Towards a Design Science-Driven Product-Service System Engineering Methodology

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Abstract. Customers are increasingly demanding integrated solutions so that Product-Service Systems (PSS) have been proliferated in the global economy. The resulting PSS effects of utilization are of versatile nature for both suppliers and demanders. Especially the field service is characterized by the integrated provision of product and service wherefore service technicians need support by mobile information systems (IS). Although different PSS Engineering methods exist, a fundamental base, including the triple of Product, Service and the support through IS, is needed for the conceptual development of PSS. Therefore, within the Design Science Research (DSR) field established concepts are inspected for their applicability in the PSS Engineering process. Goal of this contribution is to extend the scope of information systems in order to derive a methodology which enables a design science oriented development of IS as an essential part of PSS.

Keywords: Product-Service System, Service Science, Design Science Research.

1 Introduction

The number of Product-Service Systems (PSS) has increased proliferated in recent years, which is reducible to a growing share of the service sector [1]. According to current statistics, the German economy for example registered a growth of the performance of the service sector in 2012 in defiance of a simultaneous decrease of the manufacturing and building industry [2]. Especially in leading industrialized countries the service sector represents a considerable ratio of the gross domestic product (GDP) which makes it to an indispensable branch of industry in the global economy [3][4].

In order to persist in the economic competition, companies increasingly internalize to act as a solution provider on the market, which are highly characterized by their combined offer of both products and services [5]. This results from the fact that customers are increasingly demanding integrated solutions to meet their individual needs [6]. In this way, a value generation in form of hybrid value bundle takes place, which is also called hybrid value creation [7][5]. Also known under the name Product-Service System, the concept of the integrated provision of goods and services offers benefits and potentials for providing companies [8]. Monetary benefits [6], a clear

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distinction from competitors and as well as increasing customer satisfaction [9] and the concomitant enhanced customer loyalty [10] may result as useful effects from PSS.

Since the machinery and plant engineering constitutes an important industry and is also characterized by the use of services as parts of their portfolio, PSS are discovered especially in this industry field [11]. In addition to the manufacture of machinery and equipment, the Technical Customer Service (TCS) is furthermore taking care of product-specific requirements and is, to this end, in interaction with the customer [12]. The tasks service technician has to cope with are characterized by diversity which makes an assistance system to a necessity to master the service complexity. Beside technical problems, the TCS also has to be equipped with commercial skills that are incurred as part of a service process, such as procurement of spare parts, guarantee measures and invoicing [13]. In addition, the TCS has an important function by its role as an interface to the customer [14], what makes him able to provide feedback about product-specific and customer-specific properties back to the company [15]. The quality of service is mainly influenced by the TCS, which is why a support of the service technician for service delivery and an efficient arrangement of the considered PSS is indispensable [16].

A research gap exists thereby through the fact that PSS-Engineering (PSSE) methodologies in the context of Design Science Research (DSR) have not been analyzed to date. The scope of our work is the investigation of existing PSSE methodologies and the development of a design science oriented PSS approach in order to create evaluation-driven, relevant and rigorous PSS.

The following section describes the concept of Design Science Research as an initial situation for the construction of a design science oriented PSS. In Section 3 the concept of Product-Service Systems is introduced by investigating relevant components of PSS. Further, an analysis of PSS-Engineering methodologies reveals former used approaches in the field of PSS research. On this basis, we established a DSR oriented Product-Service System Engineering Methodology, which is presented in Section 4. In Section 5 we will transfer our developed concept into a case study of the machinery and plant engineering to show the application. Section 5 concludes our approach and indicates further research.

2 Design Science Theory

2.1 Concepts of Design Science Research

The design science paradigm is a legitimate Information System Research paradigm to create an innovative Information Technology (IT) artifact to address a certain problem [17][18]. To specify this paradigm HEVNER ET AL. has established seven guidelines that describe characteristics of well carried out research [17]. These guidelines are also reflected in the Design Science Research (DSR) Cycle View presented in figure 1. The *Design Cycle* as the core cycle iterates between building artifacts and evaluating them against certain requirements [18] until the utility, quality and efficacy is rigorously proved [17]. These certain requirements are considered in the *Relevance Cycle* that not only provides the problem to be addressed but also defines the satisfying criteria for the final evaluation of the research result [18]. As DSR is motivated to improve the environment [19] by solving a relevant business problem with innovative and purposeful artifacts, HEVNER ET AL. argues that a combination of technology-based artifacts such as system conceptualization, organization-based artifacts like structures and people-based artifacts as for example training and the process for building these, have to be designed [17]. DSR artifacts can be in the form of constructs, models, methods and instantiations applied in the development and use of information systems [20].

