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ScienceDirect
Procedia CIRP 47 (2016) 108 – 113
www.elsevier.com/locate/procedia

Product-Service Systems across Life Cycle

Requirements for cross-domain Knowledge Sharing in collaborative Product-Service System design

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Abstract

In the case of Product-Service Systems (PSS), the design phase is characterized by a demand for intensive exchange of knowledge between stakeholders from different domains. Thus, a comprehensive approach for knowledge sharing would support the integrated development of PSS. Existing attempts are however mainly focusing on using explicit service knowledge for product design and service operations only. Knowledge exchange between domains, including tacit knowledge and sentiment, for the integrated design of products and services have received less attention. The objective of this paper is to present the initial results on the requirements for cross-domain knowledge sharing when designing innovative PSS.

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

Keywords: Knowledge Management; Product-Service System Design; Collaborative Networks

1. Introduction

Companies are becoming increasingly aware of the fact that knowledge is a resource requiring explicit management methods, if it is to be processed efficiently: storing knowledge, communicating, forging links and synergy between each individual's knowledge, and generating new collective knowledge [1]. Product and service design is also becoming more and more collaborative. The design of services and physical products requires knowledge that is usually scattered among different persons, departments or even organizations. Manufacturers are working closely with service providers, suppliers and customers to perfect designs of new product-service bundles before they are realized [2]. This network of partners defines the underlying problem and solves it through the application of knowledge, generating new knowledge.

The required knowledge exchange depends on the types of products and services involved and on the depth of their integration. In the case of Product-Service System (PSS), where the tangible and intangible components are entangled and dependent on each other, the design phase is characterized by a demand for intensive exchange of explicit and tacit knowledge for the engineering process, like user and system requirements, sentiments, competences, design specifications or processing instructions between the involved stakeholders from different domains [3]. To this end, both knowledge from the product side as well as the service side must be shared in an appropriate way, combined and utilized, in order to create an attractive product-service bundle for the customer.

In the scientific discipline of Knowledge Management (KM), several approaches to capture, develop and apply knowledge effectively during product design have been developed. Knowledge-Based Engineering (KBE) for example is aiming at establishing engineering knowledge models, for application in product design and along the whole product life cycle. First attempts have also been made to include service knowledge into a KM framework for PSS as well. These attempts are however focusing on using service knowledge for

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle
doi:10.1016/j.procir.2016.03.118

product design and service operations only. Furthermore, most approaches have been focusing on explicit formalized knowledge inside an individual organization. [4]

Thus, an integrated approach for knowledge sharing, considering the special characteristics of PSS and avoiding the limitations of the existing approaches is required. It shall enable the stakeholders to exchange explicit and tacit product-service design knowledge beyond organizational borders in order to facilitate an integrated development of PSS. Furthermore, sentiment could be used as an additional source of knowledge. The aim of this paper is to give an outline of the requirements for knowledge sharing in PSS design.

2. Research Approach

The analysis of requirements for knowledge sharing in Product-Service System design is based on a literature review of existing approaches, as well as on the analysis of four industrial use cases aiming to design new PSS. As the work with the use cases is still ongoing, it can be seen as an exploratory approach at this stage.

The literature review has been conducted by accessing scientific papers through the multidisciplinary SCOPUS database, as PSS are a cross-domain research topic. For practical reasons, the search was limited to journal and conference papers in English language. As several expressions are used in literature to describe the PSS concept, we applied *TITLE-ABS-KEY ("product-service" OR PSS OR IPS OR "Extended Product")* as the first search term, combined with *AND TITLE-ABS-KEY ("knowledge management" OR "knowledge sharing")* as the second term.

The search yielded 214 results in total, which were checked for relevance and redundancy by assessing the abstracts. Based on this, 40 papers were selected for in-depth analysis of the content. The literature review was complemented with papers from additional sources, such as Google Scholar. [5]

The outcome of the literature review is discussed in the following sections. In a first step, the role of knowledge in the life cycle of products, services and integrated PSS is analysed. The relevant stakeholders and the knowledge exchanged between them is identified. This is complemented with the results from the use case analysis. Secondly, the State-of-the-Art in knowledge sharing for PSS Design is examined for open issues and gaps. There are several existing approaches, mainly from product engineering, which could provide a good basis for sharing explicit and formalized knowledge. These are assessed towards their suitability for the design of PSS. The main criteria are the suitability for PSS engineering, the underlying processes and stakeholders and the extent to what their re-use or adaption will increase knowledge sharing in PSS design. The analysed approaches then can be selected for further requirements in order to be applicable for PSS.

