Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 47 (2016) 150 – 155

www.elsevier.com/locate/procedia

Product-Service Systems across Life Cycle

A Literature Review to Understand the Requirements Specification's Role when Developing Integrated Product Service Offerings

Sara Nilsson*, Mattias Lindahl

Linköping University, Linköping 581 83, Sweden

** Corresponding author. Tel.: +46-13 28 11 84; E-mail address: Sara.K.Nilsson@liu.se*

Abstract

This paper's objective is to analyze, based on a literature review, how existing IPSO design methods support and manage requirements when developing an IPSO. Issues analyzed are e.g. which types of aspects existing methods should consider, such as environmental issues and demands from stakeholders and customers. Another issue is what types of stakeholders are involved in the process. There is also an interest in finding out which of these methods are used in the industry. The goal is that the results will provide insight into how the requirements specification is used when developing an IPSO in theory, and in what way this insight will contribute to future studies on how companies currently derive and manage requirements when developing an IPSO.

The literature review started out with the analysis of 201 papers, yielding 22 papers within the area of working with requirements for an IPSO. These papers were reviewed and summarized with the above issues and interests in mind. Findings are that when deriving requirements, existing IPSO design methods are lacking in regard to a holistic life cycle and system perspective of the offering. Few of the methods consider both requirements regarding the environmental impact of the offering and demands from all involved stakeholders, normally only the customer. Furthermore, few studies have ended with a clear work process regarding how to initially find the requirements to analyze them and later interpret them as actual metrics. There are also no signs that existing methodology is used in the industry's day-to-day work.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle

Keywords: Product Service System (PSS); Integrated Product Service Engineering (IPSE); Engineering design

1. Introduction

1.1. Background

An Integrated Product Service Offering (IPSO), also known as a Product Service System (PSS)[1], consists of combinations of physical products, services and systems that have been integrated and optimized from a life cycle perspective in relation to customer value [1]. Service in this paper includes e.g. operation, maintenance, repair, upgrade, take-back, and consultation. An IPSO often implies that instead of buying the actual product, the customer pays for the function [2]. This transfers the responsibility of care for the product to the provider instead of the customer, and moves the focus from consuming to using products. Therefore, the IPSO is often seen as a way toward a more resource-efficient and effective solution with less environmental impact, see e.g. Tukker and Tischner [3].

The integration and collaboration with stakeholders and actors in an IPSO is, according to e.g. Vasantha, Roy, *et al.* [4] and Mont [5], seen as an important aspect of creating a successful IPSO. Lindahl, Sundin, *et al.* [6] highlight in their conclusions that it is important to be able to handle and balance various types of requirements (identified physical or functional needs that a design must be able to perform), and not only from either environmental or customer-driven aspects. Mont [5] has also found the relationship between the suppliers and developers essential when creating an IPSO in order to have a sustainable production and consumption system. In their review of IPSO methodologies, Vasantha, Roy, *et al.* [4] found that creating requirement lists when developing an IPSO and stakeholders' involvement is some of the areas with the weakest maturity among different aspects for developing an IPSO.

[1]In this paper, IPSO is used as a synonym for PSS.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle
doi:10.1016/j.procir.2016.03.225

1.2. Objective and research questions

The Mistra REES program – Resource-Efficient and Effective Solutions – is a 8M€ 4-year research program started in 2015 and with the vision "*…to advance the transition of the Swedish manufacturing industry towards a circular and sustainable economy"*. This includes determining which IPSO design methods are used in the industry, and an identified research gap, that is seems to lack of a wider understanding of the requirements specifications' (RS) role when developing an IPSO. With this initial study for a wider understanding as the objective, three research questions (RQ) were identified as important in relevance to the objective of both this paper and the research program.

RQ1. What types of stakeholders are involved when deriving requirements for an IPSO?

RQ2. What types of aspects are considered in a requirements specification for an IPSO?

RQ3. What IPSO methods are utilized in the industry to derive and manage requirements?

Since environmental aspects are of importance in the program, they will be crucial when answering the research questions above, especially RQ2. The answers to these questions should provide a good perspective on how the RS is used and worked with when developing an IPSO with existing methods. It will also be possible to compare the answers with what the literature says about how the development should be in later development stages to see how these aspects are considered in the RS.

