INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

INTEGRATION OF USER KNOWLEDGE ACROSS THE LIFECYCLE OF INTEGRATED PRODUCT-SERVICE SYSTEMS – AN EMPIRICAL ANALYSIS OF THE RELEVANCE FOR PSS DEVELOPMENT AND MANAGEMENT

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Abstract
Integration of user knowledge in corporate innovation processes enhances firm innovation performance. Despite the relevance of the topic, research on when to integrate user knowledge into corporate innovation processes is scarce. We address this gap by empirically investigating the relevance of user knowledge across the lifecycle of complex product-service systems (PSS). Using matched interview data from both users and producers, we find, that user knowledge is useful for many important phases across the PSS lifecycle. When comparing the relevance of user and producer knowledge, we find that user knowledge is particularly relevant for early ideation- and late use-related phases, as well as for service-related development and delivery stages. With regard to product-related production and logistics, firms tend to rely on knowledge that is available internally. Our findings have several implications for the development and management of integrated product-service systems, including guidelines about when to integrate users into their PSS development.

Keywords: User centred design, Open Innovation, Design process, Knowledge management

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

User integration in corporate innovation enhances firm innovation performance (Chatterji and Fabrizio, 2012). Users located outside of firm boundaries hold distinct knowledge sets complementary to corporate knowledge. Firms' ability to develop new knowledge internally is limited due to a number of reasons such as local search behavior (Rosenkopf and Nerkar, 2001) or strategic resource allocation (Christensen and Bower, 1996). Integration of external user knowledge is one option for building new knowledge (Chatterji and Fabrizio, 2013). Despite the relevance of users' innovative activity for corporate innovation, so far little is known about when and in which processes integration of user knowledge is most beneficial for firms. In this paper we address this gap by empirically investigating the relevance of user knowledge for corporate innovation development and management throughout the whole lifecycle. We study this phenomenon using the context of integrated product-service systems (PSS). As integrated PSS are complex systems that require multiple types of knowledge they are suitable for studying collaborative innovation and knowledge complementarities from multiple sources (Schenkl et al., 2013, Tukker, 2004).

This paper builds on and extends on existing literature on user innovation and its value for corporate innovation. We add to the understanding of this literature stream by exploring relevance of user knowledge across the lifecycle of PSS. Using matched interview data from both users and PSS providers, we show that the integration of user knowledge is particularly relevant in early ideation- / development related as well as in later use-related process steps. For the stages in the middle of the PSS lifecycle, related to product design and production, internal corporate knowledge is more important than user knowledge. Also, we show that user knowledge is particularly important for service-related process steps. Due to the relative proximity of services to use experience, user knowledge is more important for service-development than it is for product-development.

Our research has three important implications for the development and management of integrated PSS. First, our paper shows that user need-related knowledge provides benefit for the management of PSS. According to our analysis, user knowledge is very useful with regard to many important phases of the PSS lifecycle. Our paper provides advice for managers, in which phases of the lifecycle and for which functions / processes the integration of user knowledge is most beneficial. Second, it investigates the relevance of user knowledge for different components of PSS. Particularly we find, that user knowledge is relevant for the development of service related components. Second, we give guidance about the detailed nature of the relevant user knowledge needed throughout the lifecycle. Third, our paper shows that the integration of external user knowledge with internal corporate knowledge is crucial for the development of PSS. Since both types of knowledge are important for both different development phases and components an integration of both knowledge sets is essential for successful PSS development.

The structure of the paper is as follows: Section two describes relevant constructs from existing literature. We provide an overview of the relevance of user knowledge and describe the PSS lifecycle model we used in this paper before lining out our research gap and objective. In section three, we explain our methodology and the measures we used. Throughout section four, we describe relevant analyses and results. In section five, we conclude with managerial implications and suggestions for future research.

2 THEORETICAL BACKGROUND

2.1 Integration of user knowledge in the lifecycle of PSS

For a long time providers have been regarded as the principal source of innovation. Providers' motivation to innovate is driven by monetary profit expectations from selling products and services. Within the last decades literature on the user innovation has identified users as an important complementary source of innovation. Users' motivation to innovate is driven by their own needs and expected benefits from using the innovation themselves (von Hippel, 1988). Research has shown that users are an important source of innovation in various industries and for many different innovations.

Users have been found to develop various product (Lettl et al., 2006), process (von Hippel, 1977), and service (Oliveira and von Hippel, 2011) innovations.

