and background, and the main part with questions about the product design process, activities, involved actors, requirements specification, conceptual design, and analysis and evaluation. To end and sum up the interview, reflections from the interviewee were requested. Before interviewing the interviewees, two pilot interviews were conducted in order to test the questions and format of the interview (Bell and Nilsson, 2006, Kvale, 1996).

The focus of the interview was oriented around a white sheet of paper, where the respondent was asked to illustrate an actors-system map visualising involved actors, their relationship, and links to the offering design process (Desai et al., 2017). An actors system map visualizes participating actors, their roles and connections within a working system (Lindahl and Sakao, 2014). An actor in this case can therefore represent, for example, an individual, a group or a function that plays a specified role in interacting with an offering (IIBA, 2015). By doing this, actors involved in an offering network can be illustrated, as well as flows of information, activities, products and services in between them. The map facilitates in identifying unnecessary flows or distances between the actors in order to improve the system (Lindahl and Sakao, 2014).

To document the interviews, what was discussed, and what was illustrated on the sheet of paper, a video camera was used. All discussions were also audio recorded, and the interviewer with the role of observer took notes. By using proper recording equipment, the interviewer could focus on the dialogue with the interviewee (Kvale, 1996).

To minimize the risk of what Bell and Nilsson (2006) called biased and what Wårneryd (1990) described as over- or under-reporting, the interviews were performed at each company and the questions were formulated in a way that would minimize their risk to be perceived as problematic, for example, too personal.

Analysis and Verification

The analysis was also performed as a joint activity in the research project, but the procedure described below focused on the research topic requirements specification.

The interviews were analysed by reviewing recordings, where relevant information and quotes were added to an excel spreadsheet divided into the three research topics of the research project. For the research topic *requirements specification*, the following subtopics were used: *elicitation*, *considered environmental aspects*, *prioritization*, *communication* and *tools*. These subtopics were chosen in a research group discussion in the research project. Within each subtopic, information was divided into current status and future desires. Information for each company was summarised into reports and was then presented to each company. In meetings with each company, the reports were discussed and the findings were verified. The author of this thesis reviewed 11 out of the 24 interviews, and summarized these reviews in

three out of the eight company reports. The author also helped prepare and participated in two out of the eight verification meetings, and performed revisions accordingly in the affected company reports.

3.6.2 INTERVIEW STUDY 2

Master's program students conducted Interview Study 2. Eleven interviews were performed at four large companies regarding how requirements engineering was carried out in the design of integrated offerings. This was done without the focus of effective and resource-efficient offerings, with the aim to get a deeper understanding about requirements development in general for integrated offerings. A more detailed description of execution, analysis and verification can be read in Johansson (2017).

The author's role in this study was that of a supervisor giving comments and support during the execution process as quality insurance. The responsibility also included defining the project, choosing the companies to be included and determining which topics should be focused on.

3.7 REFLECTIONS ON RESEARCH APPROACH

Here, some reflections and discussions are presented in relation to the research execution.

3.7.1 RESEARCH CONTEXT

Being a part of the Mistra REES program has been a great asset with regard to available resources and collaborations. Most activities within the research project were performed collaboratively between the three PhD students, with strong support from senior researchers such as the project leader and the program director, both of whom are located at Linköping University.

Working in a collaborative manner provided the opportunity to gather a lot more data than would have been possible to as individuals. It also kept quality at a high level, with good discussions on execution and conclusions throughout the project.

Working in this manner has also influenced the focus of the research, as it was a predefined research program with goals on topics, deliverables, and so forth. Group efforts have primarily been about gathering raw data, and the author of this thesis has solely conducted all analysis activities for the research topic relevant to the thesis. This has provided opportunities to use results from predefined activities in a more independent way. By carrying out complementary studies, for example, the In-depth Literature Review and Interview Study 2, some of the limiting issues have been solved.

As integrated offerings consist of a combination of elements from different engineering domains (for example, software, services and products), the scope has to address what domains to focus on. The requirements development processes vary for each domain, and

few lessons are learned between them. Requirements engineering, as a concept, originates from systems engineering and software engineering, and therefore both of these engineering domains have a high influence on requirements development as a research field. An important consideration in this research is the focus on the manufacturing industry, which implies a need to understand more traditional product design and mechanical engineering to get an insight into where the companies come from and their prerequisites. The last engineering domain that can be a part of an offering is service engineering. This domain has not been covered in depth, due to the fact that requirements development in this domain has not come up as an issue or a solution in the empirical studies.

3.7.2 SELECTED COMPANIES

Usability for industrial application is one of the keys in this research's purpose. Involved companies will affect the outcome, and the result might have looked different with other participants. As companies from the Mistra REES program have primarily been included, this has limited the selection to some extent. It is, however, also facilitating to work with these companies since they are committed both in written agreements and financially to support this research, and thus they had a great motivation to contribute. The level of involvement from the companies has differed, and was dependent on individuals and their capacity and willingness to be involved. Companies outside the Mistra REES program have been included to broaden the study in relevant subjects.

This research is primarily based on companies working in Sweden, but that have markets all over the world. How well the challenges and solutions match for companies in other countries is hard to anticipate, especially regarding which sources and aspects that are relevant for effectiveness and resource efficiency might need to be reconsidered.

3.7.3 LITERATURE REVIEWS

Both systematic literature reviews were restricted to papers that included some sort of focus on resource use and/or environmental issues. It could have been interesting to also investigate further into adjacent research fields, but this would have been more relevant before conducting Descriptive Study II, as Blessing and Chakrabarti (2010) suggest, when starting to look into developing a more detailed solution on how the requirements development process should support in the design of effective and resource-efficient offerings. From adjacent fields, possible learnings could be found from other successful requirements development processes, for example Design for X.

3.7.4 INTERVIEWS

Table 3 presents a summation of the scope of the interview studies, with the total number of companies and interviewees included. The scope was assessed in the research project to give a sufficient foundation for this explorative study.

Table 3 – Summation of the number of companies included and interviews performed in the interview studies.

Interview study	# of companies	# of interviewees
Interview Study 1	8	24
Interview Study 2	4	11
Total	11*	35

*one of the companies was included in both studies

The desired number of interviewees was to be at least two for each company to avoid getting a one-sided picture, but preferably three were desired to be able to triangulate the individual responses. Results from companies with less than three interviewees have been used carefully, without drawing strong conclusions from them, and none of these companies has been included in the appended papers. For the SMEs in particular, it was difficult to find enough respondents, and that is mainly the reason for the collaboration with *Bremer Institut für Produktion und Logistik GmbH* at the *University of Bremen* - to get some additional input on how requirements development processes work at SMEs.

Two noticeable remarks have to be made about Interview Study 1: there was no transcribing performed, and no coding was done in the analysis. Transcription was not done due to the number of interviews performed and the resources (for example, the time or cost to hire someone to do it) that would have been required to spend on transcribing. The documentation created was considered enough for its purpose. By not transcribing the interviews, this also led to not coding them, and by having clear topics and subtopics to divide the findings in the interviews, coding was not considered necessary. This categorisation also gave a good foundation to go back to when information was desired for a specific topic, and did to some extent fulfil the purpose of the coding.

3.7.5 RESEARCH ETHICS

The research in this thesis has been conducted with the best ethical approaches possible by maintaining transparency regarding how the research has been conducted and which results have been identified. When using others' research, it has been critically reviewed and properly referenced. Confidentiality has been promised to the interviewees, and all companies have been allowed to verify findings before publishing results to ensure that integrity towards them has been maintained. Contributions that have resulted from activities in the Mistra REES program have been described in the methodology chapter, without the author taking any unnecessary credit. To avoid self-plagiarism, especially regarding the appended papers, relevant contributions to this thesis has been substantially rewritten and properly referenced.