3. Knowledge in Product-Service System Design

The design phase in the life cycle of products and services is characterized by an intense exchange of knowledge [6]. This even increases if an integrated PSS shall be designed in a collaborative way [7–9]. On the one hand, it has to be elaborated which process steps are typically conducted in PSS design [7,10,11] (section 3.1). On the other hand, the involved stakeholders have to be identified and described as the relevant knowledge sources and targets [3,7,12] (section 3.2). Based on the results, the relevant types of knowledge and appropriate exchange mechanisms and standards have to be defined [2,7,13] (section 3.3).

3.1. PSS Life Cycle

Based on the targeted integrated design of PSS, product and service life cycle must also be integrated to provide the required interactions during the design phase [7]. Meier and Uhlmann [14] derive a PSS life cycle directly from the combination of product and service life cycle as shown in Fig. 1:

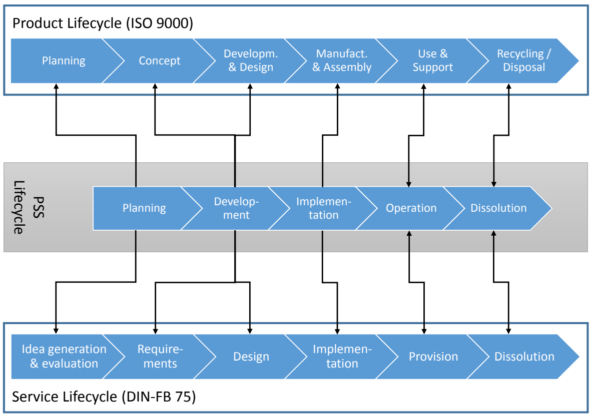

Fig. 1. PSS Lifecycle according to [14].

The PSS life cycle focuses no longer only on the operation, but the satisfaction of customer needs is in the foreground [15], leading to long life cycles and an increased proportion of service [16].

3.2. Stakeholders in PSS Engineering

The PSS Engineering process is characterized by the inclusion of competences in the form of various actors during the development phases [7,17]. These stakeholders are the relevant sources and targets of knowledge and can be assigned to PSS specific roles [3,12,18] for the process.

The Customer initiates the process, because demands towards the PSS will be drawn up and implemented based on the determined customer needs [17]. The PSS Provider or OEM coordinates the design of the product-service bundle [16], while the Production and Service Networks comprises the partners who are responsible for provision of components or services for the PSS Provider [19,20]. The PSS Project Manager coordinates the PSS actors and their knowledge sharing along the development process [21], while the PSS Architect fosters PSS idea generation, documentation and management [22].

3.3. Knowledge exchanged during PSS Engineering

As the engineering of PSS is a dynamic process, with fluctuating actors [3,23], knowledge residing in individuals has to be combined with knowledge assets that are essential for creating the intended (customer) value and have to be shared between the roles, as centred in the so-called "2nd wave of knowledge management" [24].

While in "traditional" product development knowledge assets are mostly explicit and formalized in the form of documents, specifications and design etc. managed by applications such as CAD, PDM or PLM, during PSS engineering when the intangible aspects come into play knowledge is usually tacit, like skills, know-how, emotions and the like [13].

Explicit knowledge for PSS engineering includes market needs and customer requirements, product specifications and concepts, as well as the detailed product design or model [11]. This knowledge can be formalized in text documents, spreadsheets, diagrams, CAD drawings and the like. However, only about 4% of organisational knowledge is formalized [25]. Recent studies on open innovation, e.g. in the form of application of crowdsourcing techniques [26] or implicit feedback leveraging from social media [27], have established the important role of open, crowd-oriented opinion and sentiment in enhancing products and services. This knowledge is mostly informal and unstructured, consisting of individual posts and discussions, ideas, comments and other interactions. Thus, it is difficult to codify and share, as it requires individual interaction to transfer. It is however equally important as knowledge for PSS engineering.