2. Method

To fulfill this paper's objective, there was a need to find out what methods exist and what areas are taken into consideration when developing a RS for an IPSO. To realize the literature review to accomplish this, the methodology from Jesson, Matheson, *et al.* [7] was used. A structured approach will ensure reproducibility and that the study is explicit.

In order to limit the scope, this study covered only journal and conference articles written in English and published during or after 2000. The literature search was conducted on the 5th of October 2015, and Scopus and Web of Science was chosen as the databases for this study. 16 different search combinations with distinctive search terms and filters were used out to find a result with relevant papers. The search that was the basis for this literature review used the following search terms: *Product & service & system & requirement & develop* & design* & (lifecycle OR "life cycle" OR sustainab*)*.

The result was 354 papers, 340 when excluding non-English papers, and 275 when also excluding papers written before 2000. This resulted in 201 unique articles after removing duplicates. After reading all 201 articles' abstracts and conclusions, 22 articles [8-29] were found to show a connection to driving and working with requirements within the IPSO area. When performing the search for literature it was rather difficult to get relevant hits, as few of the resulting papers actually dealt with how a RS is derived and managed when developing an IPSO.The main search was limited to papers with a clear focus on requirements management within some sort of product and service system. Several of the papers found from the different search combinations were either not about developing or designing IPSOs, or they dealt with requirements on IPSO design methods, and not how requirements were handled for the IPSO itself. For each of the 16 different search combinations approximately 20 of the first abstracts were analyzed, and the combination with the highest relevance and appropriate scope was chosen. In future research a search combination with *(develop* OR design*)* will be used, but was for this initial paper rejected due to the limited scope. Regarding the decision to only look at articles from during or after 2000, it has to be emphasized that this only excluded 19 unique papers.

Data in the included papers were extracted and organized into different categories connected to the research questions. In this way, each identified IPSO design method or tool could be easily coupled to what aspects and stakeholders were taken into consideration and how they have been used in the industry.

3. Theoretical framework

3.1. Integration of stakeholders

The importance of a high level of integration of stakeholders involved in the development of an IPSO [4-6] was highlighted earlier. The early stages of the development process have a high impact on the final performance of the developed concept [30-32], sometimes called the design paradox, as illustrated in Figure 1. Time spent on developing a well-founded RS and truly understanding the customers' needs will be recovered later in the development process [32].

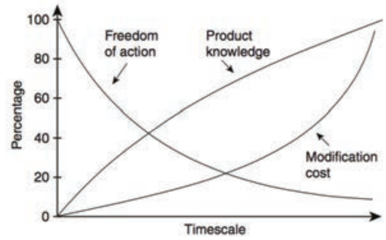

Fig 1. Illustration of the design paradox [32]

3.2. Requirements specification

Many different terms, more or less synonyms, are used in design processes to describe the RS concept (e.g., product design specification [33], performance specification [34], target specification [35] and design specification [36]). The RS is essential in all types of design processes and is the compilation of requirements on the potential offering (a combination of products and services) that is aimed to be developed. All requirements ought to be quantified or in any case defined in the clearest possible way; i.e., they must be comprehensive, unambiguous and cover all relevant life cycle phases of the potential offering (see and compare, e.g., with Pugh [33] and Pahl and Beitz [37]). In the end of the design process the outcome, i.e., the offering, must be in balance with the RS, even though the RS most likely has changed during the process.

4. Involved stakeholders when deriving requirements

Based on the literature review, it was found that when considering stakeholders’ opinions in deriving requirements, it was most common that customers, sometimes called users, were considered and consulted. Five [8-12] of the papers only considered the user as an influence on the IPSO. Three [13-15] papers mentioned both the user and some sort of supplier or manufacturer to consider and use as an information source from where requirements could be derived.

Seven [16-22] of the papers discussed involving stakeholders throughout the entire product life cycle. These papers were often written with a more holistic perspective of the offering and its related system. In these papers, it was rare that any special types of stakeholders were mentioned. Among these, Fiksel [16] also highlights what he calls stakeholders beyond the usual supply chain. He states that the requirements should be considered in a wider context adapted to the system boundaries as a way to create a more sustainable and resilient IPSO.

A couple of the papers had a greater focus on specific parts of the IPSO's life phases. Therefore, Chen, Chen, *et al.* [23] and McKay and Kundu [24], who mainly look at the manufacturing and use phases, only mention the supply chain and service engineers.