Users and producers differ in terms of their knowledge sets. Users have detailed need-related knowledge focused and shaped by their own needs and use experience (von Hippel, 1994, Chatterji and Fabrizio, 2012), whereas producers tend to have in-depth technical solution knowledge built via systematic R&D (Chatterji and Fabrizio, 2012). Producers' ability to develop new knowledge internally is limited (Anderson and Tushman, 1990) due to a number of reasons such as local search behavior (Rosenkopf and Nerkar, 2001) or strategic resource allocation (Christensen and Bower, 1996). They can benefit from integrating user knowledge in their innovation processes (Chatterji and Fabrizio, 2013). Research has shown that user knowledge integration in corporate innovation enhances a firms innovation performance, particularly with regard to radical innovations (Chatterji and Fabrizio, 2013) and customers have been found to be the most important information source with regard to idea generation for new R&D projects (Cohen et al., 2002). So far user innovation and integration has not been explicitly investigated in the context of integrated PSS. For PSS producers the integration of user knowledge in innovation processes is particularly relevant. Due to the complexity of integrated systems comprising both product- and service components, diversified types of knowledge are needed for successful management and development of PSS.

2.2 A lifecycle model for integrated PSS

We need a detailed PSS lifecycle model in order to investigate varying degrees of relevance of user knowledge throughout different phases of the cycle. Existing research has identified several approaches in relation to PSS lifecycles. Becker et al. (2008) presented a model of PSS including the phases of design, delivery and replacement. The PSS lifecycle of (Meier et al., 2007) is analysed both from the company's and customer's perspective. However, as it is focused on giving an initial picture of the information arrangement throughout the lifecycle, their presented model is not detailed enough. These models rather give a high-level overview of the PSS lifecycle. In order to understand the integrative perspective or explain how to deal with different information throughout the lifecycle, it is necessary to get a more detailed cycle model, including all different aspects considered throughout all PSS lifecycle phases and accounting for the interrelations within the lifecycle and its phases.

We used the model from (Hepperle et al., 2010, Hepperle, 2013) for this reason. In comparison to other existing PSS lifecycle models, this model presents a more detailed overview not only of the whole lifecycle but also of the singles phases, tasks and states a PSS runs through. It presents an integrated model of the lifecycle of PSS throughout the phases of planning, designing, delivering/using and decomposing PSS. This model consists of the superordinate phases of PSS planning, PSS development and PSS production, delivery and decomposition. The model consists of 9 superordinate phases detailed by subphases, 32 working operations and 18 states on the product perspective, as well as 4 superordinate phases, 15 working operations and 12 states on the service perspective. In order to emphasise the integration of product and service, this model contains elements describing the interaction between both product and service components within the lifecycle. Throughout the lifecycle, product and service related processes are either performed integrated (e.g. planning) or they are being solved separately with a continuous communication and alignment between the respective processes.

2.3 Research gap and Expected results

For suppliers of PSS it is essential to understand the boundaries of knowledge that is available internally and when to integrate user knowledge across the PSS lifecycle. Despite the high managerial relevance of the topic, so far research on when user knowledge should be integrated throughout the lifecycle of novel products, services, or PSS is scarce (Bogers et al., 2010). Recent research finds that corporate (product) innovations integrating user knowledge occur more frequently early in the product lifecycle than conventional corporate invention (Chatterji and Fabrizio, 2012). This paper builds and extends on this research. We add to the understanding of user integration across the life cycle of integrated PSS. We investigate the relevance of user knowledge across the lifecycle and differentiate between process stages for product and service development. We expect that the relevance of user need knowledge in relation to producer knowledge will vary over the lifecycle. I.e. we expect that –

consistent with existing research (Chatterji and Fabrizio, 2012) – user knowledge will be relatively important in the early life cycle stages dealing with planning and development, as well as in late stages related to customer usage. We take a differentiated view distinguishing between product- and service-development related life cycle stages. Based on prior research on user provider interactions, we expect user knowledge to be relatively important for life cycle stages related to service development due to the proximity to usage, but relatively unimportant for stages related to product-development that are rather technical (Preissner et al., 2014).