For being rigorously proved, the *Rigor Cycle* is aimed at providing grounding scientific theories and methods along with domain experience and expertise [18]. Those evaluation methods, which are obtained in the current knowledge base, contain observational methods like case or field studies as well as analytical, experimental, testing and descriptive methods [17]. Furthermore, the Rigor Cycle not only provides foundations but also return new knowledge generated by the conducted DSR [18]. Finally, the results of DSR have to be presented to researchers who study the artifacts in context and extend them, to practitioners who implement them in a technical way and to a management-oriented audience that apply the artifacts within the organization.

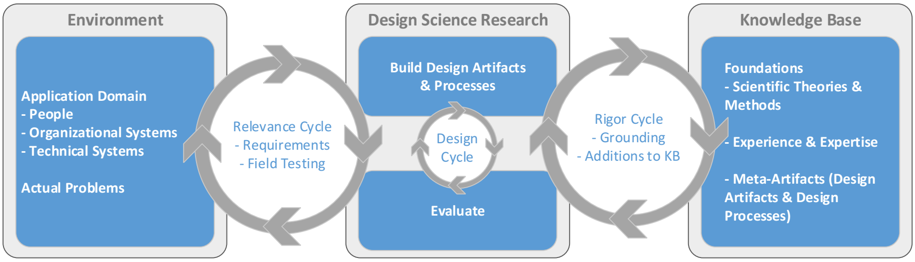

Fig. 1. Design Science Research Cycles [18]

PEFFERS ET AL. developed a Design Science Research Methodology (DSRM) Process Model [21], which i.a. obtains the DSR guidelines and the understanding of the DSR Cycles mentioned before (see figure 2). The first step (1) comprises the identification of the problem to show the relevance. After that, (2) the objectives of a solution are defined and (3) the actual designing and development (d&d) phase begins. After the first instance of the artifact has been build, the functionality will be demonstrated in a convenient context (4). In the more formal evaluation phase (5), it should be observed how well the designed artifact suits to solve the defined problem using relevant metrics and analysis techniques. Thereafter, the process either iterates back to the d&d phase to improve the artifact or, if the artifact is already satisfying, the communication of the results (6) takes place.

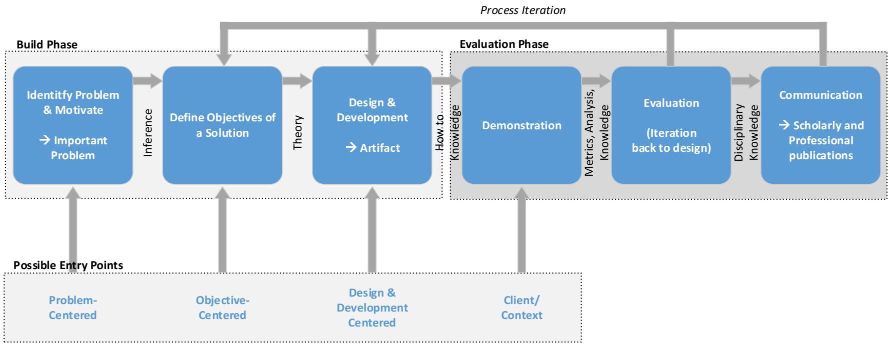

Fig. 2. DSRM Process Model (referring to [21][37])

In reality not every DSR process proceeds from step 1 until 6. Hence, PEFFERS ET AL. defined possible research entry points like a problem-centered (start-step: 1), an objective-centered (start-step: 2), a d&d-centered (start-step: 3) or a client/context initiation (start-step: 4). [21] As we can see DSR is conducted in an iterative research process with the aim to generate new knowledge. The presented DSR research contributions already propose frameworks for the successful usage of generic DSR and provide elementary concepts for a clear contribution into the application environment. As the DSR methodology is already established to create innovative IT artifacts and IS should be an essential part of PSS engineering, the insights of DSR are used to improve the PSS Engineering process, which is presented in the following.