4. SUMMARIES OF APPENDED PAPERS

This chapter introduces the content of the appended papers in order to assist in the understanding of coming results in the following chapters. Each paper is summarised with the aim and method, and conclusions.

4.1 PAPERS' CONTRIBUTIONS TO RESEARCH QUESTIONS

The appended papers are presented in chronological order, as they have been developed over time and as more knowledge in the area has been gained. Table 4 illustrates how each paper contributes to answer the research questions, where the large X indicates a great contribution and a small x indicates a lesser contribution.

Table 4 – Contributions from the appended papers to answer the research questions.

Paper	By	RQ1	RQ2	RQ3
Paper 1	Nilsson, S, & Lindahl, M	X	X	x
Paper 2	Wiesner, S, Nilsson, S, & Thoben, K-D		X	x
Paper 3	Nilsson, S, Lindahl, M, & Sundin, E	X	X	X

4.2 PAPER 1: A LITERATURE REVIEW TO UNDERSTAND THE REQUIREMENTS SPECIFICATION'S ROLE WHEN DEVELOPING INTEGRATED PRODUCT SERVICE OFFERINGS

4.2.1 AIM AND METHOD

This paper's objective was to analyse, based on a literature review, how existing offering design methods develop and manage requirements when designing an offering. Issues analysed were, for example, what types of aspects existing methods consider, such as environmental issues and demands from different sources. Another issue was what types of sources are involved in the requirements development process. There was also an interest to find out which of these methods are used in industry. The goal was that the results would provide insight into how the requirements development process could offer support when designing an offering. These insights contributed to sequential studies on how companies currently develop requirements when designing offerings.

The literature review started out with the analysis of 201 papers, ultimately yielding 22 papers within the area of working with requirements for an offering. These papers were reviewed and summarized with the above issues and interests in mind.

4.2.2 CONCLUSIONS

This review shows that little research has been carried out about how to work with the requirements when designing an offering. Still missing is a complete solution that can be implemented in industry. Methods or tools are currently specialized in one engineering domain or another, even though an offering requires a holistic perspective, and consider the offering from a life cycle perspective. Integration of, for example, products, software and services throughout the offerings design process is essential to achieve an effective and resource-efficient offering that has less environmental impact, and to satisfy not only the

customer but also other actors involved with the offering. To successfully achieve the mentioned conclusions there is a need for a well-structured method that can provide support throughout the entire requirements development process.

4.3 PAPER 2: INTEGRATING REQUIREMENTS ENGINEERING FOR DIFFERENT DOMAINS IN SYSTEM DEVELOPMENT – LESSONS LEARNT FROM INDUSTRIAL SME CASES

4.3.1 AIM AND METHODS

Based on five selected case studies, this paper aimed to investigate how requirements development methods and tools are applied in industrial SMEs to design integrated offerings. To do so, there was first a need to know what characterizes the design of integrated offerings and which characteristics are relevant for the requirements development process, and second, which methods and tools exist and how they are applied in industry. Based upon such an analysis, needs were identified for an integrative approach for requirements development when designing integrated offerings.

In order to reach this objective, an exploratory approach was used, analysing requirements development methods and tools for different domains described in the literature and applied in several industrial use cases. Relevant literature has been identified based on previously published papers, mainly literature reviews by Wiesner et al. (2017b) and Nilsson and Lindahl (2016). Working with the industrial use cases, information was gained either by conducting on-site workshops or through interviews with representatives from different departments.

4.3.2 CONCLUSIONS

The research in this paper focused on SMEs moving from providing isolated elements in different domains to integrated offerings. Five industrial use cases were analysed, searching for what types of methods and tools were applied in the requirements development process. It was concluded that approaches adapted for integrated design are rarely used. Mainly, approaches from the original business domain of the company are used for requirements development, neglecting part of the relevant requirements needed for integrated offerings and demanding additional integration in the end that could have been prevented.

It is clear that methods and tools for requirements development that are currently used do not provide full support for designing integrated offerings. The main points identified are challenges with a greater complexity, multiple distributed actors and the involvement of several engineering domains, such as product, service and software that all have their own formalisms and models.

The involvement and integration of different domains requires common standards and/or appropriate interfaces between domain-specific and common models. Future work ought to deal with the solutions or support of such interfaces that are able to interpret between different models without losing or delaying information, as it might be impossible to replace domain-specific models in all cases.

4.4 PAPER 3: INTEGRATED PRODUCT SERVICE OFFERINGS – CHALLENGES IN SETTING REQUIREMENTS

4.4.1 AIM AND METHOD

The objective of this paper was to explore what challenges exist in requirements development to obtain an effective and resource-efficient offering. The literature has shown that academia have contributed with methods or tools for requirements development, but these seem to not be extensively implemented in industry and the methods and tools lack in appropriate support for designing effective and resource-efficient offerings. The objective of this paper was to explore what challenges exist in the requirements development process to design effective and resource-efficient integrated offerings, focusing on larger companies.

Results were based on interviews conducted at three larger companies and a systematic literature review. During the interviews, the method of actors system mapping was used to get a visual and mutual picture to discuss together with the interviewee.

4.4.2 CONCLUSIONS

This paper concludes that requirements developed to obtain an effective and resource-efficient offering are currently challenged by; Identification and inclusion of relevant aspects from relevant actors throughout the offering's life cycle; Understanding the underlying aspects for all requirements on all elements; Prioritization of requirements; Difficulty to track how requirements affect each other between different elements in the offering. Furthermore, possibilities in requirements development to obtain better offerings are to utilise relevant theory and tools to make better use of traceability to get a better understanding of why an offering is designed the way it is. To be able to obtain more effective and resource-efficient offerings, the requirements development process needs to integrate environmental aspects in a more efficient way compared to traditional product-focused requirements development processes.

5. SOURCES AND ASPECTS CONSIDERED IN REQUIREMENTS DEVELOPMENT

This chapter aims to answer RQ1, which asks: What sources and aspects should be considered in the requirements development process in the design of effective and resource-efficient offerings? The literature and industry have contributed with insights regarding what sources and aspects exist. In this chapter, relevant results from different studies are presented and discussed, ending with conclusions for RQ1. The source, for example, is the actor, item, or activity from where a requirement originates, and the elicited aspects are, for example, the need, desire, or demand that should be considered.

5.1 RQ1. WHAT TYPES OF SOURCES AND ASPECTS SHOULD BE CONSIDERED IN THE REQUIREMENTS DEVELOPMENT PROCESS IN THE DESIGN OF EFFECTIVE AND RESOURCE-EFFICIENT OFFERINGS?

The first research question asks what sources and aspects are considered when developing requirements for effective and resource-efficient offerings. This aims at investigating what types of sources are considered, and what types of aspects are elicited from them. This will create the foundation for sequential research questions on how these sources and aspects are embodied currently in the requirements development process, and how this could be done in the future. Both the source and the aspect are identified to have impact on effectiveness and resource efficiency, and will be further utilised in RQ3, which is further elaborated in chapter 7 Success Factors for an Improved Requirements Development Process.

5.2 SOURCES AND ASPECTS CONSIDERED IN LITERATURE

In this section, a summary of the findings is presented. More detailed descriptions of sources and aspects can be found in Paper 1 (Nilsson and Lindahl, 2016) and Paper 3 (Appendix 3).

5.2.1 SOURCES CONSIDERED

Table 5 presents some examples of types of sources used when developing requirements. As can be seen in Table 5, most commonly customers (sometimes called users) are considered and consulted in the elicitation step of requirements development. Five papers only (Herzfeldt et al., 2011, Maussang et al., 2009, Trappey et al., 2011, Yang et al., 2010, Zhao et al., 2008) mentioned the user as an actor of the offering. Geng et al. (2011), Sadek and Welp (2009) and (Büyüközkan and Berkol, 2011) mentioned consideration of both the user and some sort of supplier or manufacturer as an information source in the elicitation process. A couple of the papers have a particular focus on individual parts of the offering's life cycle phases. Chen et al. (2009) and McKay and Kundu (2015) primarily look the manufacturing and use phases, and only mention the supply chain and service engineers as relevant actors. Wong et al. (2008), Crowder et al. (2012) and Centrich et al. (2014) delimit themselves to only consider actors relevant for maintenance, for example maintenance engineers, as relevant sources to collect information from.

