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Validation of Product-Service Systems in Virtual Reality

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Abstract

Research in the area of the integrated development of products and services, designated as Product-Service Systems (PSS), is maturing and a transition in industrial practices is noticeable. Nevertheless, PSS development methodologies lack consistent approaches regarding the integrated validation of different PSS elements rather than a separate development and validation. To prevent an expensive roll-out and testing in late development stages new methodologies and techniques need to be developed and applied. The challenge is the enablement of experiencing and thus testing of PSS in early stages, like planning and concept phase. In order to address these challenges for an integrated validation of PSS a prototyping approach named SHP4PSS has been introduced on a conceptual level [1], integrating virtual and physical prototypes in a Virtual Reality (VR). To complete the methodology a matrix is presented to derive test cases out of early PSS concepts. Furthermore, the evaluation matrix regarding the test phase and the current version of the demonstrator is introduced.

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Keywords: Product-Service Systems; validation; evaluation; Virtual Reality; experiencing

1. Introduction

Product-Service Systems (PSS) have to be researched under many perspectives due to the complexity of PSS and their interdependent elements, e.g. products, services, business models and software. The definition and emphasis regarding PSS are manifold and differ in many ways [3]. Nevertheless, a basic statement is shared widely; PSS have to be developed in an integrated manner. In realizing this, a company will transform from a product manufacturer with additional services to an Original Service Provider (OSP) [4].

The transition to a PSS provider has to be supported by a PSS development methodology and an implementation strategy including methods and tools [5]. Research regarding the development methodologies of PSS has been matured since 2000 as well as introduced and tested in industry by different researchers [6]. The main focuses of these approaches are generic development processes including methods and tools regarding concept development, business models, life-cycle perspective etc. However, a validation of PSS is inherent in these approaches due to following a methodology, but not specifically integrated regarding the validation of PSS. In conclusion, a validation methodology for PSS is a crucial factor for a successful development of PSS.

In order to cope with the lack of validation methods for PSS widely disseminated prototyping approaches for the classical product or service development have been analyzed and a concept for prototyping of PSS has been introduced as SHP4PSS [2]. In this paper, further research results regarding the SHP4PSS method will be discussed.

2. Relation to existing theories and work

In this chapter research with a reference and importance to the development and validation of PSS will be introduced and analyzed. This comprises previous results regarding SHP4PSS as well as new insights for validation dimensions and validation perspectives for PSS.

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2.1. Development and validation of PSS

The validation of PSS has not been in focus of PSS researchers [2] due to the emphasis on PSS development methodologies. Different concepts have been introduced, whereby the most common methodologies are: Lifecycle oriented PSS approach of *Matzen* and *Tan* [7, 8, 9], Methodology for PSS (MEPSS) of *Halen*, *Vezzoli* and *Wimmer* [10], IPS² concept modelling of *Sadek* [11], Layer-based Development Methodology for PSS of *Müller* [3], Service Engineering of *Sakao*, *Shimomura* and *Tomiyama* [12, 13, 14, 15, 16] and PSS design approach of *Lindahl* [17]. In summary, these methodologies do not focus on the validation of PSS, but on the development of complex PSS in general.

Nevertheless, some methods and tools for the validation of PSS have been presented, e.g. the requirement checklist [18] for requirement definition, the PSS-Inspector [19] for design reviews and the adaption of the Service Self Checklist SSC4IPS² [20] for evaluation and improvement of existing PSS. *Müller* developed a comprehensive PSS development methodology, which includes also aspects of the validation of PSS. Based on this research further aspects regarding the validation of PSS by prototyping will be considered.

2.2. Previous work regarding SHP4PSS

The development of a method for the validation of PSS with an emphasis on prototyping started in a research project 2012. Since then, an approach for an integrated validation of PSS, named SHP4PSS, has been introduced on a conceptual level [1]. The main idea is to use the Smart Hybrid Prototype (SHP) approach to integrate physical prototypes, digital models and software in Virtual Reality (VR) to enable an experiencing of PSS for an urban mobility use case [2]. The main objective is to realize a realistic experiencing of different lifecycle phases in VR. Fig. 1 symbolizes the idea of this concept:

Fig. 1. Pedelec and user in Virtual Reality.