3 Product-Service System

3.1 Constituent Parts of Product-Service Systems

PSS represent hybrid products that consist of an immaterial component, the service part, as well as a material good, the product [22][23]. While traditionally products and services are developed independently and organized in different departments, the concept of PSS targets to an integrated product and service offering [4]. Depending on the PSS configuration variable amounts of service and product can be present and the ratio can continuously change over time, for example due to technological developments or of changing customer needs [8]. Figure 3 illustrates the structure of PSS.

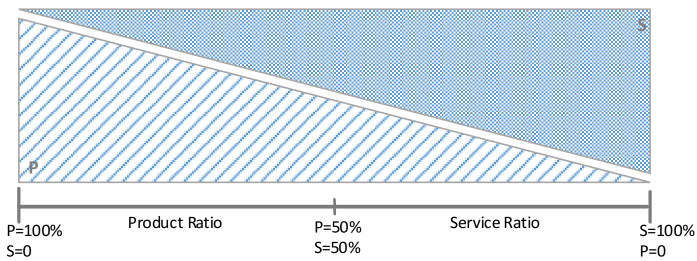

Fig. 3. Structure of Product-Service Systems (referring to [24][7])

To make a quantitative differentiation of the ratio of PSS components, a distribution on a percentage basis of each PSS part can be made [7]. The less service ratio (S) in a PSS is present, the higher is the product proportion (P). As long as both components are used as a combination the integration can be called a Product-Service System. Only if one of the PSS components is discontinued and e.g. merely the proportion of product is 100%, the composition is no longer a PSS and thus no hybrid power bundle. Elementary for the success of PSS providers is the knowledge about customer behavior with regard to the use of products and potential sources of errors during the usage [4]; especially, if they provide both product and service from a single source.

3.2 Product-Service System Lifecyle

Towards a PSS, requirements of different origin can exist. PSS developers, -providers and within the context of PSS involved stakeholders as well as customers that demand for PSS have claims on a Product-Service System, which need to be fulfilled and regarded in the development process. In addition to these actors, additional components of a PSS are also software and processes that are required for a value proposition [25]. A special requirement and at the same time also essential characteristic of PSS is the extension of the product life cycle, because within a product's life cycle it is possible to provide in all of its phases a physical good combined with services [7].

In order to include the needed requirements for a PSS systematically already in the development phase, the consideration of existing industrial structures is necessary. Hence, it is important to support the developer of a PSS with the integration into an overall concept. Figure 4 illustrates the considerable elements of a PSS within a lifecycle [25].

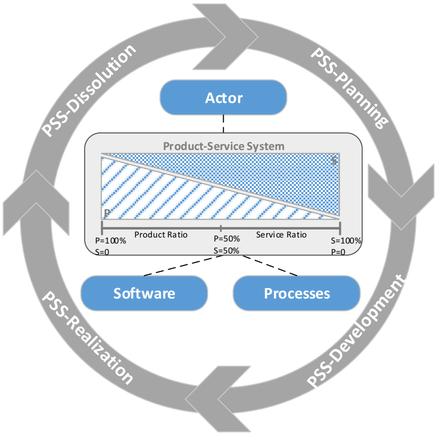

Fig. 4. Underlying Requirements of a PSS-lifecycle

A PSS is essentially marked by the use of product and material interests, the use of software and processes, and by means of actor's value proposition. The life cycle of PSS consists of the phases of PSS-planning, -development, -realization and -dissolution [25]. Essential elements of a PSS are, in addition to the service and the product, the interplay of actors, software and the identification of processes.

For the design of PSS it must be clearly defined, which actors are present, which are in interaction with the PSS, what processes exist and what software is needed to run the expenses incurred in connection of PSS activities efficiently. So, before a user-oriented design of PSS can take place, the requirements of the user need to be considered first.

3.3 Engineering Methodologies for Product-Service Systems

In the field of service research a plethora of conceptualizations of PSS already exists but only few consider specific methodologies for Product-Service System design from the view of development [26].