Table 5 – Examples of types of sources considered when developing requirements.

Type of requirements source	# of papers mentioned in	References
Entire life cycle	7	Agostinho et al. (2014), Fiksel (2003), Harrington and Srai (2012), Kim et al. (2011), Peruzzini et al. (2014), Riel (2010), Song et al. (2013)
Customer/user	15	Azadi and Saen (2013), Brown (1991), Büyüközkan and Berkol (2011), Chen et al. (2011), Geng et al. (2011), Ghahramani and Houshyar (1996), Ghahramani and Wang (1998), Herzfeldt et al. (2011), Maussang et al. (2009), Sadek and Welp (2009), Song et al. (2013), Trappey et al. (2011),

		Van Der Merwe et al. (2015), Yang et al. (2010), Zhao et al. (2008)
Maintenance/service	6	Centrich et al. (2014), Chen et al. (2009), Crowder et al. (2012), Goffin (2000), McKay and Kundu (2015), Wong et al. (2008)
Manufacturing	7	Büyükközkan and Berkol (2011), Chen et al. (2009), Geng et al. (2011), Ghahramani and Wang (1998), McKay and Kundu (2015), Sadek and Welp (2009), Vianello and Ahmed-Kristensen (2012)
Law and standards	2	Berkovich et al. (2009), Song et al. (2013)

Berkovich et al. (2009) and Song et al. (2013) explicitly mention laws and standards as a type of source that needs to be considered in the requirements development process.

Agostinho et al. (2014), Fiksel (2003), Harrington and Srai (2012), Kim et al. (2011), Riel (2010), Song et al. (2013) and Peruzzini et al. (2014) discusses considering sources throughout the entire life cycle of the offering. These papers often consider the offering and its related system with a more holistic perspective. In these papers, specific types of sources are rarely mentioned. Fiksel (2003) emphasises so-called *stakeholders beyond the usual supply chain*, and that aspects from sources need to be considered in a wider context depending on the system boundaries in order to be able to develop requirements that could support the design of effective and resource-efficient offerings.

5.2.2 ASPECTS CONSIDERED

Table 6 presents some examples of aspects used when developing requirements. In the performance category in Table 6, aspects mentioned, for example, by Isaksson et al. (2009, p.329) such as “*easy to maintain, upgradeable, with built-in sensors for collecting in-use and service data, and easy to use*” are included. On a similar note, Gu and Sosale (1999) describe how integrated offerings require life cycle design and need to balance simultaneous consideration of functionality, manufacturability, assemblability, serviceability, reusability and recyclability. The papers mentioning maintenance use it as an argument for enabling a prolonged lifetime and effective usage of the offerings, and that this would then imply a more effective and resource-efficient offering.

Table 6 – Examples of aspects considered when developing requirements.

Type of aspect	# of papers mentioned in	References
Performance	3	Durugbo (2013), Gu and Sosale (1999), Isaksson et al. (2009), Maussang et al. (2009)
Maintenance	4	Agostinho et al. (2014), Centrich et al. (2014), Crowder et al. (2012), Gu and Sosale (1999), Wong et al. (2008)
Remanufacturing	4	Hatcher et al. (2011), Kurilova-Palaisaitiene et al. (2015), Lindkvist and Sundin (2012), Sundin and Bras (2005)
Marketing	2	Cocca and Ganz (2015), Durugbo (2013)
Sustainable	2	Cocca and Ganz (2015), Durugbo (2013)

Environmental	13	Büyükoğkan and Berkol (2011), European Commission (2006), European Union (2003), European Union (2009), Fiksel (2003), ISO 14006 (2011), Kim et al. (2011), Luttrupp and Lagerstedt (2006), Maussang et al. (2009), Peruzzini et al. (2014), Trappey et al. (2011), Vezzoli and Sciamia (2006), Zhao et al. (2008).
Economic	4	Geng et al. (2011), Kim et al. (2011), Maussang et al. (2009), Peruzzini et al. (2014)
Social	3	Büyükoğkan and Berkol (2011), Fiksel (2003), Peruzzini et al. (2014)

Cocca and Ganz (2015) use sustainability as a marketing possibility, and therefore consider it in the requirements development process. By studying eco-labels, they developed requirements based on, for example, resource consumption, infrastructure, emissions, waste, and wastewater. An integration of green services in the offering could create additional values for the offering and increase customer satisfaction (Cocca and Ganz, 2015).

A large amount of the literature regarding requirements for integrated offerings fails to consider environmental aspects at all, and rather has an economic focus even though the provided business model has an implicit thought to reduce environmental impact. An example is Maussang et al. (2009, p. 364-365), who claim *“Indeed, the evaluation of PSS solutions from an environmental, economical and technical point of view is crucial to ensure enterprises switch largely to these solutions”*²; these categories, however, are not mentioned again in the proposed design process in the step of developing requirements.

5.3 SOURCES AND ASPECTS CONSIDERED IN INDUSTRY

These findings are based on results from Interview Study 1. Some additional detailed company findings can be found in Paper 3 (Appendix 3).

5.3.1 SOURCES CONSIDERED

The companies mentioned three primary sources: *customer, law and standard, and company strategy*.

As an example of how much influence the customer can have is that one company explicitly mentions that requirements that are closely related to the customer are always prioritised. For environmental requirements, this implies that it is more thankful to work with, for example, fuel economy over issues related to materials, as the cost of fuel will directly affect the customer experience when driving compared to if the materials applied in the car are recycled, which does not affect the customer as directly.

² PSS in this quote refers to Product Service Systems, that is a *“...system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs, and have a lower environmental impact than traditional business models”* (Mont, 2002, p. 239). In some research, PSS is used as a synonym for integrated offering, but in thesis only implies the business model.

Some of the companies express that they are highly controlled by product-specific ISO standards and regulations. This is perceived by the affected companies to inhibit what offerings could be designed. Directions and standards can also be used to help determine what environmental issues need to be considered, for example: the *Ecodesign Directive* (European Union, 2009); *Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)* (European Commission, 2006); *Restriction of Hazardous Substances Directive* (European Union, 2003); and the *Environmental Management Systems Standard* (ISO 14006, 2011).

Company strategy is also mentioned as a strong influence on what types of offerings are developed, or if they are developed at all. Even though the company strategy is more or less a function of the two earlier mentioned sources (customer, law and regulation), it still contains several interpretations and assessments that are not always a direct result of, for example, the customers' desires or what is the minimum baseline.

Among the SMEs, the business model itself was commonly used as an argument for effectiveness and resource efficiency, but relating aspects are rarely applied in the requirements development process when designing the offering.

5.3.2 ASPECTS CONSIDERED

Six major aspects were identified: *financial, materials used, reducing waste, prolonged life, and work environment*.

As one of the companies put it, *"the offering with the lowest environmental impact is the one you don't design"*. But looking at this cynically is impossible, and implies that there will always be several aspects to balance. Therefore, one also has to consider making an effective and resource-efficient offering economically sustainable so the company can make enough revenue to sustain itself while trying to balance environmental impact together with the costs and possible revenue. One of the companies uses, for example, the EU's barometer based on society's attitude towards the environment and what will be the most important environmental issue in the future. These results help in identifying what environmental issue to prioritise.