4. Open Issues and Gaps

The design of PSS has to focus on the identification and interpretation of interactions between products and services to fully reflect stakeholder requirements [28]. Design decisions are not technology driven nor manufacturing related, but the customer problem is in focus. In this context, user centred design has become a driving force [29]. Thus, in the case of PSS, innovation relies on sharing knowledge between partners from different domains, maintain a common understanding of the design concept derived from customer needs and re-use experiences from other PSS projects [8]. The usage of "downstream" knowledge from later phases of the life cycle and the inclusion of the customer into the design process is important as well [30].

While in a conventional static OEM-supplier relationship contractual obligations set by the leading company define what and how knowledge is shared, such a model is not feasible for the dynamic collaboration required for PSS. Besides the missing lead-time required setting up such an arrangement, there might simply not be a partner powerful enough to impose its standards. With respect to the ability to merge explicit knowledge from different domains, ontologies are capable in terms of multi-domain knowledge (e.g. Web Ontology Language – OWL [31]). Tacit knowledge, in the form of personal opinions and sentiments regarding PSS, poses extra challenges for the design and implementation of knowledge sharing. The informal nature of the relevant data and the inherent lack of formalization creates additional issues [32].

The aspect of sharing explicit, formalized knowledge during PSS design is well covered with concrete approaches and frameworks in literature. Nemoto et al. describe a framework to manage PSS design knowledge represented by five elements (core product, need, function, entity and actor) [7]. Zhu et al. and Zhang et al. formalize knowledge from previous PSS cases in a physical and a service model [10,11]. Baxter et al. define a KM framework for PSS design process knowledge, manufacturing knowledge, service design and service operations knowledge [4].

Concerning tacit or unstructured knowledge, some approaches can be found in literature, but mainly on a conceptual basis. Bertoni emphasizes the importance of "bottom-up" knowledge sharing in PSS design and suggests Web 2.0 tools such as blogs, wikis or social networks to capture tacit and unstructured knowledge and tap into the "wisdom of crowds" [13]. This idea is extended by Larsson et al. into the concept of "Engineering 2.0", applying easy to use technologies for knowledge sharing [9], while Chirumalla explores the use of Web 2.0 tools for knowledge sharing in a PSS case study [8].

Based on this analysis, it can be stated that knowledge sharing during PSS design is torn between the necessary formalization of explicit engineering knowledge and the flexible exchange of unstructured and tacit knowledge between the stakeholders involved. A balance has to be found that supports a "bottom-up" knowledge sharing without sacrificing an efficient way to search and identify relevant knowledge. Bertoni and Larsson have identified seven barriers for knowledge sharing in PSS design, which have to be overcome [32]:

- Acceptability and self-censorship
- Commitment and reward
- Resignation
- Time loss
- Awareness
- Language and models
- Trust

In addition to the identified issues, established standards in research and industry should be observed. In this way, the usability is increased and the approach requires a lower effort to be implemented.

5. Requirements for Knowledge Sharing in PSS Design

According to the current research on knowledge sharing in PSS design, some overarching requirements can be derived for knowledge sharing in PSS design.

- **The capability to represent PSS related elements along the life cycle and enabling their re-use:** In order to avoid time loss or even resignation, the approach should provide capabilities to represent the design knowledge required by the stakeholders at each step of the design process.
- **Support collaboration among different domains and map informal content to PSS terminology:** In order

to support the integration of product and service elements, an easy incorporation of knowledge from different domains should be supported, e.g. by model transformation for explicit knowledge and social platforms for tacit knowledge, which can be processed, cleaned and filtered.

- **Map information to specific PSS features and design process:** In order to extract meaningful knowledge, the approach should not only capture information but to tie it to specific PSS context.
- **Support visualization of knowledge to combine and evaluate different sources:** Visualization support can be one key advantage to overcome communication barriers between different domains. Furthermore, mechanisms to evaluate and combine knowledge are required

5.1. Knowledge Sources and Targets

In order to raise awareness, i.e. where relevant design knowledge can be found ("knowing who knows") and who might be interested in a specific knowledge asset ("knowing who should know"), it is required to define distinctive roles for a PSS design project. Such roles can be derived from the PSS lifecycle (see section 3.2), as well as the requirements of the industrial use cases. Possible roles are illustrated in Fig. 2 below:

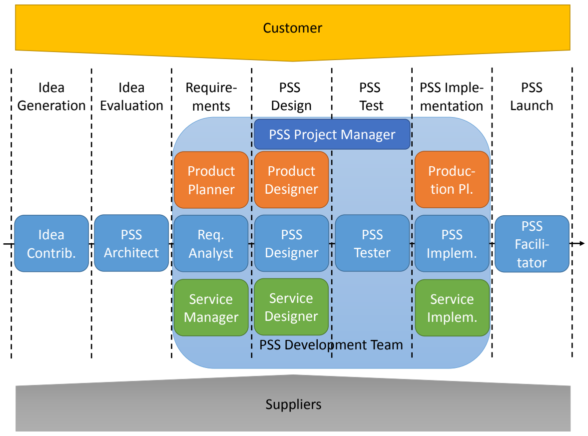

Fig. 2. Outline of Roles in PSS Life-Cycle.

The roles of the PSS Provider (in blue) act as coordinators and are responsible for the execution of design, development and realisation of the PSS. The **PSS Architect** generates documents and manages PSS concepts. The **PSS Project Manager** coordinates the development team and their communication over the phases along the development process. The **PSS Development Team** is comprised of representatives from the different domains and deals with the coordination of the product and service development process.

The roles of the Production Network (in orange) are responsible for provision of materials, parts and components or system modules to the PSS Provider. The **Product Planner** defines the tangible portfolio for the PSS according to the information from PSS Architect. The **Product Designer** is responsible to specify the product components according to the PSS requirements. The **Production Planner** plans the production and manufacturing processes for the products.

The roles of the Service Network (in green) include the market-specific adaptation of the integrated service shares and the handling of client orders including the individual PSS configuration. The **Service Manager** conducts comprehensive and frequent communication with customers and the PSS Provider about Service Engineering results; monitoring of the project's economy regarding development efforts and benefit for customer / revenues. The **Service Designer** reacts flexibly to short-term changes of customer and PSS Provider demands, even in late development phases. The **Service Implementer** plans the implementation of the services.

The **Customer** plays another key role because demands towards the PSS will be drawn up and implemented based on the determined customer needs. Furthermore, he/she is the user of the PSS and gives feedback about quality.

The **Suppliers** deliver the necessary materials, components and missing competencies to realize the product and service portfolio together with the PSS Provider.

5.2. Knowledge to be shared

As knowledge is context specific, the roles have to share a common vision of the intended result of the design process. A possible instrument introduced by Mouritsen and Larsen (2005) is the "intellectual capital statement". Although intended to describe the knowledge resource inside an organisation, it can be adapted to create a common vision for a PSS development team. It provides a knowledge narrative that can be used to describe the intended PSS, its value for the user and the required knowledge resources and their constellation. Management challenges are described by the use of the knowledge resources and their relation. Efforts are defined by initiatives to compose, develop and procure knowledge resources and indicators are defined to monitor them. [24]

According to the analysis of knowledge exchanged during PSS design and the situation at the industrial use cases, it can be summarized, that a certain set of content formats and standards has to be supported to share explicit knowledge during PSS Design. **Text** will mainly be used in the early stages of the development process, and in communication with non-technical stakeholders such as the customer of the PSS. In order to enrich the textual information with a meaning, templates for requirements questionnaires, idea collection or PSS description could be provided. **Office files** (word processing, spreadsheets, presentations, multimedia etc.) are used mainly for communication with the customer and between PSS stakeholders to visualize the intended PSS solution and present it to non-technical users in a comprehensible way. It has to be ensured that compatible file formats are used for all involved stakeholders and that pre-defined layouts can be followed. **Models** (CAD, UML, SysML etc.) can be used for knowledge exchange between the technical or expert domains. On the one hand, standard formats for each domain have to be selected, while on the other hand knowledge has to be exchanged between domains with a common standard.

Based on the sources of tacit knowledge and the identified needs of the industrial use cases, initially retrieved information is mostly textual, e.g. social media content in the form of JSON files retrieved from web services. The use cases validated the need for leveraging of **discussions and exchanged ideas** both internally by employees (e.g. through Yammer) and in a broader crowd-oriented scope (using a custom ideation-platform). Usage of informal **feedback from sales** people in the form of comments or reports is required as well. Finally, monitoring of **social media** (e.g. Twitter and Instagram) and selected blogs is targeted. No generic templates can be claimed to exist, since each social network has a different document format, intranets and ideation platforms also model and store discussions differently etc. However, social networks and platforms are required to offer detailed documentation of their services / APIs and expected outputs in order to be widely used adopted. At the same time, NoSQL databases facilitate storage and usage of documents that conform to different formats, allowing to adopt a more flexible strategy regarding the data types to be included.