The wider approach of SPATH AND DEMUß examines services during product design and determines the development of PSS as a socio-technical system, which is characterized by the interaction on human and machine. The foundation for the design is appropriated through an integrated requirements engineering within the development process of the physical good [27].

MCALOONE treat the development of Product-Service Systems in two different ways. First of all, they take the product life cycle and afterwards attach a dedicated service lifecycle to the usage period of the product. So, they propose to design services when they are needed during the use of the product [28].

Another approach for the design of Product Service Systems was found by WEBER ET AL. and their application of the Property-Driven-Development (PDD) on Product-Service Systems. They basically decide between structure-based and behavior-based characteristics of Product-Service Systems and design them through different iterations in an integrated way also regarding customer integration by beginning with customer needs [29].

THOMAS ET AL. describe the design of PSS by employing an engineering cycle. The focus is given for material and service characteristics that are designed in an iterative process consisting of two cycles (customer cycle and developer cycle) on the base of customer requirements. The development, which ends with the finished PSS, begins with recording customer requirements and, consequently, with the problem identification. Furthermore, the integration of the customer and developer cycle allows also both the demonstration and the evaluation of the created artifact [26].

According to ISAKSSON ET AL., the development of PSS represents the engineering work to transform requirements to solutions which means that the engineering design of PSS has a wider range of what design parameters are available. The provided process of a functional product development (FDP) starts with the integration of customer needs and the objective of developing a solution [30].

BOUGHNIM AND YANNOU see the development of PSS similar to service development and provide a map of a PSS system using the Blueprinting Method according to SHOSTACK [32] and regarding all processes, actions and interactions inside as well as outside the company [31].

MAUSSANG ET AL. identified, in their research of current approaches for designing PSS, two different research priorities, the design of PSS from the system point of view and the design from the product point of view. From a system point of view the designer of the PSS focusses a new combination of technological artifacts on the basis of functional parameters while within the product point of view the designers consider that both services and products should be developed in an integrative manner. Based on that, they have designed a two stage approach for PSS development. First the elements of PSS are defined and second a detailed design phase is determined to define technical solutions [33].

Another PSSE methodology is presented by LEE AND KIM who investigate the functional modelling of PSS by including also information of service providers and receivers. They provide a functional modelling framework to facilitate the arrangement of product and service elements to produce various PSS concepts [34].

TAN ET AL. defined four dimensions and methodology steps which cover the essential design elements of a PSS. The analysis of value proposition, product life cycle, activity modelling cycle and the actor network enable the alignment as well as a good understanding of how products and systems work [35].

Overall, for all the approaches the focus is given for the design of services and products combined, iteratively and on the basis of customer demands. However, the basis for most of the modern services and products is the IT-Infrastructure that serves as enabler. This is why the product-service engineering methods have to be adapted to include the development of IT artifacts. From the analysis of the methodologies proposed in literature we ascertained that most of them focus implicit on the first three DSR process steps embracing the problem identification, definition of the objective of a solution as well as the design and development of PSS. Merely, the PSSE methodology from THOMAS ET AL. contains five steps of the DSRM Process Model according to PEFFERS ET AL. including the demonstration phase by the transition of the engineering process result, the construction of a PSS and back to the customer, where also the evaluation takes place [21]. Based on our literature findings we construct in the following adjusted design science oriented PSSE methodology drawing on THOMAS ET AL. The superior aim is to transfer DSR methodologies on PSS research in order to show the applicability and relevance of the design science paradigm to service science.

4 Construction of a Design Science Oriented Product-Service System

Although the DSR approach is primarily aimed at the field of Information Systems, it has implication for information technology associated areas such as engineering disciplines [18][35]. So far it has been used to construct a wide range of socio-technical artifact as for instance decision support systems, governance strategies, methods for the IS evaluation and chance interventions [36].