All companies have good knowledge about the materials in their offerings. Some work with "black lists", as one company calls them, which state what materials are not allowed to be in the offerings, for example, hazardous or scarce materials. These lists are primarily based on regulations, and internal requirements are often set higher than what is demanded by society in order to stay competitive and anticipate future possible laws. One company mentioned challenges with setting requirements for material choices, since these requirements can only be set as functional requirements and do not specify the preferred materials as such.

Most of the companies agreed that reducing the amount of materials required, not only it the final offering but also during the manufacturing, should imply a more effective and resource-efficient offering. One company discussed that it could benefit from involving the

manufacturing department to investigate how to develop requirements to minimize spillage when manufacturing the product elements of the offering.

Most of the interviewed companies either work with providing maintenance services or remanufacturing in order to prolong the product elements in the offering's life span. They both use environmental and cost arguments to support this type of business. One company also mentioned that high-quality products usually last longer, which affects what requirements are set for the products in order to make them sustain longer. One company expresses that few requirements are included in the design of new offerings to benefit remanufacturing, and compared to requirements that do not support remanufacturing implicitly, remanufacturing-related requirements have a rather low prioritization. Several of the companies are struggling with including aspects related to maintenance or remanufacturing in the beginning of the requirements development process. Usually, the departments that are responsible for these activities are included after the offering has already been defined.

One interesting finding that had not been identified in the reviewed literature was that several companies mentioned social aspects such as the working environment of the offering, for example, noise and vibrations. What this depends on is difficult to surmise, but should be fairly regular for the companies to think about since it is not uncommonly regulated, especially for CE marking in Europe, when considering the use phase of the offering. This should be an interesting topic to further discuss in future research.

5.4 IDENTIFIED KEY SOURCES AND ASPECTS

Some sources and aspects have been identified from the literature and industry to have a high influence on the potential effective and resource-efficient offering, and ought to be considered in the requirements development process.

- **Customers.** The customer is one of the most commonly used arguments by both the literature (see Table 5) and by all of the companies (see Section 5.3.1, Sources Considered) as to why offerings are designed the way they are. As the customer in the end is the one paying for whatever the company is supposed to provide, this is a strong argument for why this actor has such a strong influence. The company has to take the customer's desires strongly into consideration in order to keep them satisfied and keep up revenue. With such a high influence, this could also be a source for effective and resource-efficient-type requirements that will be highly prioritised. As the customer has high influence on the final performance of the offering, customers is highlighted as an important source to consider when designing effective and resource-efficient offerings.
- **Laws and standards.** Another profound influence stated primarily by the companies (see Section 5.3.1, Sources Considered) but not as widely discussed in the literature (see Table 5) is laws and standards. One clear example of this is how well established it is for the companies to work with the materials that should or should not be in the offerings. There are, however, missing guidelines on how to use the materials

efficiently. As the companies aim strongly at living up to laws and standards, this is a great possibility to affect effectiveness and resource efficiency in the offering and is therefore highlighted as a key source to consider.

Academic contributions show that there are great potentials in *maintenance* activities and *remanufacturing* (see Table 6) that should be considered, but this is rarely done currently in industry, yet is desired (see Section 5.3.2, Aspects Considered). This could, however, be a good way to find solutions on how to use materials more effectively and efficiently.

An interesting finding to consider is the perspective of the *entire life cycle*, as one of the most important things to avoid is sub-optimisation. If the offering is not designed with a full life cycle perspective for each element and the system as a whole, sub-optimisation of any specific life cycle phase may result in a higher environmental impact (Sundin, 2009). It is important to have a full life cycle perspective for each element and the system as a whole in order to avoid sub-optimisation. Aspects from each source should be considered from a sustainable viewpoint, implying environmental, social, and economic impact. This balance between environmental, economic and social impact is something that is commonly neglected today (see Section 5.3.2, Aspects Considered).

How the key sources and aspects are incorporated and considered in the requirements development process is further elaborated on in the following Chapter 6, Challenges in the Requirements Development .

6. CHALLENGES IN THE REQUIREMENTS DEVELOPMENT PROCESS

This chapter aims to answer RQ2, which asks: What challenges exist in the requirements development process when designing effective and resource-efficient offerings? Noteworthy is that both academia and industry have provided insights into what challenges exist in approaches currently used. In the chapter, results from different studies are presented and discussed, ending with conclusions for RQ2.

6.1 RQ2. WHAT CHALLENGES EXIST IN THE REQUIREMENTS DEVELOPMENT

PROCESS WHEN DESIGNING EFFECTIVE AND RESOURCE-EFFICIENT OFFERINGS?

This research question is designed to give insights into the challenges that exist in the requirements development process when designing effective and resource-efficient offerings.

6.2 CHALLENGES IDENTIFIED IN THE LITERATURE

In order to identify challenges that exist at companies through a review of the literature, focus has been on identifying approaches for requirements development, such as methods and tools that have been developed to help overcome challenges. Looking at these potential supports and what they try to simplify provides insights on what challenges are the main issues in industry. This has also provided insight on some challenges in the implementation of methods and tools in industry.

As can be seen in Table 7, the most commonly used tool when developing requirements in the reviewed papers is Quality Function Deployment (QFD) (which is a tool to translate customer needs into quantitative parameters). It is also mentioned in a variety of different versions by, for example, Geng et al. (2011), Peruzzini et al. (2014), Tomohiko (2007), Yang et al. (2010) and Trappey et al. (2011). As an example, Geng et al. (2011) extend the original QFD to include both product and service-related engineering characteristics, and Tomohiko (2007) adds on environmental aspects as a part of the voice of the customer.

Table 7 – Compilation of methods and tools mentioned in the literature based on Paper 3 (Appendix 3).

Methods/Tool	Comment	References
Quality Function Deployment – original conditions	-	Azadi and Saen (2013), Brown (1991), Büyüközkan and Berkol (2011), Chen et al. (2011), Ghahramani and Houshyar (1996), Sousa-Zomer and Miguel (2017), Van Der Merwe et al. (2015)
Taguchi Method	-	Chen et al. (2011)
Data mining	-	Goh et al. (2009), Igba et al. (2015)
Kano model	-	Van Der Merwe et al. (2015)
Blue Ocean Strategy	-	Van Der Merwe et al. (2015)
Knowledge Desktop	Based on ontological hypertext.	Crowder et al. (2012)
Manufacturing information process	An approach to process manufacturing information through analysis of relationships by evaluating what is significant and where to allocate resources.	Ghahramani and Wang (1998)
Design for supportability	-	Goffin (2000)
Scenarios	Used to describe actions between the offering and the user and actions	Maussang et al. (2009)

	inside the integrated offering between the included elements to identify needs and wishes.	
Web-based integration framework	-	Shu and Wang (2006)

Some authors have highlighted the gap between needed and available support for incorporating and consideration of relevant sources in the requirements development process. One example is Sadek and Welp (2009), who claim that there is a lack of methods for integrating preferences of relevant sources. Another example comes from Yang et al. (2010), who indicate a need to better map connections between actors' needs and how they are fulfilled by functions in the offering as a whole, or by the functions in the individual elements in the offerings. Lastly, Berkovich et al. (2009) have identified two problems: first, that tractability between the sources' desires and the final requirements is lacking, and second, that the individual elements of the offering are designed separately and not with the purpose of fulfilling the requirements as an entity.

In Berkovich et al. (2011a), a structured literature review was carried out analysing different requirements development approaches originating from software engineering, and how appropriate they are for designing integrated offerings. This paper was followed by Berkovich et al. (2011b), where approaches from different engineering domains (product engineering, software engineering, service engineering and integrated approaches) were analysed in a similar way to the previous paper to evaluate how appropriate these approaches are for requirements development when designing integrated offerings. One highlighted result is the deficit of cooperation between the different engineering domains, which also makes it difficult to apply approaches between domains (Berkovich et al., 2011b).