3 METHODOLOGY AND MEASURES

3.1 Interview study with Yamaichi Electronics Deutschland GmbH

In order to assess the relevance of user and producer knowledge for the lifecycle of PSS in a real life setting, we conducted interviews with company representatives working for an international PSS provider, covering different functions across the PSS lifecycle. The respective company – Yamaichi Electronics Deutschland GmbH – is an international company established in 1986 in Munich. The company offers PSS in the area of electromechanical components. The company has approximately 3,000 employees worldwide with manufacturing facilities in Japan, China, Korea and Germany. The subsidiary in Germany works in the areas of sales, design and development, manufacturing and distribution, covering all relevant PSS-lifecycle phases. A total of n=12 interviews was performed with employees holding different positions and coming from several departments in the company, including product managers, a design engineer, a production planner, a supply chain manager, a production supervisor, a manufacturing engineer, a quality manager, a group chief in the area of logistics, a sales representative and an environmental management representative.

3.2 Data collection and analysis

A questionnaire containing detailed lists of both user and producer knowledge was used for the assessment of knowledge relevance by company representatives. Representatives could choose between three different values for the assessment of each relation (Schmidt et al., 2014): 0 meaning that the knowledge element doesn't apply in the operation (not necessary), 1 meaning that the knowledge element is rather used as a tool for the performance of the activities (helpful) and 2 meaning that the knowledge element is necessary for the operation (very necessary). Our data analytic approach is based on (Wickel et al., 2013). To identify relations between knowledge elements and PSS lifecycle phases, we collect all relevant information in matrices, displaying all phases and working operations of the PSS lifecycle on the upper axis, and all user and producer knowledge elements on the left axis. First, a single matrix was created for each interview. For further analysis the results were consolidated in one matrix.

3.3 Measures of user and producer knowledge

The objective of this paper is to analyse and assess the relevance of user and producer / company knowledge across the lifecycle of PSS. We use approaches and methods from the research area of knowledge management for analysing user and producer knowledge (Nonaka and Takeuchi, 1995). Based on knowledge mapping, we consider knowledge as a structure composed of knowledge elements (Eppler, 2001). According to Eppler (2004), a knowledge element can describe experts, written text, applications or lessons learned. By analysing the number of knowledge elements and their relations, we obtain results about the distribution and the relative importance of knowledge (Schmidt et al., 2013, Ahn et al., 2006, Housel and Nelson, 2005).

Users and producers have distinct and complementary knowledge sets. Producers focus on building technical solution knowledge through systematic R&D, whereas users employ need use related knowledge. This knowledge is build and enhanced through in-depth use experience that provider R&D employees are usually lacking. Users provide a source of complementary knowledge for producer firms (Chatterji and Fabrizio, 2012, Chatterji and Fabrizio, 2013). For the purpose of this study we used detailed listings of user and provider knowledge making it easy for company representatives to assess the relevance of each knowledge element throughout different phases of the PSS lifecycle. The measures we used will be described in the following.

3.3.1 User need knowledge

The integration of user knowledge in the lifecycle of PSS is the central object of this research. For the assessment by company representatives we used a detailed list of user knowledge categories. Since such a list is not readily available from existing literature, we conducted an exploratory pre-study, using n=4 in-depth interviews with heavy users of different technical products and related services (Flick, 2009). We used a maximum-variance sampling strategy (Miles et al.; 2013), i.e. we searched for users of rather different technologies (e.g. including sporting or photographic equipment) in order to get a broad picture of relevant user knowledge categories. The interviews were semi-structured using a guideline. After data collection, interviews were coded and analysed using MAXQDA (Miles et al., 2013). Based on our analysis n=38 categories of user need related knowledge were extracted for assessment by company representatives. Categories can be grouped according to the subject of knowledge. Users hold knowledge on different subjects, such as the product itself, complementary products and services, usage techniques, general market structure and preferences.

3.3.2 Producer / company knowledge

The categorization of provider knowledge used for the interviews is based on the research from (Petermann, 2011, Ahmed, 2005, Vianello and Ahmed, 2009, Trevelyan, 2008). Hereby the classification is simplified into product-dependent and product-independent knowledge. The first group describes all the categories related to a product, such as the product features and the reasons for product features. The second group is based on categories, which serve as tools for the employees, in order to perform their daily tasks. The product-independent knowledge is subdivided into basic knowledge, containing general categories – such as documentation and project management – and specific knowledge that covers specialized knowledge from different disciplines – such as e.g. chemistry or electronics. The categorization used covers the most important aspects of internal company knowledge for the creation of a new PSS. For analyses comparing the relevance of user and producer knowledge sets, we only used product-independent knowledge categories on the producer side. Product-dependent knowledge was not suitable for this comparison, since it is bound to a specific type of product, whereas product-independent and user knowledge categories are rather generic.