Besides the virtualization of the product (see Fig. 1) a hybrid prototype will enable interaction with physical and virtual elements as well as the environment. Furthermore, the classical product centered perspective will be enhanced with additional elements to ensure an integrated PSS perspective of products and services:

- Digital city model
- Smartphone application to rent the pedelec and integrate further services
- Pedelec station to park and rent pedelec

The actual development and test results will be discussed in chapter 4.

2.3. Validation dimensions and perspectives of PSS

Regarding the validation of PSS two questions need to be analyzed: 1. Which properties or dimensions of a PSS can be validated and how is this different to the classical validation of products and services? 2. What perspectives regarding the validation of PSS need to be considered?

Burger et al. [21] derived in a study ten clusters which should be considered for providers of technical services. Furthermore, *Stark* et al. [22] determined three critical perspectives regarding the validation of mechatronic systems. These findings can be transferred to the validation of PSS. As a result of an evaluation Table 1 provides an overview for the relevance of the dimensions for the different perspectives.

Table 1. Relevance of validation dimensions for perspectives of PSS.

Dimensions	Perspectives		
	Customer	Developer	Decider
1. Process	◕	●	◑
2. Concept	◕	◕	●
3. Resources technology	◔	◕	◑
4. Resources employee	○	◕	◕
5. Contact to customers	◑	◑	◑
6. Customer acceptance	◕	◑	●
7. Interaction	◕	●	◑
8. Customer reaction and emotion	◑	◑	●
9. Technical requirements	◑	●	◑
10. Variables service environment	◑	◕	◑

Nomenclature

○ no importance
◔ minor importance
◑ medium importance
◕ high importance
● very high importance

The results of this evaluation need to be verified in a further step. Therefore, a workshop will be conducted to ensure an empirical backing of these findings. Nevertheless, qualitative statements are already possible and Table 1 indicates that the concept (2) is equally important for all perspectives. In addition process (1) and interaction (7) are very relevant for all perspectives. Due to these insights a validation method should focus on these dimensions and has been the main emphasis for SHP4PSS.

3. Research approach

To ensure a holistic view regarding the validation of PSS with SHP4PSS the research approach will be illustrated and missing elements will be discussed. Therefore, different aspects need to be considered to ensure a consistent methodology, see Fig. 2:

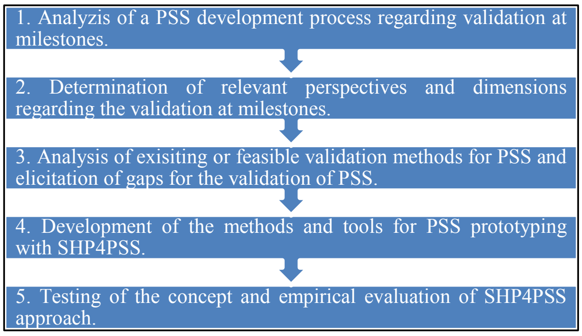

Fig. 2. Development of the SHP4PSS methodology.

Milestones in a PSS development process, e.g. the PSS V-Model [3], need to be analyzed regarding properties which have to be validated to these milestones. A consistent analysis in this matter is not conducted sufficiently so far. Nevertheless, the SHP4PSS approach will refer to the end of the concept phase (see Fig. 3) following the system concept design with PSS Layer Method [3]. The Layer Method supports the development of PSS concepts by defining PSS elements on horizontal levels and by linking them vertically.

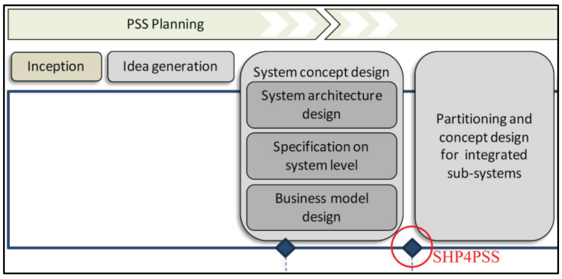

Fig. 3. Inclusion of the milestone for SHP4PSS in an excerpt of the PSS V-Model [3].