Some more elaborate methods and tools have been developed and are further described in Papers 1 (Nilsson and Lindahl, 2016) and Paper 3 (Appendix 3). These methods/tools were developed by Zhao et al. (2008), Meuris et al. (2014), Maussang et al. (2009), Berkovich et al. (2014), and Song et al. (2013).

6.2.1 VERIFICATION OF NEWLY DEVELOPED TOOLS

To investigate the industrial impact of methods discussed in literature, articles describing case studies were especially of interest. Fourteen different case studies were identified in the literature review (Agostinho et al., 2014, Büyüközkan and Berkol, 2011, Centrich et al., 2014, Crowder et al., 2012, Geng et al., 2011, Harrington and Srail, 2012, Kim et al., 2011, Maussang et al., 2009, McKay and Kundu, 2015, Peruzzini et al., 2014, Song et al., 2013, Trappey et al., 2011, Vezzoli and Sciama, 2006, Wong et al., 2008). The type of sector each case was applied in and some additional details can be found in Paper 1 (Nilsson and Lindahl, 2016).

The most interesting finding was that none of these papers describe or mention anything about the usage of the tools outside the scope of the specific case study. Primarily, case

studies were used to showcase examples of application, rather than evaluating methods utilized in industry.

6.3 CHALLENGES IDENTIFIED IN INDUSTRY

One major finding is how different SMEs work in comparison to larger companies, and therefore the following results have been divided into two sections. Findings presented here are based on Paper 2 (Wiesner et al., 2017a) and Paper 3 (Appendix 3), and were compiled with relevant results from Interview Study 2 in order to expand to experiences from large companies. Further details and knowledge gained from Interview Study 2 can also be found in the master’s thesis by Johansson (2017).

6.3.1 SME FINDINGS

Table 8 presents an overview of the methods and tools used by the SMEs. For each company, what part of the offering had the primary requirements focus is presented, as well as what types of methods and tools were applied during the requirements development process. These methods and tools are not the only ones used, but are brought forward as examples of applications. Most of the methods and tools are very simple and basic means.

Table 8 – Examples of methods and tools utilised by SMEs, based on Paper 2 (Wiesner et al., 2017a).

Company	Requirements Focus	Methods and Tools
SME 1	Product	<ul style="list-style-type: none">• Paper Template• Drawings
SME 2	Service	<ul style="list-style-type: none">• Notes• Alternative Options
SME 3	Product and software	<ul style="list-style-type: none">• Catalogue Options• Spreadsheets
SME 4	Product	<ul style="list-style-type: none">• Extrapolation• Prototyping
SME 5	Product	<ul style="list-style-type: none">• Lists• Surveys

From the study, it can be claimed that the SMEs use non-formalised requirements development processes and approaches from their original field of business, for example, product engineering for manufacturing companies, or service engineering for service providers. When the SMEs try to integrate new elements into their offerings they are provisionally aligned with each other, which can be explained by the lack of experience outside the core business. This lack of integration between the offering’s elements may inhibit the functionality and quality of the offering. This is often a result of the fact that these SMEs often neglect requirements development, which leads to unnecessary integration activities later in the offering’s design process that could have been avoided if the requirements would have been right from the beginning (Wiesner et al., 2017a).

Furthermore, it can also be identified that most SMEs do not use a defined requirements development process. Some activities might be performed, but they rather stem from good practice than a typical developed method or tool. This, on the one hand, enhances flexibility and shortens delivery time, but on the other hand might have negative impact on the quality of the requirements specification and the lack of knowledge regarding what actually can be expected by the offering’s functionality.

Two main challenges were identified for the SME cases:

- *Formalisation of the requirements development process.* This entails formalising their requirements development process and extending it to other domains in order to facilitate integration between elements in the offering.
- *Missing methods and tools.* Missing are dedicated requirements development methods and tools suitable for SME demands on functionality and pricing.

More detailed information can be found in Paper 2 (Wiesner et al., 2017a).

6.3.2 FINDINGS FROM THE LARGE COMPANIES

Table 9 presents an overview of the methods and tools used by the large companies in the study. Presented for each company is the part of the offering that had the primary requirements focus, and which type of tools they applied during the requirements development. These methods and tools are not the only ones used, but are brought forward as examples of applications. Compared to applications at the SMEs, more complicated and well-structured methods and tools are utilized.

Table 9 – Examples of methods and tools utilised at large companies.

Company	Requirements Focus	Methods and Tools
Large 1	Product	<ul style="list-style-type: none"> • Systematic function breakdown • Complex software
Large 2	Product	<ul style="list-style-type: none"> • Spreadsheets
Large 3	Product	<ul style="list-style-type: none"> • Lists
Large 4	Software	<ul style="list-style-type: none"> • Kanban • Scrum • Blueprint, or framework • Complex software
Large 5	Product and services	<ul style="list-style-type: none"> • Root-cause analysis • Quality function deployment
Large 6	Product	<ul style="list-style-type: none"> • Spreadsheets

From the interviews, a common factor lies within the importance of the earliest phases of the design process in order to “do the right thing” from the beginning. All the companies studied have a large focus on the paying customer, who is mainly represented by internal voices at the company; for example, the marketing department represented the customers instead of involving the actual customer or end user. The needs of the customers, together with relevant laws and regulations, are used to define baselines for the integrated offering to

fulfil. These are later engineered into requirements for different levels of the integrated offering. The interviewed companies have a similar way to break down requirements, for example, the entire offering, subsystems, and individual elements.

Four main challenges were found for the large-company cases:

- ***Life cycle perspective.*** This entails the identification and inclusion of relevant aspects from relevant sources throughout the offering's life cycle. Primarily, the companies struggled with identifying and including which sources and aspects they should take into consideration in the requirements development process.
- ***Understanding the underlying aspects for all requirements on all levels.*** An issue raised was that in several cases, it was difficult to understand why requirements were defined the way they were. This meant missing out on linkages to the original source of the requirement and change history.
- ***Prioritization of requirements.*** This is both within individual items in the offering and between them.
- ***Difficulty to track how requirements affect each other between different elements in the offering.*** This is a major challenge when trying to prioritise among the requirements.

More detailed information about Company Large 1-3 can be read in Paper 3 (Appendix 3), while additional detailed information about Company Large 4-6 can be found in the master's thesis by Johansson (2017).

6.4 IDENTIFIED KEY CHALLENGES

Requirements development processes have challenges in coping with developing integrated offerings that are effective and resource efficient. In order to obtain more effective and resource-efficient integrated offerings, the requirements development process should incorporate relevant aspects (described in Section 5.4, Identified Key Sources and Aspects) in a more efficient way compared to traditional product-focused requirements development processes. Requirements development is rarely done as an integrated process between different engineering domains (for example, software and hardware), even though the different domains impact the same underlying needs of the offering. This implies the sub-optimisation of requirements that affect effectiveness and resource efficiency.

There are few signs, in both the literature and at manufacturing companies, of comprehensive tools and methods for requirements development that support the design of effective and resource-efficient integrated offerings. It is shown that methods used in the industry tend to originate from the original business domain, and methods and tools for integrated approaches are seldom used. This neglects important prerequisites for designing integrated offerings requiring additional integration that, in the end, could have been avoided if they had been considered from the beginning.

Three prominent characteristics exist for designing offerings that make requirements development especially challenging:

- ***Involvement of different engineering domains.*** As an offering consists of elements that originate from different engineering domains that all have their own formalisms and traditions, it is challenging to work in an integrated requirements development process. Requirements stretch beyond the individual elements, and it is essential that all domains come together to get the highest value of the finite offering. It has to be a communal view of the targeted offering's purpose and goal.
- ***Large number of sources to consider.*** Several sources affect the offering, both internally and externally. Trying to cooperate between departments internally can be difficult in itself, but also including external actors, for example, makes the consideration and fulfilling more voices, desires and constraints in the requirements development process even more complex.
- ***Complexity of the offering.*** With a large number of elements in the offering it is demanding to synchronize functions and requirements among them. Interoperability between requirements and the development of them can become extremely complex. Unwanted emerging behaviours are also more difficult to anticipate in a complex system.