Wong, Crowder, *et al.* [25], Crowder, Fowler, *et al.* [26] and Centrich, Shehab, *et al.* [27], on the other hand, delimit themselves into only studying and considering maintenance aspects, and therefore only collect information from maintenance engineers. Only Berkovich, Leimeister, *et al.* [28] and Song, Ming, *et al.* [21] explicitly mention that laws and standards also need to be considered in the requirements. Vezzoli and Sciama [29] do not mention involvement with any stakeholders, but their paper is strictly focused on eco-efficient design and how environmental aspects can be introduced into guidelines.

There are also three papers that highlighted issues close to the background and purpose of this paper that need to be raised, starting out with Sadek and Welp [14], who state that methods are missing for integrating stakeholder’s preferences. This continues with Yang, Xing, *et al.* [10], who mention the need to create a better way to map the customers’ needs to attributes of both the product and services simultaneously. Lastly is Berkovich, Leimeister, *et al.* [28], who also identified a problem with the understanding of requirements between stakeholders and developers. Berkovich, Leimeister, *et al.* [28] also mention that requirements for products and services are at most times developed separately, and not as the integrated offering that it is supposed to be.

The authors mentioned above [10, 14, 28] were investigated further after the main review to see if their subsequent research had looked into their highlighted issues. Sadek and Welp [14] did not have any later papers together, but Sadek had a couple of papers in the IPSO area written with other authors. where in [38] they once again highlight the importance of early design phases and create software that enables a tool-based design process. The tools that are included are common tools for traditional product development, so no new tools or methods are developed. This process should help with guiding designers through the design process with a higher level of stakeholder involvement. There is no mention, however, of how this is done specifically during the derivation and management of requirements because it has a higher focus on following design phases.

Yang, Xing, *et al.* [10] had three later papers that were more focused on concept generation, so they had not done further research in the problem areas they had found.

Berkovich, Leimeister, *et al.* [28] had quite a few papers following the one reviewed in this paper. In [39] they perform a structured literature review to analyze if different techniques in software engineering are suitable for IPSOs. This paper was followed by [40], where different approaches from different domains (product engineering, software engineering, service engineering and integrated development of IPSOs) are analyzed to see how suitable they are for requirement engineering in IPSOs. Highlighted is that cooperation among the different domains is a deficit, and is therefore making it hard to transfer approaches between the domains, which is necessary in the field of IPSOs since they all need to cooperate in the system. Later in [41] they create a management system used in for example structuring, enabling tractability and finding conflicting requirements.

A summation of key findings:

- When stakeholders are involved, it is primarily the customer of the IPSO that is considered.
- A lot of different approaches exist in how to work with stakeholders and how they are considered in the derivation and management of requirements for the IPSO.

5. Types of aspects considered in a requirements specification for an IPSO

In the research, papers addressing requirements for physical products, services and systems as separate parts have been reviewed. The papers mostly focus on one or the other, and rarely do they analyze what happens if both service and product development is considered as an integrated process. No paper clearly considers aspects within the entire IPSO to create an ideal offering. As the IPSO has a high level of customer and environmental focus, it is of interest to find out how these aspects are considered in the earliest steps of the development.

Almost every paper describes integrated products and services as more environmentally friendly in comparison to traditional product sales. Despite this, the environment is rarely considered later on in the papers within existing methods or tools. If sustainability as a term is used in the papers, it is primarily environmental issues that are raised. In the papers talking about environmental considerations, either the entire life cycle is looked at or only maintenance is highlighted to facilitate a longer life of the product part of the IPSO.

Eight [9, 11, 12, 15, 16, 18, 22, 29] papers mention in some way that the environment needs to be considered in the development of an IPSO. There are four [20, 25-27] other papers that are highly focused on the maintenance part of the product's life cycle, and use this as an argument for how to create a more sustainable use of the offering.

Ten [8, 10, 13, 14, 17, 19, 21, 23, 24, 28] papers fail to mention consideration of environmental aspects at all in their existing methods or tools, and half of these ten papers still define the IPSO as a more environmentally friendly solution than traditional product sales.

A couple of papers look at aspects other than environmental. Geng, Chu, *et al.* [13], Kim, Lee, *et al.* [18], Maussang, Zwolinski, *et al.* [11] and Peruzzini, Marilungo, *et al.* [22] are the only ones who mention that budgetary and economic issues need to be considered. Büyüközkan and Berkol [15], Peruzzini, Marilungo, *et al.* [22] and Fiksel [16] are the only ones who raise social aspects that need to be considered to create a sustainable IPSO

A summation of key findings:

- Environmental aspects are considered in about half of the articles when deriving or managing requirements for an IPSO.