Due to the build-evaluate pattern of DSR, it is only about proving the usefulness of an artifact. According to SONNENBERG AND VOM BROCKE a rigorous DSR process also requires the validation of the artifact design decisions before evaluating the artifact in the field [37]. Hence, they proposed three principles that should be considered in the building phase. They claim to have multiple evaluation episodes during a single iteration of the DSR process to evaluate not only the usefulness of the artifact (exterior modes: ex post evaluation) but also the constituents and the design decisions (interior mode: ex ante evaluation). In addition to that, the prescriptive knowledge should be documented in a particular way, meaning that i.a. also justificatory knowledge (why an artifact may work in a given context) or information about the expository instantiations to reason about the feasibility and applicability at build time in the interior mode. Performing the documentation already during the build phase and not just after the evaluation has been conducted, immediately effects the way the upcoming evaluation can be accomplished. [37]

This is why the given PSSE Framework [26] should be extended by evaluation cycles in the build phase as it is shown in figure 5. Considering that, SONNENBERG AND VOM BROCKE propose exemplary evaluation criteria and evaluation methods, which are used in the following [37].

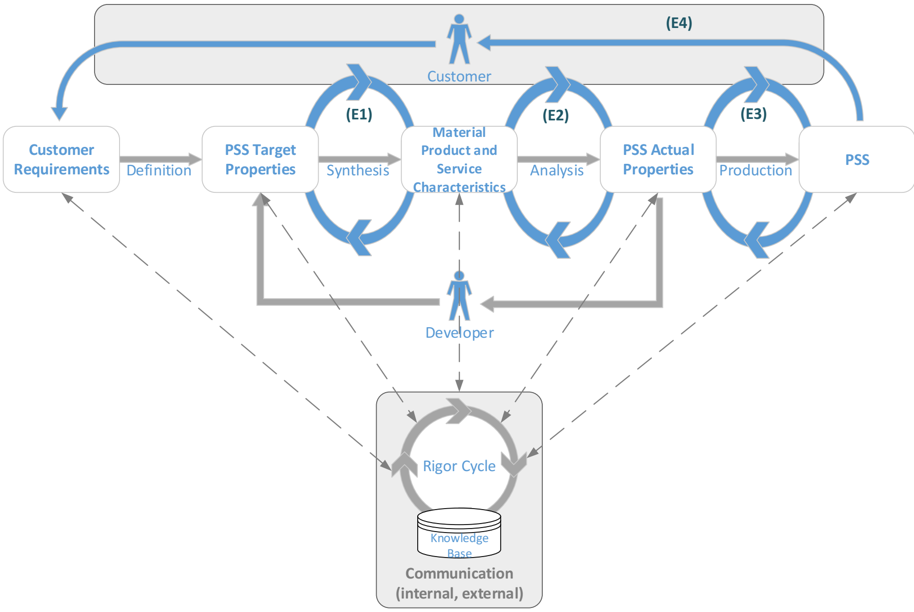

Fig. 5. Extended Design Oriented PSSE Framework (referring to [26])

After the customer requirements have been translated into target properties and the material products and service characteristics have been defined, they should be evaluated against criteria such as the applicability, the suitability, the importance, the novelty and the feasibility using methods like a literature review, reviews of practitioner initiatives, interviews of expert or focus groups or surveys with customer (E1). Having conducted the evaluation, the characteristics became justified design objectives. To evaluate the actual PSS properties for getting a validated design specification criteria like the feasibility, simplicity, completeness, consistency and operationally should be considered. Those can be evaluated by demonstration or simulation, benchmarking or again surveys and interviews (E2). After the actual PSS properties have been defined and a component has been build, the artifact should be proved of applicability in an artificial setting. By prototype experiments or demonstrations of the components to a focus or expert group the ease of use as well as the effectiveness and efficiency, the robustness and the suitability of the instance can be evaluated (E3). The fourth evaluation step (E4) already exists in the present PSSE Framework: By evaluation through the customer for instance in a case study, a field experiment or a survey the artifact instance can be validated in a naturalistic setting. As described in Section 2 HEVNER ET AL. considers a three cycle view to conduct DSR [18]. The relevance cycle view and the design cycle view have been implemented already through the four evaluation steps (E1-E4); however, the rigor cycle is still missing so far. Heretofore, there is not any knowledge management activity explicitly designated. To ground the PSSE steps and to add further knowledge to improve the internal and external PSSE processes and results, a knowledge base has been added to the framework. Depending on the confidentiality degree it should be considered, whether the new insights are going to be communicated to the scientific community or solely to the internal corporate knowledge base for instance in case of key PSS.

5 Case Study

To show the applicability and the associated additional value of our developed design science oriented PSS approach a case study of the wind power market is presented in the following. Although the case study is fictional, the insights and experiences are based on a project with a real PSS development. Due to actual discussion of renewable energies the sector of wind power is raising with annual growth rate about 28% over the past 15 years [38].