Tied to the above characteristics, some specific challenges have also been identified for incorporating effective and resource-efficient requirements in the offering. Effective and resource-efficient requirements affect the entire offering, and therefore designing effective and resource-efficient offerings has to be a part of the common view of the offering's purpose. There is, therefore, a great challenge in how to incorporate requirements that affect effectiveness and resource-efficiency in the offering, and how this applies to several engineering domains. To avoid sub-optimising the offering, it is required to have a holistic perspective of the offering's life cycle and affected actors during the requirements development process. An explicitly mentioned challenge from industry is difficulty in prioritization with requirements that do not affect effectiveness and resource efficiency against those that do, due to, for example, difficulty in measuring the effect of the requirements regarding effectiveness and resource efficiency, which also creates uncertainties and risks.

What type of support that is desired by industry to meet these challenges is further elaborated on in the following chapter, 5 Success Factors for an Improved Requirements Development Process.

6.4.1 DIFFERENCES BETWEEN LARGER COMPANIES AND SMES

To some extent, both SMEs and large companies are struggling with similar challenges but have very different prerequisites on how to tackle them, something which is largely neglected in the literature.

Large companies

At larger companies, a common challenge was structuring and communication requirements throughout the organisation. The trace between the requirement and its original source as well as the rationale is often missing, making it difficult for the designer to understand the

purpose of the effective and resource-efficient requirements. Large companies also struggle with incorporating effectiveness and resource efficiency as a common goal for the offering, which also makes it hard to justify why requirements that are considered to affect effectiveness and resource-efficiency are defined in the requirements specification. This is essential in order to include and get a higher prioritization of aspects benefiting resource efficiency and effectiveness in the offering.

SMEs

One great advantage mentioned by the SMEs is that they commonly have good communication between departments, which facilitates the design of integrated offerings that consider relevant sources, and should also give a better understanding of the common goal of the offering. Regarding the amount of experience within the company, it can be a challenge for SMEs to incorporate aspects enhancing effectiveness and resource efficiency (Le Pochat et al., 2007). SMEs also tend to undervalue or not consider the design process (Moultrie et al., 2007), thus excluding essential parts such as requirements development.

At the interviewed SMEs, approaches adapted for integrated design are rarely used. With limited resources and competences they seem especially challenged to adapt and apply a suitable requirements development process, methods and tools accordingly. If there even exists a requirements development process currently at the SME, it most likely originates from the original business domain of the company, which is likely to neglect relevant aspects in the requirements development process for designing integrated offerings, for example, consideration of relevant sources and aspects.

Processes, methods and tools that currently exist are not well adapted or even suitable for SME businesses and their working models. There are already solutions for support identified among the large companies, but these are too expensive and complex for SMEs to be able to apply in practice.

7. SUCCESS FACTORS FOR AN IMPROVED REQUIREMENTS DEVELOPMENT PROCESS

This chapter aims to answer RQ3, which asks: How could the requirements development process be improved in order to support the design of more effective and resource-efficient offerings? This is done by synthesising knowledge from the theoretical framework with the learnings from the earlier RQs.

7.1 RQ3. HOW COULD THE REQUIREMENTS DEVELOPMENT PROCESS BE IMPROVED TO SUPPORT THE DESIGN OF MORE EFFECTIVE AND RESOURCE-EFFICIENT OFFERINGS?

This research question aims to identify success factors for how the requirements development process could support the design of effective and resource-efficient offerings. By utilising the understanding from the theoretical framework together with the gained knowledge from the previous two research questions, a suggestion is proposed on how the requirements development process could be improved to support the design of more effective and resource-efficient offerings.

7.2 IDENTIFIED SUCCESS FACTORS

Four main success factors have been identified for the requirements development process when designing effective and resource-efficient offerings:

- ***Clear and common goal.*** This applies to all who are involved in the offering's design. This can be achieved by having the goal clearly specified in the requirements development process.
- ***Consider entire life cycle.*** During elicitation, this will help in overcoming, for example, sub-optimisation and in finding the offering that, from a life cycle perspective, is the most effective and resource efficient.
- ***Utilisation of requirements attributes.*** It is important to create a specific *type* for effective and resource-efficient requirements. This will support communication and to some extent support *traceability*, which actually is the fourth success factor.
- ***Traceability.*** There are four types of traceability that can especially support the design of effective and resource-efficient offerings:
 - *Trace to parent*, to understand how requirements regarding effectiveness and resource efficiency have been derived between different levels of the offering's requirements.
 - *Trace to source*, to keep track on the purpose and rationale of the requirement and how it connects to effectiveness and resource efficiency.
 - *Trace to interface definition*, to comprehend how requirements affect effectiveness and resource efficiency between the different elements in the offering.
 - *Trace to peer requirements*, to understand how requirements affect effectiveness and resource efficiency between components in the elements within the offering.

These success factors are mainly based on knowledge gained from the literature, and are selected as they could potentially help overcome challenges identified in Section 6.4, Identified Key Challenges. Table 10 provides an overview of the challenges each identified success factors could help overcome. A more detailed description of how each success factor helps to overcome the identified challenges can be found in the following sections.

Table 10 – Overview on how each identified success factor can help in overcoming the identified challenges.

Success factors \ Challenges	Involvement of different domains	Large number of sources to consider	Complexity of the offering
Clear and common goal	x		x
Consider entire life cycle	x		x
Utilisation of requirements attributes	x	x	x
<i>Traceability</i> To parent		x	x
To source	x	x	x
To interface definition	x		x
To peer requirements	x		x

How the identified success factors can then be utilised in the requirements development process is further described in Section 7.3, Suggested Requirements Development Process. That description will further describe the motivation regarding why these specific success factors were selected for this research.

Clear and common goal

Setting clear and common goals should facilitate the involvement of different engineering fields and the complexity of the offering, as this gives a common goal for the different domains to work toward and for them to design an offering as a whole that also strives toward this common goal. As it is in the earliest phases where one has the greatest possibility to affect the environmental impact (British Standards Institution, 2017) and the final performance of the designed offering (Lindahl, 2005, Lindahl and Sundin, 2012, Ullman, 2002), it is important to try to "do the right thing" from the beginning.

Consider the entire life cycle

Considering the entire life cycle may actually contribute to the challenge of including a large number of sources as it might provide more sources to consider, which according to Kurtz and Snowden (2003) may worsen the offering's design process, making it even more complicated and complex. The life cycle perspective should, however, give a better understanding of the different engineering domains involved, as they all will be given a chance to contribute with aspects from their own points of view. The life cycle has to be considered for each individual element and the offering as a whole to avoid sub-optimisation, which otherwise may lead to a larger environmental impact (Pigosso et al., 2010). A life cycle perspective should, therefore, support understanding of the complexity of the offering by providing better insight into how each element of the offering works by itself as well as together as a whole.

Utilisation of requirements attributes

By utilising requirements attributes, additional information can be added to a requirement without making it an overcomplicated statement (Hull et al., 2011). By adding more information to the requirements it should, if done accurately, support communication between the different engineering domains involved by giving a more elaborate

understanding as to why the requirement is set the way it is. In a similar way, with more information the requirements attribute should also give a better understanding of the complexity of the offering. An example given by Hull et al. (2011) is to add on the source as a requirements attribute, which should support the challenge of several involved sources by making it easier to see how each requirement ties to each considered source.

Traceability

Traceability ensures that it is clear where the requirement came from, what requirements are related to it, and what requirements were derived from it (Hull et al., 2011). This should facilitate all of the identified challenges, depending on what type of traceability is used.