6. IPSO methods utilized in the industry

It is not stated clearly in the papers if the companies themselves drive the studies that have been performed together with industry. Mostly, the companies seem to only provide information about their current situation and do not have much to say about the results.

Five [10, 12, 14, 23, 42] papers do not mention any close connection to the industry or anything about implementation or evaluation of their method or tool. Of these, only Fiksel [16] speculates and discusses implementation issues that could occur if it would be typical to implement, as he calls it a resilient and sustainable system for the offering at a company.

Three separate cases, presented by Wong, Crowder, *et al.* [25], Crowder, Fowler, *et al.* [26] and Centrich, Shehab, *et al.* [27], are described and performed at Rolls-Royce All of these three papers are focused on different aspects in creating a product that is easier for Rolls-Royce to maintain in its IPSO.

Continuing, a variety of different case studies has been carried out within a mixture of sectors in the industry and are described in a couple of the papers. There are cases with a coffee machines [24], AC power adaptors [9], pumps [13], washing machines [22], air compressors [21], superconducting cables [11], and vending machines [29], and Agostinho, Bazoun, *et al.* [20] and Kim, Lee, *et al.* [18] both use cases from the clothing industry. Büyüközkan and Berkol [15] have a case in the energy sector, which also presents implementation in the industry of different types of the tool Quality Function Deployment (QFD) (which is a tool to translate customer needs into quantitative parameters), in scenarios separately of their case.

In their paper, Harrington and Srai [19] discuss many different cases, but none of these seem to have led into implementation and usage in the daily work in the industry.

Finally, there are three papers that have not worked with cases but have done other sorts of evaluations of their methods. Herzfeldt, Kristekova, *et al.* [8] have a semi-structured questionnaire that they gave to 65 students. Riel [17] states that his method has been developed "based on the demands of numerous industrial sectors". Berkovich, Leimeister, *et al.* [28] conducted interviews with 15 people with a variety of roles at 13 different companies to create a framework of what the industry needs and wants.

A summation of key findings:

- Many cases have been conducted to show functionality of existing methods or tools.
- No clear signs exist of any methodology or tool that has been implemented and is being used in day-to-day life.
- Development and research seem to be driven by academia and not the industry, as the papers do not mention the contrary.

7. Other findings

QFD is the most commonly used tool in these papers when working with requirements. Both the original as well as a variety of different versions, some are mentioned in these papers [9, 10, 12, 13, 22]. Otherwise, most of the methods and tools are new developments of the authors. One of these is Zhao, Wan, *et al.* [12], who have created a method based on the Six Sigma philosophy. This method is however concentrated on the development of the services in the IPSO, and not entire integrated systems with both products and services as one.

One thing that has been mentioned throughout most of the papers is that management of complex systems requires a structured way to handle and work with the system requirements. Several of the papers deal with information flows and how to identify and collect knowledge within the system.

8. Discussion

8.1. Involved stakeholders when deriving requirements

One way to identify who to consider within an IPSO is to create visual mapping systems to show and analyze included actions, physical artifacts, and relations within the system. This has been done in some of the reviewed papers (e.g. [23, 24]), but it is more commonly done to identify information flows and influential stakeholders. This information could however be utilized to derive requirements. An example of this is in the paper by Trappey, Ou, *et al.* [9], where suppliers and manufacturers are considered in the LCA, LCI and LCIA which are conducted, and the resulting information is used in the derivation of requirements.

If an offering is to be developed only focusing on one perspective of the involved stakeholders there is a high risk that the IPSO will become sub-optimized. In difference to traditional product development, the IPSO is intervened with many other interests from e.g. suppliers and service providers. It is therefore essential that the requirements specification consider a wider perspective of the life cycle.

One article [16] raised an interesting aspect of considering stakeholders depending on the system boundaries. This statement fits in well with the IPSO development, since it is all about an optimized system and not only the products and services within it. It is also interesting since the term "system boundaries" has a strong correlation to LCA, and should therefore also fit well together with environmental considerations throughout the IPSO life cycle. This is at least one sign that it should not be too complicated to develop a method of deriving and managing requirements for an IPSO that could consider both stakeholders and the environment's best interest.

