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Review of Factors influencing Product-Service System Requirements along the Life Cycle

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Abstract. Rapid technological changes within a highly competitive global market have induced a transformation in the manufacturing industry. A wide range of services is added to the physical product in order to deliver new customized functions and other benefits in the form of Product-Service Systems (PSS). These developments induce a change from quasi-stable and simple socio-technical systems to a more complex and instable dynamic configuration. Various environmental factors also influence the requirements towards the PSS in all life cycle phases. However, such factors have yet to be systematically identified and categorised. Thus, this paper presents the results of a structured literature review on factors influencing the system requirements along the PSS life cycle. The review has classified such factors in three life cycle phases and four categories. Gaps in research have been identified for factors during operation and end of life, especially beyond functional requirements. Thus, future research opportunities have been derived.

Keywords: Product-Service System, Life Cycle, Requirements Engineering, Dynamic System Environment

1 Introduction

Rapid technological changes within a highly competitive global market have induced a transformation in the manufacturing industry. Digitalization increases the connectivity between production facilities, products and the customer, while extending their functionality along the whole life cycle [1]. In addition, reduced product cycles demand for reconfigurable manufacturing systems [2]. Following these trends, companies need to consider economic, ecological and functional requirements, in order to make a more sustainable value proposition, to be more efficient and effective on the market, and to satisfy the user needs [3]. As customers increasingly demand support for all phases of the product life cycle, from development over assembly and distribution to operation, a wide range of services is added to the physical product in order to deliver new customized functions and other benefits.

This trend has led to the introduction of Product-Service Systems (PSS) as a promising framework describing the integrated development, realization and offering of specific product-service bundles as a solution for the customer [4]. The growing complexity of these systems, combined with a dynamic environment, creates new challenges for the design process [5].

The system development process needs to handle competing stakeholder demands and dynamically respond to continually changing requirements coming from the environment [6]. In order to secure a comprehensive fulfilment of requirements in such an environment, it needs to be conducted across domains, throughout the whole value network and beyond the development phase. Only by considering such dimensions, it can be ensured that all requirements towards a solution are captured, taken into account when developing system components and that the solution is adaptable to changing requirements in later life cycle phases.

2 Methodology

A descriptive literature review was conducted for identifying factors influencing the PSS requirements along the system life cycle. To systematically screen all relevant literature, the review methodology was oriented on PRISMA, as one of the most widely used frameworks [7]. Due to the limitations of a conference paper, it is intended to describe the methodology and results in an upcoming journal paper in more detail. In summary, the following criteria were applied for the literature review:

- Search terms: *TITLE-ABS-KEY ("*PSS" OR "product-service system*" OR "functional product*" OR "extended product*") AND ("life cycle" OR lifecycle) AND requirements)*
- Database: SCOPUS, limited to journal articles, books and reviews in English or German, in subject areas related to PSS

The objective is to determine the current state of research on factors influencing PSS requirements along the life cycle. Specifically, two questions are addressed: 1) Which life cycle phase do the articles focus on (from begin to end of life, or across the life cycle)? 2) Which types of influencing factors do the articles consider (PSS functional requirements, or coming from different perspectives of the system environment)?

In order to cluster the papers according to the PSS life cycle stages, we had to define a common framework for categorization. While for PSS the product and service life cycles do often not coincide with each other, or are not linear [8], at high level it can be concluded that PSS have a begin-of-life phase, in which initial requirements are determined and the solution is designed, a middle-of-life phase, in which value is being created for the customer, and an end-of-life phase, in which the PSS is reconfigured or decommissioned. Thus, the papers are classified according to the criteria that they focus on methods, tools or applications for a single, multiple or all of these phases.

Regarding the influencing factors, the clusters were compiled descriptively with criteria derived from the analysed literature. The majority of the papers deals with functional requirements for PSS coming from the customer or user. However, sustainability

or decrease of resource consumption has been a core topic of PSS research for a long time. Papers addressing such issues are categorized with an ecological focus. Papers focusing on factors such as servitized business models are clustered with an economic focus. Finally, collaboration of different actors with complementary competences is an important enabler of PSS solutions. Papers dealing with influencing factors from the value network are classified with a network focus.

The life cycle phase and type of influencing factors are especially relevant due to the dynamic nature of PSS. While the functions of traditional products are designed during begin-of-life for the rest of the life cycle, the adaptability of PSS demands for the analysis of influences affecting its requirements during middle- or end-of life as well. Furthermore, due to the variety of stakeholders and the extended value network for PSS, it is necessary to go beyond the functional perspective for the solution. Because PSS also affect business processes and models, as well as answer to societal demands, such as sustainability, these perspectives should be included as well.

3 Literature Review Results

Following the methodology described above, 65 unique records were identified through the database search. After screening the titles, abstracts and keywords, 36 records were excluded due to weak relevance. These papers are apparently not addressing the influencing factors on PSS requirements and could thus not be assigned to any of the mentioned clusters and were not analysed in detail. For seven records, only title, abstract and keywords are open accessible through Scopus, while the full text requires additional subscriptions, which were not available. For the remaining 22 articles, the full text was analysed and included in the qualitative synthesis. The results were structured along the two main issues addressed by the review, PSS life cycle phases and categories of influencing factors on requirements. Percentages add up to a value greater than 100%, as some of the papers are related to more than one category.

Which life cycle phases do the articles focus on?

Out of the 22 papers, 17 papers have a focus related to the design phase of PSS. This was expected, as an emphasis is put on requirements engineering during this phase. However, it seems to confirm “traditional” engineering approaches for PSS, where requirements are more or less static and “fixed” after the design phase [9]. While interdisciplinarity between the product, service and software domain is commonly addressed, the view across a dynamic life cycle is missing.