The regarded wind energy plant provider is already experienced in building the provided products; uncertainties especially appear by the conception and implementation of services to offer a combined solution. The most important results of the case study are presented in figure 6.

The provider got a request of investors in form of the management of an investment fond who demanded to build a new wind energy park in the north of Germany. Given by the fact that the investors are just a group of financiers without any capabilities to care of the wind power plants themselves, they were searching for a solution provider who offers a package of combined products and services to warrant a viable wind energy generation.

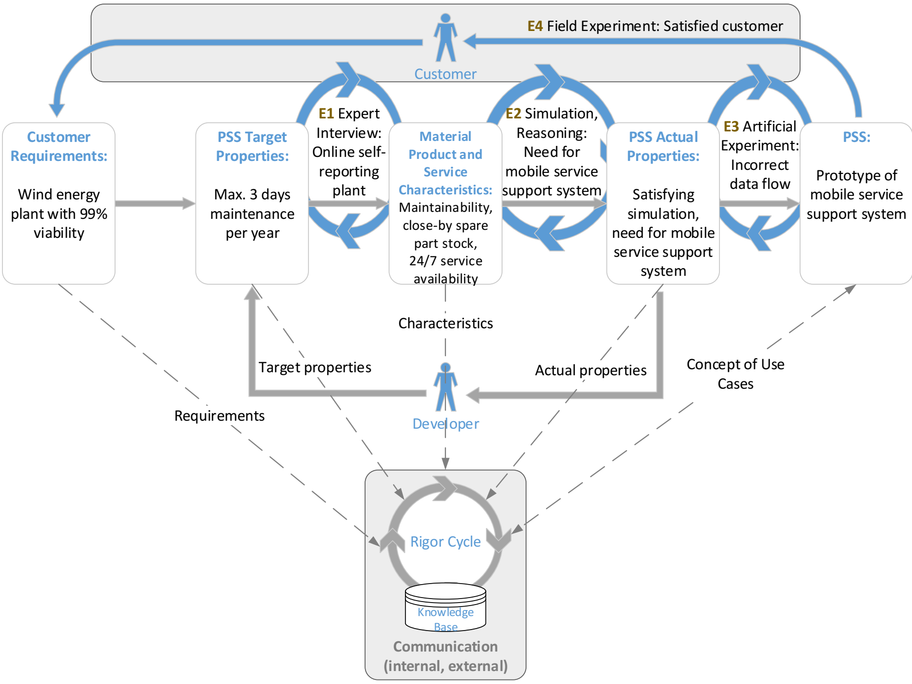

Fig. 6. Results of the Case Study

The recorded customer requirements consisted of four wind energy plants that should be viable 99% of the year. In a next step, the customer requirements were translated into the PSS target properties as a basis to communicate in the specialized terminology: 99% viability requires that the plant runs at least 362 days in a year implicating that there are only three days in a year to service and maintain the plants. The characteristic synthesis from the target properties for the PSS was mainly characterized by the experience of the developer. In the following, the central material products and service characteristics are presented without discussing the detailed construction process, because the paper focusses on concept of hybrid bundle and not on the construction of a product itself. Due to the properties of short service cycles, the developer determined the product to be constructed as an easily maintainable plant. Spare parts have to be stored in close-by stocks with a convenient infrastructure and the TCS consisting of the service center and the technicians themselves have to be available 24 hours a day. After the characteristics had been defined the first evaluation cycle started. Experts in form of PSS researchers were interviewed about the feasibility, simplicity, completeness, consistency and operationally of the concept. Meanwhile, it became apparent that the wind energy plants have to be online to immediately report back malfunction. The concept of an online plant was added to the characteristics and the actual PSS Properties were defined: the products and the IT-systems were designed and a training concept for the TCS technicians was created. Subsequently, the plant itself was evaluated by simulation to get an impression of the effectiveness and efficiency as well as the robustness. The simulation was successful due to the fact, that the wind energy plant provider is already experienced in building the plant itself as mentioned above. Furthermore, the TCS process was evaluated by reasoning. The process models were analyzed and potentials for improvement were detected: to support the complete process chain, the TCS technicians have to be connected via mobile service support system. To meet the short service time, the technician have to receive the order with all necessary plant information at the point of service, in case of repair services he needs to order the spare parts immediately and after having finished his service he has to document his work steps for further service requests. For the specification the outcomes of the second evaluation were added and a first prototype of the mobile service support system was built. Thereby the developers draw on the scientific knowledge base using the concept of Use Cases, to construct a support system, that considers every possible use case representative for all eventual activities of TCS processes (for further information see [39], [16] and [13]). The instance of the first prototype was evaluated in an artificial setting. An experiment conducted by the developer and selected TCS technicians took place. On that point, the whole process beginning by the wind energy plant reporting back a malfunction up to the TCS technician repairing the plant using the mobile service support systems was tested. As a result an incorrect data flow between the technician and the service center was detected. In the next step, the errors were fixed and the scenario could be evaluated in the field. Necessary to that, the PSS was shown to the customer and the earlier contacted expert group of researchers. Due to the fact, that the focus group was satisfied, there was no further iteration of the PSSE Cycle necessary. The PSSE Cycle was finished with the roll-out of the product and signing the service contracts.