In order to be able to compare the relative importance of both need and solution knowledge, both category lists of user and provider knowledge were compared in terms of their depth and breadth in order to check for common levels of fragmentation and granularity. The knowledge elements for both user and producer knowledge are concrete and easy for the employees to understand. Detailed descriptions of each knowledge element were available if company representatives had problems understanding some categories. Therefore, relations between knowledge elements and PSS-lifecycle phases could be easily identified by company representatives.

4 RESULTS

Based on the matrix displaying the relevance of user and producer knowledge throughout the PSS lifecycle, we conducted several analysis to address our research questions. The first analysis deals with comparing the relative importance of user and producer knowledge across the whole lifecycle (4.1). In the following subchapters we take a more differentiated perspective showing: when user knowledge is beneficial for companies (4.2), in which phases (4.3) and for which PSS components (4.4) user knowledge is comparatively more important than producer knowledge and vice versa.

4.1 Relative importance of user and provider knowledge throughout the PSS lifecycle – The Relational Knowledge Connectivity

One objective of our research is to assess the relative importance of user knowledge in comparison to the relevance of provider knowledge. In order to identify which knowledge is needed to which degree (not necessary, helpful or necessary) throughout the whole lifecycle, we define the "Relational Knowledge Connectivity" (RKC) as a measure for analysing the matrix of knowledge elements and PSS-phases. RKC is derived from the measures for Structural Complexity Management (SCM) and defined as relational density (Vanderfeesten et al., 2007, Kreimeyer, 2010) or as degree of connectivity (Eichinger et al., 2006, Puhl, 1999, Lindemann et al., 2009). This measure evaluates to which degree a network is interconnected. It describes the number or degree of existing relations compared to the maximum number of possible relations. Applying this measure to the results of our interview study, we define the relational knowledge connectivity as follows:

$$RKC = \frac{\sum_{m=1}^{k}\sum_{n=1}^{p} KL_{m,n}}{\max(KL)\cdot k\cdot p}$$

RKC…Relational Knowledge Connectivity
$KL_{m,n}$…Knowledge Level for knowledge element m and phase n
k…Number of knowledge elements
p…Number of phases

The knowledge level describes relation quality of a knowledge element to a phase, in our case there are the three options: no need (0), helpful (1) or necessary (2). For our study, the maximum of knowledge level is 2 and the number of phases is 37. Applying this measure to user knowledge (43 %) and for (product-independent) producer knowledge shows that user knowledge exhibits a higher degree of RKC (RKC_{UK}=43%) than producer knowledge is (RKC_{PK}=39%), i.e. user knowledge in general is linked to the PSS lifecycle to a slightly higher degree than producer knowledge is. In general, this finding indicates a high need for integrating user knowledge throughout the PSS lifecycle.

4.2 Relational Knowledge Connectivity for user knowledge in PSS-Phases

Another aim of our research is to identify the phases of the PSS-lifecycle, which require most of user knowledge. We claim that open innovation methods and approaches for user integration should be applied for those phases of the PSS lifecycle, which need more user knowledge. To identify those phases, we used the RKC for the user knowledge in PSS-phases. We calculated the RKC of user knowledge for every single phase, using the following formula:

$$RKC_{Phase} = \frac{\sum_{m=1}^{uk} KL_{m,Phase}}{\max(KL)\cdot uk} = \frac{\sum_{m=1}^{uk} KL_{m,Phase}}{2\cdot 38}$$

uk…Number of use knowledge elements

The RKC_{Phase} describes the need for user knowledge in this phase. The result for all phases is shown in Figure 1.

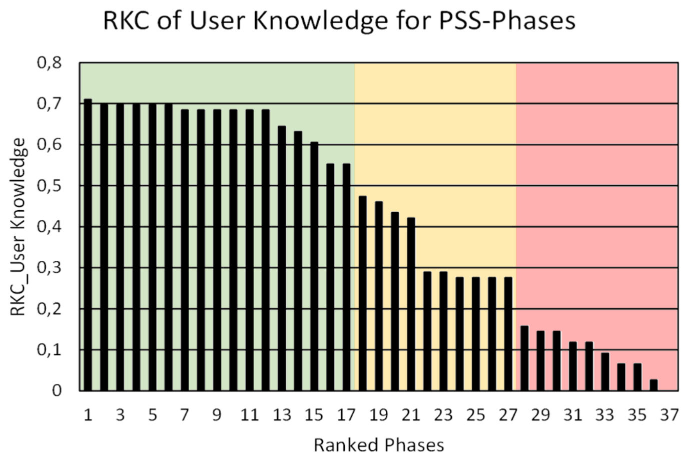

Figure 1. Relational Knowledge Connectivity for User Knowledge

The median of this set of RKC_{Phase} data is 0.5, meaning that 50% of user knowledge elements score above and 50% score below that value (green area Figure 1). We took the median value as a threshold for deciding in which phases integration of user knowledge is useful. Phases of higher RKC_{Phase} than 0.5 are suitable for approaches for integrating user knowledge. This category of a high-level need for user knowledge enables us to identify phases with a great suitability for integrating user knowledge.