In order to define the particular objectives for SHP4PSS at this milestone an analysis has been conducted (see chapter 2.3) to identify and cluster generic dimensions regarding the integrated validation of PSS. Furthermore, the perspectives of different stakeholders (developer, customer and manager) in the validation process of PSS have been reflected. Subsequently, methods and tools to validate the properties of products and services have been analyzed and evaluated regarding their value for a transfer in the PSS domain [2]. Afterwards, a comprehensive set of methods and tools to enable a validation with SHP4PSS need to be developed. For this reason, a matrix (see chapter 4) is introduced to derive test cases out of early PSS concepts developed with the PSS Layer Method [3]. This approach ensures the availability of test cases already in the concept phase. Furthermore, a method to develop Smart Hybrid Prototypes for PSS [2] to provide interactive devices for experiencing PSS has been developed [23]. Finally, an evaluation method is introduced (see chapter 4) taking into account the conditions of the first two objectives. In conjunction with the mentioned test environment of SHP4PSS a comprehensive methodology regarding the validation of PSS has been developed. The introduced methods will be tested according to a use case for urban mobility as well as a comparative empirical study.

4. Findings

The actual findings include a new method to extract test cases out of PSS concepts as well as the evaluation process of the PSS including the evaluation matrix. Additionally, the current status of the demonstrator is presented.

4.1. Test cases for SHP4PSS out of early concepts

A new method is required in order to ensure a systematic approach and enable a complete and thorough derivation of test cases from rough PSS concepts. Therefore, a matrix (see Table 2) has been developed to transfer the results of concepts by the PSS Layer Method [3].

Table 2. Excerpt of matrix to derive test cases from PSS Layer Method.

Process (customer view)	Services and software	Product, periphery and infrastructure	Validation dimensions	Validation perspectives
		[…]		
2.4 Go to pedelec	Smartphone app, navigation (app)	GPS transmitter	Human-machine interaction, precision of navigation, […]	Usability of the app with navigation (customer/ developer)
2.5 Examine for damages	Checklist (app)	Pedelec, smartphone holder, GPS transmitter	Usability of the app, functionality and design of the pedelec, […]	Usability of the checklist (customer/ developer)
		[…]		
2.9 Remove pedelec of charging station	Guidelines (app)	Pedelec, charging stations, smartphone holder	Usability of the app	Usability of the guidelines
		[…]		
3.1 Defect while usage	Guidelines (app), provide help/ alternatives (phone)	smartphone holder , repair and transport infrastructure, customer service center	Usability of the app, driving properties, […]	Support by unknown events (customer), process (developer)
		[…]		

The main thought is to transfer and enhance the process of the PSS concepts and use the vertical links in the PSS Layer Method to integrate the connected PSS elements in the matrix. Additionally, the validation dimensions and perspectives (see chapter 2.3) are defined for each process step. The development of the prototyping device is described in a further paper [23] and therefore excluded in this matrix. Otherwise an inclusion of the needed prototypes and the test environment would be seen in this matrix, but is out of scope in this paper. Table 2 presents the matrix for an excerpt of one of the use cases which is described more explicitly in *Exner* et al [2], thus the matrix is shortened to enhance the clarity. The method enables the developer to choose relevant test cases which should be tested with SHP4PSS. A decision-making process is not integrated. The main focus is to summarize possible test cases and provide an overview without missing important process steps and their linking to the PSS elements.

4.2. Evaluation with SHP4PSS

The evaluation with SHP4PSS needs to be considered for two objectives. Firstly, the feasibility of the method as well as the test procedure itself needs to be surveyed. Secondly, the method needs to be compared with another validation method for PSS to enable valid statements for the cost-benefit consideration due to the considerable effort in developing and providing the test environment for SHP4PSS. The second aspect is especially challenging regarding the lack of validation methods for PSS. In adapting the utility analyses for PSS [24] a low fidelity method to evaluate PSS concept has been introduced and tested in a case study. In order to cope with both perspectives an evaluation approach has been developed. The hypothesis for the evaluation is: By using SHP4PSS the inter-reliability will be increased. The composition of the evaluation procedure is shown in Table 3:

Table 3. Framework of the evaluation for SHP4PSS.