8.2. Types of aspects considered in a requirements specification for an IPSO

To develop an IPSO with a lower environmental impact within a sustainable system requires that all relevant aspects are considered from the first step of the development process. This should provide a system that is sustainable in the sense that it is resilient and economically beneficial for the providing company. It should also give the possibility to have a sustainable IPSO that satisfies the customer, and at the same time reduces the environmental impact compared to traditional product sales. As shown by Lindahl and Sundin [32], if you want to make an influence on the offering's environmental impact it has to be considered from the first step, which the reviewed papers seems to miss out on. Today, the focus seems to be divided into either the customer or the environmental aspects, where one does not exclude the other.

It is surprising that even though the IPSO is considered the environmentally friendly alternative to traditional product sales, several methods in the reviewed papers still do not consider environmental aspects. Sometimes, when the IPSO is called sustainable by the authors, it is not the traditional three parameters of environment, economy and social that are considered; rather, it is mostly (if at all) only the environment that is talked about.

8.3. IPSO methods utilized in the industry

Within the reviewed papers there are limited mentions of methods that are actually used in the industry. Most of the existing methods are only applied as cases. This could imply that methods for traditional product development are still used for deriving the requirements for an IPSO, or as mentioned earlier, only the product in the IPSO. This should definitely mean that there exists a potential need for a new method, or that the methods that already exist from traditional product development work well even for developing IPSOs. Two examples that point out that how there is a lacking of integration between the derivation of requirements for services and products are Kim, Lee, *et al.* [18] and Harrington and Srai [19]. The paper by Kim, Lee, *et al.* [18] starts out with a predefined product that the IPSO is created around, while Harrington and Srai [19] begin their paper with "Many manufacturing firms have developed a service dimension to their product portfolio." This is clearly an example of how the development of products and services is not seen as an integrated process. As stated by e.g. Geng, Chu, *et al.* [13], the customer's satisfaction is dependent on both the offered product and service, and both of these aspects need to be considered as one when developing an IPSO.

There also seems to be a lack of interest regarding implementation in the industry. None of the reviewed papers mention cases where the involved companies actually work with these methods in their daily work. It also seems that the driving force of the research comes from academia, and not the industry itself. This has to be considered in future research to understand why these methods to work with requirements have not yet had any major breakthrough, even though the development of IPSOs has caught the industry's interest.

8.4. Concluding discussion

It is clear what is missing: a holistic method for working with stakeholders' involvement together with environmental aspects when deriving and managing requirements for an IPSO that can be implemented in the industry today. Many of the statements in this paper do not reflect revolutionary news in the IPSO area, but somehow existing methods are not working in the industry and are still missing out on the lifecycle perspective – even though several of these findings are obvious. This suggests some important questions to investigate in the future, namely *why?* and *how could it be done?*

The papers that mention methods to derive requirements rarely describe a clear way for how to actually implement and perform them. Often an overview of the process is described, and not in detail with e.g. tools supporting how to identify and collect needs and requirements. Theory and earlier studies have at all times highlighted how important it is to keep the focus of an IPSO to satisfy the customer's needs, and that will contribute with less environmental effect than traditional product sales. This should permeate the entire development process, and as the design paradox states, it is important that the right information is presented at the earliest steps possible in the development process. Therefore, it is essential to create a good requirements specification with the right requirements that can represent the entire system.

9. Conclusions and future research

This review, as a starting point, shows that little research has been carried out about how to work with the requirements specification when developing an IPSO. Still missing is a complete solution that can be implemented in industry. Methods or tools are currently specialized in one area or another, even though an IPSO requires a holistic perspective, and consider the IPSO from a life cycle perspective. Integration of product and service throughout the development process is essential to achieve a sustainable IPSO that has less environmental impact, and to satisfy not only the customer but also every other stakeholder involved with the IPSO.

To successfully achieve the mentioned conclusions there is a need for a well-structured method that can provide support throughout the entire process of deriving and managing requirements. Developing this type of method with included processes and tools will be a part of the future work. This will begin with another wider literature review with a bigger scope and by collecting information from collaborative partners about their use of existing methods, as well as through gaining a wider understanding about what should ideally be included in this type of method.