- ***Trace to parent.*** By enabling traceability between requirements that have been derived from another requirement, it should support a better understanding of the complexity of the offering by providing a map over how requirements on different levels relate to each other.
- ***Trace to source.*** By utilising, for example, a requirement's attribute to tie the requirement to its original source, this traceability should support the understanding of how all the considered sources are related to each requirement.
- ***Trace to interface definition.*** As an offering consists of several elements, those elements have to be jointly designed in order to create a successful integrated offering (Mont, 2002). By utilising a trace to interface, it should support the involvement of different engineering domains as it becomes clearer how requirements between different elements of the offering relate to each other.
- ***Trace to peer requirements.*** To cope with the complexity of the offering, it is also relevant to be able to trace between components within the individual elements in the offering. This should, similarly to the trace to interface definition, support the involvement of different engineering domains as this trace shows how components within the individual element relate to each other.

7.3 SUGGESTED REQUIREMENTS DEVELOPMENT PROCESS

The following framework is presented in Paper 3 (Appendix 3), and will be used again here to demonstrate how the requirements development process could be utilized to obtain more effective and resource-efficient offerings. In particular, it focuses on how to handle the identified key challenges of discussed in Section 6.4, Identified Key Challenges. To overcome these challenges, the identified success factors in the section above (7.2, Identified Success Factors) and some other aspects have been incorporated into this suggested requirements development process to support the design of more effective and resource-efficient integrated offerings.

As a reminder, the definition of a requirement by ISO/IEC/IEEE 15288 (2015, p.8) is: “A statement that translates or expresses a need and its associated constraints and conditions”. This implies that aspects have to be processed by an engineering activity in order to be called a requirement; anything before that is referred to as aspect, for example, information, a need or a constraint.

By aggregating knowledge gained through the research process, a requirements development process is presented in Figure 9, based on both the literature and processes used in industry (both formal and informal). Short summaries of each step are presented below (more detailed descriptions are presented in the following sections):

- **Mission statement.** A document defining the starting line and containing, for example, the project background, project description, goals, primary market, assumptions, and primary actors.
- **Elicitation.** Gathering aspects from relevant sources throughout the offering's life cycle.
- **Set of aspects.** A document containing a set of aspects that is used to define requirements.
- **Analysis.** The interpretation and definition of requirements based on the set of aspects.
- **Target specification.** A set of defined and documented requirements describing the *desired* performance.
- **Negotiations.** Deviations from the target specification due to, for example, gained knowledge or new prerequisites.
- **Final specification.** A set of specified and documented requirements describing the *expected* performance.

The names of the steps are primarily taken from the literature, and content is adjusted according to both industry and the literature. A tool is seen as an instrument that enables the performance of a certain task, and can in that manner be utilized throughout the requirements development process, either in one or several of the different steps.

Figure 9 – Suggested requirements development process based on Ulrich and Eppinger (2011), Kossiakoff et al. (2011), and Kotonya and Sommerville (1998).

The requirements development process does not have to be seen as step that must be totally completed before moving on to designing the offering. From the elicitation step, a forward-looking dialog should be maintained to really integrate available information into the specification to make sure that it actually reflects what the offering is supposed to fulfil. The final specification might not be finished until the detailed design of the offering. By using the specification as a living document, validation can be a part of the process and not just a specific step at the end, and the specification can then progress both with what the actors desire from it and what the company is able to offer them (Kossiakoff et al., 2011).

7.3.1 MISSION STATEMENT

The mission statement is a perfect opportunity to define clear goals that are the basis for the entire requirements development process and which lay the foundation for what the offering is supposed to do. By including aspects about effectiveness and resource efficiency, this will

be derived and impregnated throughout the requirements of the entire offering and should provide support later, during negotiation.

7.3.2 ELICITATION

In this step, relevant sources for each life cycle phase are identified and their aspects extracted. Suggestions on important sources and aspects that have high influence on effectiveness and resource efficiency are described in Section 5.4, Identified Key Sources and Aspects.

7.3.3 SET OF ASPECTS

When sources have been identified and aspects elicited, one has a set of aspects. To enable traceability, it is important to document both the source (for example, person, organisation, document, or process) and the original statement. This will become important in later phases, for example during analysis and negotiation, to show the purpose of the requirement and how it connects to effectiveness and resource efficiency.

7.3.4 ANALYSIS

During analysis it is important to keep track of how the requirements on different levels of the offering will, in the end, fulfil the primary defined mission statement. Here, interfaces between the elements in the offering are also important to investigate and define. In a similar matter, how the requirements within each element relate to each other will also be important during negotiation to understand how all requirements relate and affect each other. With a better understanding of this, unnecessary risks and uncertainties can be avoided.

7.3.5 TARGET SPECIFICATION

By documenting all requirements, target specification can be used as a great tool to, for example, communicate with actors or track versions of the design of the offering itself.

The following requirements attributes can particularly contribute to overcoming challenges in the requirements development process to provide better support for designing effective and resource-efficient offerings:

- **Type.** Any aspect considered to affect the effectiveness and resource efficiency of an offering should be viewed as a specific type of requirement, for example an "effective and resource-efficient" type.
- **Priority.** Adding a stated priority should support requirements that are considered to affect effectiveness and resource efficiency during negotiation.
- **Rationale.** The purpose of the requirement has a direct implication on if a requirement is considered to affect effectiveness and resource efficiency. Understanding the rationale should also be facilitating during negotiations.
- **Relationship to other requirements.** Documenting the four relevant tracing types mentioned earlier should facilitate the realisation of integrating the offering as well as possible. Achieving an understanding of how the requirements that are considered to

affect effectiveness and resource efficiency also affect each other should also support avoiding sub-optimisation in the offering.

- **Source.** Once again, this will allow traceability as to where the requirements that are considered to affect effectiveness and resource efficiency originate from, thus enhancing the requirement's purpose.

This document should also be of great support when designing the offering itself, giving the designer a better understanding of what the offering is supposed to fulfil.

7.3.6 NEGOTIATIONS

This step can be seen as a major part of validation, where discussions move from that originally desired for the offering to fulfil to what the offering actually will do in the end. Here, focus should be put on minimizing risks and uncertainties by clearing out prioritisations during the analysis of the requirements. By using the described attributes in the specification, requirements that are considered to affect effectiveness and resource efficiency should have a stronger argumentation and make clearer statements by utilising good traceability to the source and how they relate to other requirements.

7.3.7 FINAL SPECIFICATION

The final specification should have moved from what was in the target specification described as desires by the sources, to how the definite offering is expected to perform. Defining the ultimate requirements well, without excessively over-specifying and locking in the final specification, can open possibilities for the provider to, for example, adjust the offering so that a recycled material, that may have uncertain availability, can be used when possible, but still another material is okay to use when it is not available. This document should be an agreement on the offering's performance, still focusing on *what* and not *how*. Doing so keeps the possibility alive to adjust the offering throughout its entire life cycle, hopefully creating endless opportunities to make changes for an even more effective and resource-efficient offering the more the company learns from its behaviour.

8. FINAL DISCUSSION, CONTRIBUTIONS AND FUTURE RESEARCH

This chapter presents a final, general discussion on the topics earlier presented in the thesis, as well as a summary of its knowledge contributions to academia and industry. The chapter ends with some suggestions for future research.

8.1 FINAL DISCUSSION

The main objective of this thesis, defined in Section 1.6, Objective and Research Questions, is to “investigate how the requirements development process could be improved in order to better support the design of effective and resource-efficient integrated offerings”. This has been addressed by investigating three research questions based on: What *Types of sources and aspects* to consider, *Challenges* to overcome, and *Success factors* that could help overcoming the identified challenges. These results are then integrated into a suggested requirements developments process. All these parts should together contribute to the fulfilment of the objective of this thesis.