Validation of test case with SHP4PSS	Validation of test case with utility analysis for PSS [24]
Test group: min. 12 probands	
Procedure: • Welcome and explanation of the objectives • Introduction to the VR with an exercise • Explanation of the test case • Experiencing of the test case in VR	Procedure: • Welcome and explanation of the objectives • Introduction to the utility analysis with an exercise • Explanation and hand out of the visual and textual explanation of the test case
Evaluation of the test scenario due to given matrix and criteria Questionnaire regarding the method and standard data regarding the probands	
Standardized questionnaires regarding immersion and presence due to SHP4PSS	-
Empirical analysis and interpretation of the results	
Impact analysis of immersion and presence regarding the test results	Comparison with the results of the first study [24]

The evaluation matrix is based on the results of the utility analysis for PSS [24] and has been adapted for the described evaluation (see Table 4).

Table 4. Evaluation matrix.

Process phase	Criteria		
	effort	safety	[…]
1. Reservation of the pedelec	e.g. *10*	e.g. *-3*	[…]
2. Go to the pedelec			
3. Examination of damages			
4. Open lock at the station			
5. Remove pedelec of charging station			
6. Usage of the pedelec			
7. Defect while usage			
8. Return the pedelec			

Nomenclature

10	The criterion has a strong positive characteristic in this phase.
6	The criterion has a positive characteristic in this phase.
3	The criterion has a slight positive characteristic in this phase.
0	The criterion has no effect characteristic in this phase.
-3	The criterion has a slight negative characteristic in this phase.
-6	The criterion has a negative characteristic in this phase.
-10	The criterion has a strong negative characteristic in this phase.

The main source of input is the test case matrix (see Table 2) regarding the processes. The criteria originate of both, PSS Layer Method and test case matrix. This method will also work with other PSS concept development methods as long as a process is included. In order to assure the comparability, the evaluation matrix for the test with SHP4PSS as well as the utility analysis for PSS will be identical.

4.3. Preliminary test phase of SHP4PSS

The process phases (see Table 4) for the preliminary test require an elaborate test environment. The main elements (see chapter 2.2) have been developed and implemented. In addition to the virtual model of the pedelec, the hybrid prototype which will realize the interaction with VR has been constructed. The prototype includes pneumatic hexapods and an electric motor to enable a realistic experience during the use phase, see Figure 4:

Fig. 4. Digital Model of the SHP4PSS Prototype.

Furthermore, a digital city model of Berlin (Fig. 5) and a digital charging station for the pedelecs (Fig. 6) has been developed and integrated in Unity software.

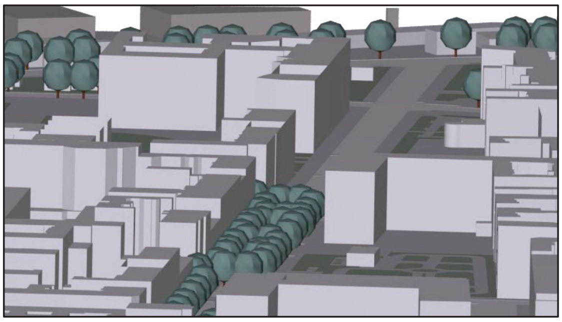

Fig. 5. Digital city model of Berlin.

Fig. 6. Digital Charging station for the pedelecs.

The most complex part is the integration of digital and physical elements. The driving simulation needs to respond realistically to the input of the user. Furthermore, additional input of other devices, e.g. the smartphone, has to cause a correspondent effect in the simulation. Due to these constraints an extensive testing is indispensable. The smartphone app and the prototype are shown in Figure 7 and 8:

Fig. 7. Smartphone App for infrastructure and services for the PSS.

Fig. 8. SHP4PSS Prototype with Oculus Rift as Virtual Reality environment.

The existing implementation is realized with Oculus Rift as VR which is sufficient for the preliminary test phase. Finally, a transfer into the Digital Cube Test Center (DCTC), a 4-side 360° visualization cube, regarding the evaluation with the study group will be realized. Nevertheless, first qualitative results with Oculus Rift and the current version of the prototype can be stated. The implementation of SHP4PSS enables a realistic experiencing of the test case. The interaction of Oculus Rift and prototype is limited due to a restricted field of vision (only virtual). Furthermore, the immersion with Oculus Rift as well as the freedom of movement is improvable. The integration into the DCTC should solve these issues by merging virtual and real environment.