For phases with a RKC_{Phase} between the 25th percentile ($RKC_{Phase} = 0.25$) and the median we cannot derive a generally valid interpretation (orange area in Figure 1). For this category, we claim that the need for use knowledge depends on the situation, which is for example defined by the product, the user group or the company. Dependent on those issues, integration of use knowledge might be useful or not.

In phases with a RKC_{Phase} lower than the 25th percentile (red area in Figure 1), less than half of use knowledge elements have the knowledge degree "helpful". For this reason, we summarize those phases to the category of low-level need for use knowledge. Phases belonging to this category have a low potential for improvement by integrating use knowledge. Those phases should be neglected for the application of approaches for the integration of use knowledge.

In Figure 1, the green area shows the phases with a RKC_{Phase} higher than 0.5 and we call this category "High-level need for user knowledge". The category includes 17 phases, 8 of them belong to the service development and implementation. Why services need more user knowledge, will be explained in chapter 4.4. 6 phases concern the user or the using phase directly, like requirements definition or upgrading. As those phases deal with the user or customer itself or are only dependent on the usage phase, those results are expectable and show the interviews' validity. In those phases, customers and users are integrated into the product development even for classical approaches. However, the three phases "Generating Ideas", "Prioritization and Specification of Ideas" and "Tests and Verification" need a high amount of user knowledge. The orange area in Figure 1 are phases, which need user knowledge on a situation-dependent base, and the red are phases with a low-level need for user knowledge. Both areas include phases of product planning or development for the physical product and phases about transportation and disposal. Those phases seem not to need the integration of user knowledge.

Concluding, Table 1 shows the identified categories of phases regarding the need for user knowledge.

Table 1. Categories of phases concerning user knowledge

Category	RKC_{Phase}	Potential for integrating user knowledge
High-level need for user knowledge	$RKC_{Phase} > 0.5$	High suitability for approaches of integrating user knowledge
Situation-dependent need for user knowledge	$0.25 < RKC_{Phase} < 0.5$	Depends on situation, provider and user
Low-level need for user knowledge	$0.25 > RKC_{Phase}$	High suitability for approaches of integrating user knowledge

4.3 Relative importance of user- and producer knowledge across the PSS lifecycle

In order to compare the relative value of user and producer knowledge for different stages across the PSS lifecycle, we compared the groups of user knowledge (n=38 categories) and respectively producer knowledge (n=32 categories) in terms of their relative importance for different phases of the PSS life cycle. We used Mann-Whitney-U tests to check for significant differences in the relative value of user and producer knowledge across the different PSS lifecycle phases (Neuhauser, 2012). We use nonparametric tests, since our data does not follow a normal distribution. The Mann-Whitney test is a non-parametric test that is used to look for significant differences in specific pairs of populations (in our case the two populations of need and solution knowledge) (see Neuhauser, 2012). Figure 2 shows the relevant summary statistics with regard to the importance of user and producer knowledge across the PSS lifecycle. We find significant differences in the relevance of need and solution knowledge for most stages of the PSS lifecycle, meaning that different stages of the PSS lifecycle require knowledge from different sources. Figure 2 shows that need knowledge originating from users is especially important in very early and very late stages – such as early PSS planning (p=0.004) / PSS development (p=0.000 [3]) – and in later stages related to usage and disposal of the PSS. We use exact two-tailed significance levels according to our data structure (Neuhauser, 2012). For the stages in the middle of the PSS lifecycle – production and delivery – we find no significant differences when taking a consolidated look on the complete stage of "production and delivery". We take a more detailed look on separated lifecycle stages with regard product and service components in the next paragraph to explain these results.

Mean ranks show the relevance of the respective knowledge category (user vs. provider knowledge). The higher the value, the more relevant the knowledge category. The significance level p shows, whether the difference between user and provider knowledge is significant. A significance level of $p<0.05$ is widely accepted threshold for significant difference. We use exact two-tailed significant levels (Neuhauser, 2012).