Four papers have a focus on the operational phase of PSS, but mostly in relation to the design phase, in the sense to either anticipate possible maintenance scenarios during development, or derive information from the operational phase for the design of next generation PSS [10].

Two papers focus on the end of life phase of PSS. The low number of papers in this category seems surprising, considering the growing discussions on reuse and sustainability of products. Both papers analysed address the need to identify components and gather information on their condition from a more technical point of view [11, 12].

Seven papers take a cross life cycle phase perspective. The focal points of these papers are mainly frameworks that take into account elements like PSS stakeholders or environmental effects throughout the life cycle [13, 14]. Little attention is given to dynamic environments or changing requirements along the life cycle.

Which types of influencing factors do the articles consider?

14 papers mainly consider factors that influence functional requirements of the PSS. This also corresponds to the “traditional” engineering perspective of value being provided by a certain functionality of the PSS [15]. Accordingly, most of these papers are addressing the design phase, but some also cover operations (maintenance), end of life or cross life cycle functionalities. Other factors, such as economic or ecological influences are mostly discussed disconnected from functional requirements.

Four papers cover ecological factors influencing PSS requirements. Here as well, the focus is on the design phase. Naturally however there is a strong cross life cycle perspective and a view on the operational phase [16]. Surprisingly, no paper has put a strong focus on the PSS end of life.

Four papers as well consider economic factors influencing requirements on PSS. A strong focus is on the design phase again, because it is argued the PSS business model is defined here [17], but also cross life cycle effects are discussed [18].

A single paper considers networking as a factor for PSS operations. This seems to be an underrated area to derive PSS requirements in general and the connection to the other articles is weak [19].

The literature review has yielded results published between 2003 and 2020, with an average of two publications per year. There is no clear progressive trend in number of publications. However, comparing the publications related to the life cycle phases and factor categories shows a focus on functional requirements during design, as can be seen in Table 1.

Table 1. Publications related to life cycle phases and factor categories

| | Design | Operation | End of Life | Cross LC |
|------------|---------------------------|------------|-------------|----------------|
| Functional | 11 [9, 11, 15, 17, 20–26] | 2 [15, 21] | 2 [11, 12] | 3 [13, 17, 27] |
| Ecological | 4 [10, 14, 16, 28] | 1 [10] | - | 2 [14, 16] |
| Economic | 4 [17, 18, 29, 30] | - | - | 3 [17, 29, 30] |
| Network | - | 1 [19] | - | - |

The shades of grey in Table 1 indicate the different amount of publications in the topic areas (□ > 4, ■ 3-4, ■ 1-2, ■ 0). The uneven distribution suggest the existence of research gaps, which are discussed in detail in the next section.

4 Discussion

The analysis of the 22 papers included in this study on factors that influence the requirements on PSS along the life cycle shows that there is a clear imbalance, both in terms of articles focusing on the different phases as well as in what factors they actually address. 17 out of 22 papers related to the design phase seem at first sight quite naturally, since this is how complex systems have been designed for decades. If these systems are to be used in a stable environment, it can be expected that the requirements will not change too much over time. However, today technology changes rapidly in a dynamic environment and thus also changing the customer requirements. It seems problematic that there is so little published research on the factors that influence the requirements in the operational phase and above all in the end of life phase. This will impact the sustainability of PSS and also the expected life time of the systems, since it is difficult to adapt to a changing environment as long as it is not known which factors to observe. Therefore, PSS require a stronger focus on detecting influences in later phases of the life cycle. This could be e.g. changes in the behaviour of the customer or user of the PSS, indicating a different application scenario. Changes in regulations regarding resource consumption or replacement of problematic materials and changes in the PSS providers' business model, e.g. shifting from a use-oriented to a result-oriented value proposition that also require a more holistic consideration of requirements during the PSS life cycle. Such changes could be detected based on the operational data recorded by the PSS, as well as business intelligence platforms relying on the analysis of big data coming from the PSS environment.

The second part of the analysis was related to what categories of factors have been examined in which life cycle phase. The overwhelming number of articles have focussed on the functional requirements, which is typically for systems that need to meet customer expectations and demand. Thus, most research for functional requirements is located in the design phase, and only three papers look at the whole life cycle process.

In terms of ecological and economic factors, it is visible that even if these are less investigated, there is a better balance of works looking across the life cycle, but surprisingly none that explore specifically the end of life with regard to ecological factors and neither operational nor end of life in terms of economic factors. This lack of published knowledge on how the requirements change over time can lead to a sub-optimal understanding of the systems behaviour and the requirements on it and thus shorten the life time of the PSS in addition to give a chance to consider economic and ecological factors in a proper way. Thus, new methods and tools supporting the monitoring of changes of ecological regulations or business model evolution during PSS operation or end-of-life would be required, e.g. supported by text mining approaches. Since only one article on network factors was identified, it is too early to conclude anything in this area.

5 Conclusions and Future Work

The imbalance of identified articles assessing factors influencing requirements across the life cycle, as well as the focus on functional requirements in existing literature, indicates that there is a need for a more holistic approach. As only 22 relevant papers were identified in this first systematic review, the significance of the findings is still limited.

In a next step, the scope of the review will be extended and the results are discussed in more detail. In order to get a better understanding on how researchers understand the topic of factors influencing requirements on PSS along the life cycle, it is intended in addition to design a survey to be administrated among the IFIP WG5.7 community. The findings shall be published in a journal paper and provide the basis to close the identified gaps during the life cycle and between the categorised factors.

It is expected that based on the analysis and needs of the manufacturing industry, especially monitoring of variations in PSS customer or user behaviour, respectively PSS application could be a major source of changing requirements. Furthermore, the inclusion of new ecological regulations and industry-related business trends through artificial business intelligence solutions could help to adapt a PSS solution proactively.

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