Based on the empirical findings in Section 6.3, Challenges Identified in Industry, manufacturing companies currently overlook requirements development during the early phases of the design process of effective and resource-efficient offerings. The value of effort does not become evident until later phases in the design process. Excluding the consideration of aspects that benefit effectiveness and resource efficiency in the early phases risks generating an offering with a lower value than necessary, for both the customer and the environment. By utilizing the suggested framework presented in Section 7.3, Suggested Requirements Development Process, it should be comprehensible how the requirements development process can support the design of effective and resource-efficient offerings.

The main challenges identified in Section 6.4, Identified Key Challenges, are tied to prerequisites set by characteristics of integrated offerings: *involvement of different engineering domains*, *large number of sources to consider*, and *complexity of the offering*. These are the main reasons why challenges exist to incorporate aspects that affect effectiveness and resource efficiency in the design of offerings. These characteristics are met by the identified success factors applied in requirements development, acknowledged in Section 7.2, Identified Success Factors: *clear and common goal*, *consider entire life cycle*, *utilisation of requirements attributes*, and *traceability*.

These success factors might appear simple to implement, but could easily become very complex in practice. Especially for companies that already have a well-established process that has to be changed and adapted accordingly, in comparison to a company without a process that can start with a clean sheet. Further research on this first version of the framework has to be considered, especially as there is a low adoption rate in industry on solutions contributed by academics (See Section 6.2.1, Verification of Newly Developed tools).

This research ends with a suggestion on how the requirements development process could support the design of effective and resource-efficient offerings, but does not include any verified results on its application. Knowledge gained through this research process and well-substantiated assumptions imply that this suggestion should be helpful. Evaluation with, for example, life cycle assessments to estimate the reduction of environmental impact, and practitioners’ feedback to assess how the process functions, is required in future studies.

8.1.1 ETHICAL IMPLICATIONS OF THE RESULTS

This research should contribute to a sustainable development that includes environmental, social, and economic aspects. The results in this thesis should support companies on how to address and balance environmental, social, and economic aspects with each other, and not at the expense of one or another of these aspects. A common myth in industry, is that aspects benefitting environmental or social aspects are always more expensive, but this does not have to be the case. Several of the companies included in this research show that designing effective and resource-efficient offerings also can be beneficial economically, by for example, reducing the required amount of material in the offering, where less material directly imply reduced costs and a reduced environmental impact.

8.1.2 RESEARCH APPROACH AND METHODOLOGY IMPLICATIONS ON THE RESULTS

Both the structured literature reviews included terms related to effectiveness and resource efficiency. It was difficult to find success factors in these reviews, but the in-depth literature review permitted the exploration of areas beyond the structured reviews. Conducting a structured literature review without including terms related to effectiveness and resource efficiency can become overwhelmingly extensive. It was challenging to identify papers relevant to the research topic of this thesis, and both the structured literature reviews were performed with extensive manual sorting to not accidentally exclude relevant papers. Using other search words and databases may have led to a different result.

The fact that this research has been a part of the Mistra REES program has provided the possibility to include companies that are truly interested and engaged in the topic of effectiveness and resource efficiency. Another context, or only including individual companies, would probably not have given the same results. Few of the included companies currently work actively with including aspects relating to effectiveness and resource efficiency in the requirements development process, but nevertheless have aspects included that do relate to this topic. Most of the companies are also primarily manufacturing companies with a traditional business model relying on selling physical products, yet all of them either have an alternative business model which provides an integrated offering, or desire to do so. Researching more companies that actively work with including aspects related to effectiveness and resource efficiency in the requirements development process would have been desirable, but these companies were a challenge to identify.

The included companies have confirmed the results in this thesis in an ongoing review of the results through workshops and discussions. The scientific relevance has been continuously reviewed through seminars and conferences, for example, where the author presented results while peer reviews and researchers from adjacent fields provided feedback.

8.2 CONTRIBUTIONS TO ACADEMIA

The original contributions of this research provide academia with insights on key challenges and success factors in requirements development for supporting the design of effective and resource-efficient offerings. This is done by presenting crucial sources and aspects that need to be considered (presented in Section 5.4, Identified Key Sources and Aspects), and highlighting important challenges (presented in Section 6.4, Identified Key Challenges). In order to overcome these challenges, success factors are identified (presented in Section 7.2, Identified Success Factors). The final results are an adapted requirements development process, utilising gained knowledge, in order to better support the design of effective and resource-efficient integrated offerings (presented in Section 7.3, Suggested Requirements Development Process).

8.3 CONTRIBUTIONS TO INDUSTRY

The primary contribution to industry is the suggested requirements development process showing how requirements development can be utilised to design more effective and resource-efficient integrated offerings. This is not the one and only solution toward designing more effective and resource-efficient offerings, but used in a correct manner, it should support both larger companies and SMEs in the design process.

8.4 FUTURE RESEARCH

The main results of this thesis have also contributed in identifying topics in need of future research. Successive research focusing on the same topic would need to find suitable approaches to solve how to incorporate, in practice, the identified success factors of this thesis into day-to-day life at the company.

Evaluation of suitable tools and methods

Manufacturing companies desire support in, for example, how to incorporate the right sources and aspects in order to achieve more effective and resource-efficient offerings. The success factors in this thesis show *what* to focus on, but are lacking a description of *how* it should be done. Here, it could be of interest to assess different methods and tools, for example, Lean, agile development, or Scrum, in how well they are suited to support the development of effective and resource-efficient requirements. Several tools exist in, for example, software engineering and systems engineering that could especially be of interest to further investigate. Results from the interview studies show that companies with a strong mechanical engineering background do not commonly use these tools.

Evaluation of impact

Future research is also needed to determine if this added support for requirements development actually provides a more effective and resource-efficient offering. This should

be assessed and evaluated in a proper manner to show clear potential benefits from a sustainability viewpoint.

Consideration of social aspects

Another interesting finding was the lack of consideration of social aspects in requirements development in the literature. It can only be speculated why this is the case, but similarly to challenges with environmental aspects, it could be that social aspects are difficult to measure and also difficult to compare values against cost.

Terminology and other frameworks

Between the different engineering domains in which this research has been conducted, one has to be careful in how to express oneself. In future research, it could be of interest to try to fit this framework into already well-established processes that are used in systems engineering, for example, ISO/IEC/IEEE 15288 (2015), which make a difference between business, stakeholder, and system requirements. Perhaps this type of structure could also help to facilitate, for example, traceability and the structuring of requirements.

8.4.1 ADJACENT FUTURE RESEARCH

Two other closely related subjects for future research have also been identified. These have a wider interest and do not only apply to the research gap that is of interest in this thesis (i.e., effectiveness and resource efficiency, design of integrated offerings, and requirements development), as they do not only relate to effectiveness and resource efficiency.

How can requirements developed in such a manner have enough value in relation to the effort that is necessary to develop them?

One general issue found in industry is that it considers the requirements development process to be too costly in both time and resources. An interesting viewpoint is the thought: When are what types of activities worth the effort? It would be interesting to conduct further research on what activities actually are necessary in requirements development, and how these activities can better show the resulting value in early design phases.

What are suitable requirements development activities for smaller companies?

Prerequisites for requirements development activities at SMEs - for example, the required effort or cost to implement and administrate - are largely neglected by both industry and academia. In line with the subject above, requirements development might not have to be as much of an extensive and workload-heavy process as it is perceived. There are solutions for large companies; for example, ISO/IEC/IEEE 15288 (2015) has clear working processes that can be utilized to structure cross-domain requirements development, but these processes are challenging for SMEs to adapt to their businesses due to the complexity of the processes. Support for "requirements light" could be a much appreciated tool for SMEs in their business development.

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Appended papers

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