This flexibility in the supported tacit knowledge and sentiment initial data formats is challenging and demanding in later stages. It is crucial to select the proper structures to which to transform the initial data and represent the extracted knowledge, since all the unstructured information needs to be processed and structured in semantically-aware models (e.g. RDF), capable of representing the data richness and allowing linking with other sources and reasoning on them.

5.3. Knowledge Exchange Mechanisms

To foster knowledge sharing during the design phase, it is important to create cross-functional teams coming from the different functions, domains and organisations involved. Leadership of the teams can be rotating, according to the current issues and problems of the project. This means that e.g. stakeholders from product, service, or system integration can lead the team at specific points of time. It is important that all members of the development team have access to the same knowledge in the right form. [1]

For explicit knowledge sharing, SysML seems to be appropriate to be extended for the purpose of modelling and exchanging PSS design knowledge, as it is an established standard for systems engineering. A key advantage lies in its extendibility. The needed meta-model layer is provided by default in the specification of UML itself. Hence, an adaption to domain specific needs can be performed.

As it is not feasible for all stakeholders to use a common standard for knowledge representation or work with models from other domains, ontologies can be used to share knowledge across domains. However, to model an ontology can become very complex, in particular if a generic ontological representation of a PSS is envisaged. The ontology needs to be filled with product and service related knowledge from different domains. To define service features and software elements demands for specific expertise not only from the field of product design but informatics, service etc. The interface to the knowledge base has to become user-friendly to ensure an acceptance by the end-user.

Tacit knowledge sharing can be supported using Web 2.0 tools for the PSS stakeholders on a dedicated social platform. Additional knowledge can be extracted from sentiments only after NLP techniques and machine-learning algorithms have been applied to extract insights and dependency patterns. Reasoning and exchange is thus performed on the extracted semi-structured knowledge. Therefore semantically aware data representations are appropriate for managing tacit knowledge and sentiment insights in a way that is both efficient and consistent for PSS design. Linking the extracted information to existing domain-dependent ontologies that allow connection to explicit knowledge is to be assessed as an approach appropriate for affective knowledge sharing. Where such strict formality cannot be achieved, less strict representations like taxonomies will be employed to provide the necessary background information required for tacit knowledge.

6. Summary and Conclusions

According to the findings, it can be stated that the development of PSS can directly benefit from the implementation of a knowledge sharing approach that balances the exchange of explicit, formalized knowledge, as well as tacit knowledge and sentiment. However, contemporary solutions often encapsulate engineering knowledge in proprietary domain formats and rarely involve tacit knowledge or sentiment.

For a solution, requirements are identified that try to integrate sharing of explicit as well as tacit knowledge and sentiment. Ontologies are proposed to provide the required flexibility to represent explicit product engineering knowledge and at the same time the service domain. Using existing (fully elaborated) ontologies as an integral part is possible. Consequently, there is no need to reinvent domain specific knowledge. However the effort and skills, which are needed to model PSS related knowledge as an ontology, are to some extend challenging for developers. His/her competencies relates to the design and development and not on formalization of knowledge. Thus, sharing of tacit knowledge has to be supported as well. Approaches from Web 2.0 look promising to enable easy to use tools to share tacit knowledge and sentiments. These assets can be subject to a sentiment analysis, which is able to extract additional knowledge assets.

In the course of research, the knowledge sharing requirements will be further detailed and used for designing appropriate solutions at the industrial use cases. In addition, the requirements for information security and trust, e.g. filtering mechanisms and access rights, will be included. This enables the development of a suitable knowledge sharing approach. Sensitive strategic product and service design knowledge will be protected by adapting role models and access rights. The final aim of the work based on these results is an integrated approach for capturing, managing and sharing explicit and tacit knowledge, as well as sentiment in PSS design.

Acknowledgements

This work has been funded by the European Commission through the FoF-RIA Project PSYMBIOSYS: Product-Service sYMBIOtic SYStems (No. 636804). The authors wish to acknowledge the Commission and all the PSYMBIOSYS project partners for their contribution.

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