CIRP Journal of Manufacturing Science and Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Engineering models to support product–service system integrated design

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Product–service system
Integrated design
Engineering models

ABSTRACT

Product- and service-design methods traditionally focus on different aspects and use specific models which are difficult to integrate. This paper proposes a PSS "multi-views" modelling framework for supporting integrated PSS design. By coupling models currently used by product and service engineers, the proposed framework should provide a communication support for these actors during PSS design. The "multi-views" perspective should allow them to detail the design of the PSS components until the most technical phases while it also should ensure integration of these components through a shared perspective on the system modelling.

Introduction: PSS integrated design challenges

Products and services have different natures and properties that raise several issues when attempting to integrate these objects for PSS design. The necessity to support integration of multiple actors' knowledge for innovative design has been emphasized in the engineering design literature [1]. Communication interfaces between product and service engineers should be created since the lack of systematic methods supporting design and development of product–service systems (PSS) is acknowledged [2,3].

Many contributions for defining an integrated PSS design and development process coupling product and service engineering generic steps have been proposed [4–6] that all converge towards the following phases:

- A "strategic phase" that encompasses: needs identification, requirements definition, strategic positioning coupled with the PSS conceptual design phase (ending by the selection of a PSS concept);
- A "product/service design phase" that can be seen as a PSS detailed design phase: concept development, embodiment design and detailed design or sub-systems identification and integration; testing;
- And an "implementation phase".

If these proposals allow framing the PSS development into sequences, the intricate steps within each stage are not well clarified [3,7]. Moreover, if several pragmatic supports have been provided for the "strategic phase", i.e. the most conceptual levels of design (e.g. [8–10]), there are only few tools for guiding the PSS design from the concept selection to the most detailed levels of the solution definition. This lack of support for the "product/service design phase" reveals that the challenge of product–service integration within the PSS design process has still not been solved. This paper emphasizes this phase that can be considered as a "detailed" one within the PSS design process and focuses on the models that could support it.

Engineers need PSS modelling supports during design particularly regarding the product–service integration step. Indeed, most of the PSS authors propose using models that adopt either a product (or system) engineering or a service approach while the other perspective is not well managed.

From a product (or system) engineering viewpoint, some proposals deal with the PSS integration issue [4,11]. They support the idea that product and service integration could be dealt through a coupling of models by using a common modelling language like Object-Oriented Modelling. However, several works dealing with the modelling issues of highly complex systems and PSS state that the main difficulty of the integration challenge actually resides in the social practices of modellers and designers [12,13].

Other models are more oriented towards the service aspects like in Service Engineering (SE) frameworks (e.g. [14]). SE has developed service concepts and supportive methods for efficiently reusing the existing engineering know-how in the area of traditional product development [15] and for systematizing the design and development of services [16]. Several SE frameworks have been developed [15–17] and generally propose using tools

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http://dx.doi.org/10.1016/j.cirpj.2016.02.004
1755-5817/

like process models, QFD, FMEA, and blueprint (or assimilated) techniques (initiated by Shostack [18]). However, these proposals for supporting service design do not integrate the product perspective.

In few works mostly dealing with computer-based support of service design, product aspects are integrated [19–21]. But if these proposals allow representing the product behaviour concurrently with service activities, they still use the blueprinting technique (and BPMN as a modelling language for Hara et al.) that seems hardly fit with the current practices of a product engineer. Morelli [22,23] proposes a hybrid approach by using a set of product- and service-oriented models (use cases, scenarios, IDEF0 and blueprint) but the coupling of these tools for integrated PSS design is not deeply detailed.

As underlined by some authors, the issue of integration in PSS design should probably be seen as resulting more from a divergence between the (design) actors' viewpoints and practices than from the different natures of the design objects [13,24]. Models from product engineering and service design are fundamentally different because their respective designers adopt different viewpoints on the object under study, i.e. the PSS. For such a reason, their coupling within an integrated framework is challenging.

This paper aims at providing a modelling support for PSS integrated design. In the proposed approach, an integrated model of PSS supports the integration of the designers' practices through a "multi-views" representation of the system. The model represents a PSS from the both viewpoints of "product engineering" and "service design" but still as a single system. The modelling framework proposed integrates product and service "views" expressing the specificities of each view within the professional models and tools used so far by each designer.