5. Conclusion

So far, an analysis of existing methods for the validation of PSS has been conducted and due to these results a new method based on prototyping approaches has been developed [2]. The main focus of this paper is to complete the validation methodology of SHP4PSS. In order to achieve this objective a comprehensive methodology, taking into account the generic PSS development process – PSS V-Model – has been introduced. Therefore, a method to extract test cases for SHP4PSS as well as an evaluation matrix has been introduced and implemented in a test environment according to the SHP4PSS approach (see chapter 4). The feasibility of this demonstrator has been tested in a preliminary phase. First quantitative results indicate a realistic experiencing of the test case. In order to verify the results a comprehensive comparative evaluation will be conducted to provide quantitative and qualitative data. The methodology has to be assessed regarding the cost-benefit ration in comparison with further validation methods for PSS eventually.

Therefore, further research regarding the validation and prototyping of PSS for different degrees of fidelity need to be conducted and integrated in this PSS validation methodology.

A first step has been successfully achieved by introducing a utility analysis for PSS [24]. The analysis of the statistical parameters of the first study with the utility analysis for PSS indicated good results. Nevertheless, some measured values differed widely due to a lack in the description of the process phase. In experiencing the process phase with SHP4PSS the research teams expect a considerable improvement regarding the reliability and dispersion of the measurement values.

Finally, two crucial steps have been identified. Firstly, the evaluation with a group of probands to assess the method is the most important aspect due to the focus of this method on the customer perspective. Secondly, the dissemination in industry, including workshops and interviews to determine the acceptance of managers and developers regarding SHP4PSS, is important for the implementation in industrial practice. These two aspects ensure a continuously improvement and adaption of SHP4PSS.

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References

[1] Exner K, Buchholz C, Sternitzke A, Stark R: Validation framework for urban mobility Product-Service Systems by Smart Hybrid Prototyping. In: Gengnagel C, Kilian A, Nembrini J, Scheurer F (ed.). Rethinking prototyping – Proceeding of the Design Modelling Symposium Berlin 2013. Berlin: Universität der Künste; 2013. p. 573-588.

[2] Exner K, Lindow K, Buchholz C, Stark R. Validation of Product-Service Systems – A Prototyping Approach. In: Hoda E, editor. Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems. Windsor: Elsevier B.V; 2014.

[3] Müller P. Integrated Engineering of Products and Services – Layer-based Development Methodology for Product-Service Systems. Stuttgart: Fraunhofer IRB; 2013.

[4] Schnürmacher C, Hayka H, Stark R. Providing Product-Service-Systems - The Long Way from Product towards Solution Provider. In Brissaud D., Boucher X, editor. 7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business. unpublished; 2015.

[5] Nguyen HN; Schnürmacher C, Stark R. Research on how to introduce the PSS Engineering into industry. In: Hoda E, editor. Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems. Windsor: Elsevier B.V; 2014.

[6] Exner K, Hagedorn L, Lindow K, Stark R, Hayka H. Interplay of styling, design and service performance in developing Product-Service Systems. In: 2014 International Conference on Engineering, Technology and Innovation (ICE 2014). Bergamo, Italy. 23 – 25 June 2014. Institute of Electrical and Electronics Engineers (IEEE). 2014. pp. 408-416.

[7] Matzen D, Tan A, Andreasen MM. Product/service-systems: Proposal for models and terminology. In: Meerkamm H, editor. Design for X: Beiträge zum 16. Symposium. Erlangen: Lehrstuhl für Konstruktionstechnik; 2005. p. 27-38.

[8] Matzen D. A systematic approach to service oriented product development. Stokkemarke: Scandinavian Digital Printing A/S; 2009.

[9] Tan A. Service-oriented product development strategies. Stokkemarke: Scandinavian Digital Printing A/S; 2010.

[10] Halen CV, Vezzoli C, Wimmer R. Methodology for Product Service System Innovation - How to develop clean, clever and competitive strategies in companies. Assen: Koninklijke van Gorcum; 2005.

[11] Sadek Hassanein T. Ein modellorientierer Ansatz zur Konzeptenwicklung industrieller Produc-Service Systeme (en: A modell oriented approach for a competence development industrial product-service systems). Aachen: Shaker Verlag; 2009.