Acknowledgements

This research was supported by the Mistra REES (Resource Efficient and Effective Solutions) program, funded by Mistra (The Swedish Foundation for Strategic Environmental Research).

References

[1] Meier, H., Roy, R., and Seliger, G., Industrial Product-Service Systems – IPS². CIRP Annals Manufacturing Technology, 2010. 59(2): p. 607-627.

[2] Tukker, A., Product services for a resource-efficient and circular economy – a review. Journal of Cleaner Production, doi:10.1016/j.jclepro.2013.11.049, 2015. 97: p. 76–91.

[3] Tukker, A. and Tischner, U., eds. New Business for Old Europe. Product Services, Sustainability and Competitiveness. 2006, Greenleaf Publishing Ltd.: Sheffield, UK.

[4] Vasantha, G.V.A., Roy, R., Lelah, A., and Brissaud, D., A review of product–service systems design methodologies. Journal of Engineering Design, 2012. 23(9): p. 635-659.

[5] Mont, O.K., Clarifying the concept of product–service system. Journal of Cleaner Production, 2002. 10(3): p. 237-245.

[6] Lindahl, M., Sundin, E., Sakao, T., and Shimomura, Y., Integrated Product and Service Engineering v.s. Design for Environment, in Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses, S. Takata and Y. Umeda, Editors. 2007, Springer: London. p. 137 – 142.

[7] Jesson, J.K., Matheson, L., and Lacey, F.M., Doing your literature review - Traditional and systematic techniques. 2012, London: Sage Publication.

[8] Herzfeldt, A., Kristekova, Z., Schermann, M., and Krcmar, H. A conceputal framework of requirements for the development of e-learning offerings from a product service system perspective. in 17th Americas Conference on Information Systems 2011, AMCIS 2011. 2011.

[9] Trappey, A.J.C., Ou, J.J.R., Lin, G.Y.P., and Chen, M.Y., An eco- and inno-product design system applying integrated and intelligent qfde and triz methodology. Journal of Systems Science and Systems Engineering, 2011. 20(4): p. 443-459.

[10] Yang, L., Xing, K., and Lee, S.H. A new conceptual life cycle model for Result-Oriented Product-Service System development. in Proceedings of 2010 IEEE International Conference on Service Operations and Logistics, and Informatics, SOLI 2010. 2010.

[11] Maussang, N., Zwolinski, P., and Brissaud, D., Product-service system design methodology: from the PSS architecture design to the products specifications. Journal of Engineering Design, 2009. 20(4): p. 349-366.

[12] Zhao, L., Wan, J., Jiang, P., and Qin, Y., Service Design for Product Lifecycle in Service Oriented Manufacturing, in Intelligent Robotics and Applications, C. Xiong, et al., Editors. 2008, Springer Berlin Heidelberg. p. 733-742.

[13] Geng, X., Chu, X., Xue, D., and Zhang, Z., A systematic decision-making approach for the optimal product-service system planning. Expert Systems with Applications, 2011. 38(9): p. 11849-11858.

[14] Sadek, T. and Welp, E.G. A model based approach for conceptual development of Industrial Product-Service Systems. in DS 58-4: Proceedings of ICED 09, the 17th International Conference on Engineering Design. 2009.

[15] Büyüközkan, G. and Berkol, C., Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment. Expert Systems with Applications, 2011. 38(11): p. 13731-13748.

[16] Fiksel, J., Designing Resilient, Sustainable Systems. Environmental Science and Technology, 2003. 37(23): p. 5330-5339.

[17] Riel, A., Integrated design - A set of competences and skills required by systems and product architects, in Communications in Computer and Information Science. 2010. p. 233-244.

[18] Kim, Y.S., Lee, S.W., Lee, J.H., Han, D.M., and Lee, H.K. Design support tools for product-service systems. in ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design. 2011.

[19] Harrington, T.S. and Srai, J.S., Defining product-service network configurations and location roles: A current and future state analysis framework for international engineering operations. International Journal of Product Development, 2012. 17(3-4): p. 228-253.

[20] Agostinho, C., Bazoun, H., Zacharewicz, G., Ducq, Y., and Boye, H. Information models and transformation principles applied to servitization of manufacturing and service systems design. in MODELSWARD 2014 - Proceedings of the 2nd International Conference on Model-Driven Engineering and Software Development. 2014.