This paper is then organized as follows. The next section proposes a PSS modelling framework. It introduces the models that have been chosen and how they are coupled within an integrated design framework. The case study of a pneumatic energy delivery PSS is introduced in the following section and some elements of its conceptual design are provided. Then, this paper illustrates the application of the modelling framework on this case to show how it can support its integrated design until the most detailed phases. The way the proposed framework could actually support integrated product-service design is discussed in the related section. A conclusion is finally proposed.

PSS modelling framework

Models used

Three types of modelling support are proposed to support three types of "views" on the system: a product-, a service-, and an integrated-view.

From the so-called "product view", the models used are those proposed by Maussang et al. [25] in a PSS design method supported by product engineering models that have been adapted from the functional analysis standard [26] for integrating some service aspects. It is one of the rare PSS design methods dealing with the "detailed" design phase since it allows refining the PSS architecture until the detailed product specifications at a technical level.

The "service view" adapts several tools from service design and Service Engineering. A process model and a service architecture model are proposed. The blueprinting technique is reused since this is an adapted tool for depicting the service delivery operations at a detailed design level. Adaptations are proposed to better integrate the product and service aspects and the characteristics of their interactions in the model.

The integrated view is used for tracing the problem decomposition made by designers. It uses an IDEF0/SADT model since this model is used in product-, service- and PSS-design [23,25,27,28]. Adaptations of IDEF0 are proposed to a better compliance with the product/service integration issues.

PSS design framework

In this paper, a PSS is defined as a set of components and their 'structural organization'. The components (or sub-systems) can be either physical products or 'service units'. A physical product is a tangible object and a service unit is an organizational entity that can be considered as a 'department' within a company. Service units can be composed of products and of teams or sub-units and the related personnel. The 'structural organization' of the system corresponds to the entire organization of the sub-systems' interactions that achieve the defined design goals. The overall PSS modelling framework proposed aims at organizing and integrating the discipline-oriented models within a co-evolutionary framework: "problem" and "solution" design spaces co-evolve. The organization of the models in the framework is schematically represented in Fig. 1.

The two design spaces for problem and solution co-evolution are supported by modelling tools: the problem space is supported by a "result" model representing the expected system (inter)-actions, and the solution space is supported by a "structure" model representing the structural system hierarchy. These two models contain decomposition links: the result initially defines the external system (inter)actions that are decomposed into internal ones; while the structure initially depicts the system in its wider system and is decomposed into sub-systems. The structure model then expresses the organization of the system boundaries that allow decomposing it into hierarchical levels. The result model allows expressing the expected (inter)actions that provide value for the beneficiary. Links named "design relations" must allow affecting the identified system structure to the expected result at each level of decomposition. Structural organization models are intermediary description that link the result to the structure models and that can be refined during the decomposition. They represent the sub-systems' interactions and then they are the basis for designers' negotiations about the fit of structure with expected results.

The framework provides a set of tools for integrated PSS design. Each space of the design framework is supported by modelling tools from both product and service engineering. The two "views" are coupled together in these co-evolutionary spaces, since product engineers and service designers differently apprehend the problem-solving process. Indeed, contrarily to the "black box" models adopted in product engineering for separating problem expression from solution formulation, service design mainly adopts activity-based models that concurrently display expected actions and actors involved in [24]. The structural organization models support negotiations between these spaces. An integrated model is proposed in the result domain that allows tracing the problem decomposition and then the design requirements at different levels of detail during design.

The proposed modelling framework for PSS design should be supportive for both product and service designers and the integration of their design tasks. Indeed, it uses current models of each view while representing the all system. The framework utility for supporting the actors' communication and product-service integration during design is shown and discussed in the two next sections that detail how it can be used for designing a pneumatic energy delivery PSS.

Introduction to the case study and conceptual design elements

This section introduces the PSS case for pneumatic energy delivery. The industrial case is explained and details about its

Please cite this article in press as: Trevisan, L., Brissaud, D., Engineering models to support product–service system integrated design. CIRP Journal of Manufacturing Science and Technology (2016), http://dx.doi.org/10.1016/j.cirpj.2016.02.004