[12] Tomiyama A. A design methodology of services. In: Samuel A, Lewis W, editors. DS 35: Proceedings ICED 05, the 15th International Conference on Engineering Design. Melbourn: Barton; 2005, p. 1970-2014.

[13] Komoto H, Tomiyama T. Systematic Generation of PSS Concepts Using a Service CAD Tool. In: Sakao T, Lindahl M. editors. Introduction to Product/Service-System Design. London: Springer Verlag; 2009, p. 71-92.

[14] Sakao T, Shimomura Y. Service Engineering: a novel engineering discipline for producers to increase value combining service and product. In: Huisingh D et al., editors. Journal of Cleaner Production. Elsevier; 2006. p. 590–604.

[15] Sakao T, Shimomura Y, Sundin E, Comstock M. Modeling Design Objects in CAD System for Service/Product Engineering. In: Horváth I, Lee K, Shapiro V, editors. Computer-Aided Design. Elsevier; 2009, p.197-213.

[16] Shimomura Y, Arai T. Service engineering - methods and tools for effective PSS development. In: Sakao T, Lindahl M, editors. Introduction to Product/Service-System Design. London: Springer Verlag; 2009. p. 113-136.

[17] Lindahl M, Sundin E, Shimomura Y, Sakao T. An interactive design model for service engineering of functional sales offers. In: Marjanovic D, editor. DS 36: Proceedings of DESIGN 2006. Dubrovnik: The Design Society; 2006. p. 897-904.

[18] Müller P, Schulz F, Stark R. Guideline to Elicit Requirements on Industrial Product-Service Systems. In: Sakao T, Larsson T, Lindahl M, editors. Industrial Product-Service Systems (IPS²): Proceedings of the 2nd CIRP IPS² Conference. Linköping: Linköping University; 2010. p. 109–116.

[19] Suvarna, S.; Stöckert, H.; Stark, R. Project and Design Reviews in IPS2. In: Sakao T, Larsson T, Lindahl M, editors. Industrial Product-Service Systems (IPS²): Proceedings of the 2nd CIRP IPS² Conference. Linköping: Linköping University; 2010. p. 307-314.

[20] Akasaka F, Nguyen HN, Nemoto Y, Lenz B, Shimomura Y, Stark R. Adaptation of the Service Self Checklist for Industrial Product-Service Systems. In: Shimomura Y, Kimita K, editors. The Philosopher‘s Stone for Sustainability. Proceedings of the 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo, Japan, November 8th - 9th, 2012. Berlin: Springer; 2013, p. 499- 504.

[21] Burger T, Schulz C. Testen neuer Dienstleistungen. Ergebnisse einer empirischen Breitenerhebung bei Anbietern technischer Dienstleistungen (en: Testing of new services. Results of a empirical large scale survey from providers of technical services). In: Spath D, Bullinger H-J, editors. Fraunhofer IAO. Stuttgart: Fraunhofer Verlag; 2014.

[22] Stark R, Beckmann-Dobrev B, Schulze EE, Adenauer J, Israel JH. Smart Hybrid Prototyping zur multimodalen Erlebbarkeit virtueller Prototypen innerhalb der Produktentstehung (en: Smart Hybrid Prototyping for multimodal experience of virtual prototypes in product development). In: Der Mensch im Mittelpunkt technischer Systeme (en: human centred technical systems). 8. Berliner Werkstatt Mensch-Maschine-Systeme 2009: 7. bis 9. Oktober 2009, Berlin: VDI-Verlag; 2009.

[23] Beckmann-Dobrev B, Kind S, Stark R. Hybrid Hybrid Simulators for Product Service-Systems - innovation potential demonstrated on urban bike mobility. In: CIRP 25th Design Conference Innovative Product Creation. in press; 2015.

[24] Exner K, Schnürmacher C, Thiele J, Schulz F, Stark R. Variants evaluation of Product-Service Systems. In: Brökel K, Feldhusen J, Grote K-H, Rieg F, Stelzer R. 12. Gemeinsames Kolloquium Konstruktionstechnik 2014. Bayreuth: Universität Bayreuth; 2014, p. 1-10.