PSS Life-cycle	Planning		Development		Production & Delivery		Usage		Disposal	
Knowl. Type	User	Prod.	User	Prod.	User	Prod.	User	Prod.	User	Prod.
Mean Ranks	41.74	28.09	46.64	21.55	33.14	37.16	44.89	24.34	38.93	29.52
p	0.004		0.000		*n.s.*		0.000		0.046	

Figure 2. Relevance of User and Provider knowledge in the PSS lifecycle

4.4 Relevance of user knowledge for product- and service development

For the analysis of product-and service specific lifecycle phases we had a more detailed look on the stages of "development" and "production and delivery" of product and service components. Figure 3 shows the relevant summary statistics with regard to the relative importance of user and producer knowledge for those lifecycle phases specifically addressing product- or service lifecycles. We find that in product- and service related stages different types of knowledge are relevant. Using Mann-Whitney-U test (see Graph 1), we find that user knowledge is particularly relevant for service-related development (p=0.000 [3]) and delivery (p=0.000 [3]). For product development and production, we find that technical provider knowledge is highly relevant for product construction (p=0.012 [3]), production (exact two-tailed p=0.000) and logistics/ transportation (p=0.000 [3]). In very early stages of product development (requirement definition, problem structuring), user knowledge is still more relevant (p=0.000 [3]).

PSS Life-cycle	Planning		Development		Production & Delivery		Usage	Disposal
Product/ Service Phases	Product Developm.		Service Developm.		Product Production		Service Delivery	
Knowl. Type	User	Prod.	User	Prod.	User	Prod.	User	Prod.
Mean Ranks	41.86	27.06	45.50	23.63	27.15	44.08	45.00	24.22
p	0.001		0.000		0.000		0.000	

Figure 3. Relevance of User and Provider knowledge for product- and service- development

5 SUMMARY AND DISCUSSION

Taken together, our analyses show that user knowledge is highly relevant for the development and management of PSS. With regard to the management of the whole PSS lifecycle our results show that user knowledge is particularly relevant for early – ideation related – and late – usage related – phases in the PSS lifecycle. With regard to the development of PSS, we see that user knowledge is especially important for the development and delivery of service components, whereas producer solution knowledge is particularly relevant for the development and production of product components. These results build on and extend on prior literature showing the relevance of user integration in early development phases (Chatterji and Fabrizio, 2012) and for different components (Preissner et al., 2014).

Our paper has three important implications for the development and management of integrated PSS. First, our paper shows that user need-related knowledge provides benefit for the management of PSS. According to our analysis, user knowledge is very useful with regard to many important phases of the PSS lifecycle. Our paper provides advice for managers, in which phases of the lifecycle and for which functions / processes the integration of user knowledge is most beneficial. Second, it investigates the relevance of user knowledge for different components of PSS. Particularly we find, that user knowledge is relevant for the development of service related components. Second, we give guidance about the detailed nature of the relevant user knowledge needed throughout the lifecycle. Third, our paper shows that the integration of external user knowledge with internal corporate knowledge is crucial for the development of PSS. Since both types of knowledge are important for both different development phases and components an integration of both knowledge sets is essential for successful PSS development.

This paper has several limitations. We identified the relevant user knowledge categories using a qualitative interview based approach. By using a maximum variance sampling strategy we tried to cover a broad range of potential knowledge categories – nevertheless due to the qualitative nature of the approach we cannot assure completeness for the set of user knowledge categories. Also, we considered the number of knowledge elements and not the knowledge content itself. Taking into account which (user) knowledge elements are needed for which PSS-phase might give recommendations about the approach applicable for user knowledge integration. It depends on the kind of user knowledge, which method is the most suitable one for integrating the user. For this, we need an evaluation of user knowledge elements regarding the suitability to methods or approaches of user integration. However, this paper's results give a recommendation to companies, which phases of the PSS-lifecycle should be selected for the integration of user knowledge. Analysing the indirect relations between the knowledge elements based on their relevance for phases will show which knowledge elements are used for similar phases. This will define which knowledge elements should be possessed by same employees and which competences employees should have. The results' quality of the interview study has to be considered critically. Especially the case of evaluating the relevance of knowledge for the PSS-phases made by employees might be problematic. Those results are influenced by subjective biases of employees (Dunning et al., 2004, Harris and Schaubroeck, 1988).

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ACKNOWLEDGMENTS

We thank the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) for funding this project as part of the collaborative research centre 'Sonderforschungsbereich 768 – Managing cycles in innovation process – Integrated development of product-service-systems based on technical products'.