[21] Song, W., Ming, X., Han, Y., and Wu, Z., A rough set approach for evaluating vague customer requirement of industrial product-service system. International Journal of Production Research, 2013. 51(22): p. 6681-6701.

[22] Peruzzini, M., Marilungo, E., and Germani, M. Functional and ecosystem requirements to design sustainable product-service. in Moving Integrated Product Development to Service Clouds in the Global Economy - Proceedings of the 21st ISPE Inc. International Conference on Concurrent Engineering, CE 2014. 2014.

[23] Chen, Y.J., Chen, Y.M., and Wu, M.S. Development of a distributed product knowledge service system. in Proceedings of the International Conference on Complex, Intelligent and Software Intensive Systems, CISIS 2009. 2009.

[24] McKay, A. and Kundu, S., A representation scheme for digital product service system definitions. Advanced Engineering Informatics, 2015. 28(4): p. 479-498.

[25] Wong, S.C., Crowder, R.M., Wills, G.B., and Shadbolt, N.R., Knowledge transfer: From maintenance to engine design. Journal of Computing and Information Science in Engineering, 2008. 8(1): p. 0110011-0110017.

[26] Crowder, R., Fowler, D., Reul, Q., Sleeman, D., Shadbolt, N., and Wills, G., An information system to support the engineering designer. Journal of Intelligent Manufacturing, 2012. 23(5): p. 1548-1558.

[27] Centrich, X.T., Shehab, E., Sydor, P., Mackley, T., John, P., and Harrison, A. An aerospace requirements setting model to improve system design. in Procedia CIRP. 2014.

[28] Berkovich, M., Leimeister, J.M., and Krcmar, H. An empirical exploration of requirements engineering for hybrid products. in 17th European Conference on Information Systems, ECIS 2009. 2009.

[29] Vezzoli, C. and Sciama, D., Life Cycle Design: from general methods to product type specific guidelines and checklists: a method adopted to develop a set of guidelines/checklist handbook for the eco-efficient design of NECTA vending machines. Journal of Cleaner Production, 2006. 14(15-16): p. 1319-1325.

[30] Ullman, D., G., The Mechanical Design Process. 2002, New York: McGraw-Hill Higher Education.

[31] Lindahl, M., Engineering Designers' Requirements on Design for Environment Methods and Tools, in Industrial Engineering and Management. 2005, The Royal Institute of Technology: Stockholm.

[32] Lindahl, M. and Sundin, E., Product Design Considerations for Improved Integrated Product/Service Offerings, in Handbook of Sustainable Engineering. 2012, Springer.

[33] Pugh, S., Total Design - Integrated Methods for Successful Product Engineering. 1991, Harlow, Essex, UK: Addison Wesley Longman Limited Publishing Company.

[34] Cross, N., Engineering Design Methods - Strategies for Product Design. 3rd edition ed. 2000, Chichester, West Sussex: John Wiley & Sons, Litd.

[35] Ulrich, K.T. and Eppinger, S.D., Product Design and Development. 2000, New York: McGraw-Hill Higher Education.

[36] Hubka, V. and Eder, W.E., Design science: introduction to needs, scope and organization of engineering design knowledge. 1996: Springer.

[37] Pahl, G. and Beitz, W., Engineering Design - A systematic Approach. 2nd ed. 1996, New York: Springer-Verlag.

[38] Meuris, D., Herzog, M., Bender, B., and Sadek, T. IT support in the fuzzy front end of Industrial Product Service design. in Procedia CIRP. 2014.

[39] Berkovich, M., Leimeister, J.M., Hoffmann, A., and Krcmar, H. Analysis of requirements engineering techniques for IT-enabled product service systems. in 2011 Workshop on Requirements Engineering for Systems, Services and Systems-of-Systems, RESS 2011 - Workshop Co-located with the 19th IEEE International Requirements Engineering Conference. 2011.

[40] Berkovich, M., Leimeister, J.M., and Krcmar, H., Requirements engineering for product service systems: A state of the art analysis. Business and Information Systems Engineering, 2011. 3(6): p. 369-380.

[41] Berkovich, M., Leimeister, J.M., Hoffmann, A., and Krcmar, H., A requirements data model for product service systems. Requirements Engineering, 2014. 19(2): p. 161-186.

[42] Fiksel, J. Design for environment: an integrated systems approach. in Electronics and the Environment, 1993., Proceedings of the 1993 IEEE International Symposium on. 1993.