During the PSSE process the developers not only referred to already existing research theories and practical methods but also stored the relevant information about the customer requirements, the specification of the PSS and the construction itself into the internal knowledge database to create the possibility to transfer them to further developments. In addition to that, the innovative mobile service support system was presented to researchers and practitioners on a leading trade fair for industrial technology in Germany.

6 Discussion of the Results

Lessons learned from the case study were in particular that the revised framework provided the user and developer of a Product-Service System with more input from different participants. With the inclusion of different groups such as experts, customers, users, etc. the development team had the chance to evaluate and judge the potential PSS from different views already during the development phase. Those additional evaluation activities lead to several insights that supported the developer, especially the inexperienced one, with the creation of a successful PSS. The chance of having a PSS that successfully cover the customer expectations and needs improves. However, one of the downsides of this approach is the extended development period and the higher costs. This might be in particular in a fast moving market an unwanted effect that has to be assessed thoroughly before taken into account. In the case study presented within this paper the market does not awaits the fast moving actions which is why the PSS Development approach is appropriate. In addition to that, oncosts for adaptations after the finished product has been presented drop for the reason that the customer and expert groups are already included in the build phase where adaptations are not that enormous as in the aftermath.

Another positive aspect of the approach was the inclusion of the Knowledge Base. Although most of the companies use the knowledge they gain implicitly in their next projects this explicit approach of adding all information to a dedicated database in order to reuse parts of them is beneficial. As the Knowledge Base might as well be further used in cooperation with scientists this leads to the positive aspect that new scientific findings might get included in new PSS and vice versa. Altogether the aspects of the revised framework assist the development of successful PSS and add vital parts to the conventional approach.

7 Conclusion and Outlook

The development of Product-Service Systems needs to be viewed from a process-oriented perspective in virtue of the complexity that exists in the provision of an appropriate integrated solution to meet customer needs. Especially in the service field, an optimal design of processes and supporting activities is important for the service delivery in order to create customer satisfaction and loyalty. For this purpose, the development of PSS has been considered from a methodological point of view with due regard to the Design Science Research paradigm. Thereto, elementary concepts of DSR which need to be considered during the design of an artifact and that are suitable for the process-oriented design of PSS were introduced. A PSSE approach was derived by investigating existing literature in PSS research and exemplified by a case study of the TCS within the wind power market. The combined consideration of these two research fields allowed us the construction of a design science oriented Product-Service System methodology as a basis for the support of the design of PSS processes in the context of hybrid value creation. This paper is a first step to extend the scope of information systems containing a design science oriented development of IS as an essential part of PSS.

Our derived PSSE methodology does not claim to be exhaustive but rather presents an integrated approach on how a PSS can be developed conceptually and considering DSR requirements. In order to improve the validity of our findings, in future we schedule to extend the scope of our investigation by different branches to achieve more results with the aim to provide a guidance and signpost for the design of PSS. Further we plan to examine applied approaches and engineering methodologies within research projects comprising the development of PSS in order to ascertain distinctions and to reveal potentials for the improvement of our presented PSSE methodology.

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