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A method to design integrated product-service systems based on the extended functional analysis approach

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ABSTRACT

Over the recent years, the growing research interest in Product-Service Systems (PSS) design and development methods has generated a large background of theoretical knowledge, conceptual methods and application case studies. After analysing the research gaps emerging for these advances, this paper propose a new integrated PSS design method, which intends to associate to 3 key contributions: an increased degree of integration among all components of the method; a higher applicability in industrial companies; specific added-value in balancing economic models of the stakeholders of the PSS delivery network. The proposition is based on extending the Functional Analysis (FA) approach (NF X 50-100), which is commonly used in product engineering, in order to cover the requirements for PSS design and development. The paper intends to provide a conceptual justification, then an industrial verification, of the pertinence and applicability of the method proposed. The industrial experimentation is developed on an industrial PSS case study dealing with the design of an industrial cleaning solution.

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Introduction

Designing Product-Service-System (PSS) offers that maximize the value for stakeholders is a crucial task to support the transformation of traditional manufacturing companies into integrated product-service providers. The successful PSS design relies on the integration of several dimensions such as product design, identification of service opportunities throughout the PSS life cycle and configuration of the PSS value network. To achieve these objectives, the notion of 'service design' must be incorporated into traditional approaches for product design [1], in order to create new offers which provide customers with the desired benefits via tailored PSS [2]. Despite the strong increase of research interests on these topics in recent years, the scientific advances concerning PSS design processes, methods and operational tools still lack of maturity to support an effective and large application within the industry [3]. Several issues may hinder these scientific contributions. But the research reported in this paper mainly puts forth the following key challenges: an integration challenge to cover within a unique method all the design phases required but also to address consistently the key dimensions of product, service

and organization design; then an applicability challenge, due to the fact that existing PSS design methods are short of operational solutions to ensure an easy implementation within the industrial context.

Following up with the above challenges, the research presented hereafter aims at outlining the main characteristics of a new PSS design method. As justified later in the paper, the proposition is based on the extension of the Functional Analysis (FA) approach (NF X 50-100), which is commonly used in product design, in order to make it consistent and fully applicable for PSS design. The review of PSS design techniques presented in Section "Advances in PSS design techniques" first analyses the positioning of various research trends in the domain, then identifies further research gaps via a qualitative comparison of a set of recent advances: the integration and applicability challenges are questioned. In Section "Conceptualization of a PSS design method based on the extended functional analysis approach", the conceptual formulation of the method proposed is presented, resulting from the integration of an existing PSS design framework within the Functional Analysis (FA) approach layout. The toolset associated with the method is explained. A case study dealing with an integrated solution for industrial cleaning is presented in the Section "Case study and detailed description" to provide a first verification of the method, emphasizing how it can concretely address the integration and applicability challenges underlined. The paper ends with a discussion on the strengths and the limits of

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the proposition regarding the initial challenges, which opens perspectives concerning standardization and practicality for all size of industries. Conclusion and perspectives for the future work will then be drawn.

Advances in PSS design techniques

Overview of current PSS design methods

Due to the high complexity underlying the shift from product to PSS design, PSS development requires innovative modelling and decision-making support in terms of design tools, techniques and methods (Cavaliere and Pezzota, [19]). The state-of-the art reveals numerous tools and methods developed to support this complex design process. Their common objective consists in designing an integrated solution embedding both material and immaterial components so as to deliver value in use to the customer. There is however discernible trends differentiating these approaches in terms of scopes and central elements used to enhance the PSS design process.

Firstly, there are numerous design methods which bring out the importance of the specification of the PSS physical system in order to design a product incorporating the PSS requirements: services activities, customer value . . . PSS development is based on the use of product design tools and attributes (e.g. life cycle thinking, modular design . . .). Typical examples of this research orientation are provided by Alonso-Rasgado et al. [5], Aurich et al. [6], Maussang et al. [7], Sundin et al. [8], and Kim et al. [9]. This first trend actually gathers the older approaches developed in the field of PSS design, initially coming from experts in product design. Alonso-Rasgado et al. [5] have developed the concept of 'total care products' consisting of architecture (physical product and service support system) and business (market attributes). The authors proposed the 'Fast-track design process' which breaks down the iterative process between the customer and supplier into distinct stages necessary for the integrated creation of the 'total care product'. A second important example in this first trend of approaches is provided by Maussang et al. [7]. Their work aims at providing engineering designers with technical product specifications linked with the whole system requirements, as precisely as possible, both for the development of the 'physical object' and the related 'service units'. They have exploited the Functional Analysis approach (FA), where the graph of interactions (APTE[®]) and the functional blocks are the elements used to bridge the gap between the physical product and the overall system.

Besides, many PSS design methods put forward the essence of service design in maximizing the customers' value generated by a PSS offer. Services engineering tools are used and often tailored in order to design services activities within the context of Product-Service-Systems. This offers a unified representation of human and physical processes to take in charge the services activities within the PSS offer. This orientation refers for instance to Refs. [10–15]. Shimomura et al. [10] have proposed a rather complete approach typical from this second trend. The method aims at maximizing the service value for customers by extending the blueprint of a service offering, in order to include information concerning the product and its service behavior. In terms of technique, a unified representation scheme of 'human process' and 'physical process' in the service activity modelling is used. Service designers can model service activities while taking into consideration the 'customer value', 'human process' (service function by human resource) and 'physical process' (service function by physical product).

Third, some methods highlight specific contributions in designing the PSS organization and its value chain during the whole design process, starting in early design stages. The PSS design process focuses on 'systemic aspects' and is based on the

assumption that its final result is co-produced by a value network of social actors [16]. These advances consist in: defining the stakeholders' value expectations and requirements for the PSS development, identifying the actors of the network, potential organizational scenarios and associated actors' interrelationships, by the use of various multi-actor modelling or mapping tools. Researches by Morelli [16], Lindahl et al. [17] and Medini and Boucher, [24] can reflect this orientation. To illustrate this statement, referring to several industrial collaborations, Medini and Boucher, [24] have developed a usage-based PSS design approach for industrial PSS projects. The approach starts with the identification and analysis of the 'usage' expectations for a PSS solution, in order to characterize the value creation potential for the customer and various stakeholders, considering – when necessary – various categories of customers. The PSS potential solutions considered along the design process are formalized throughout a progressive transformation of value expectations into product and service creative ideas, then well-defined organizational delivery scenarios which can be assessed via a simulation-based evaluation platform.

This first overview shows an active scientific production. However, it emphasizes also that PSS design approaches tend to focus on specific trends and added-value focuses. Each methodology puts forth a pre-eminent point of view on design, which structures and may limit the design models and methods proposed. There is a need to address a full integration among these perspectives, reviewed in next section.

Requirements for further integration of PSS design approaches

The hot spot of the discussion about integrated PSS design starts with the degree of perception of both notions of 'services' and 'integrated product-service systems'. Based on an intensive literature review, Vasantha et al. [4] have shown that there are multiple interpretations of the concept of 'service' and, thus, different themes emerge from the understanding of the PSS development mechanism. For instance, the authors highlighted the logics of (i) development of innovative business models, (ii) integration of products and services into a unique offer, or (iii) incorporation of services to increase the value realization of products. The outcomes of their analyses led to six dimensions required to develop effective PSS, respectively: context specification, positioning and importance of stakeholders, design stages, development cycle (generation and evaluation processes), life cycle consideration and representation rigor. However these six dimensions are not integrated in all the PSS design methods currently under development. On the contrary, some major limitations for integration remain in question:

(1) In 2006, Morelli pointed out that PSS design methodologies should embed the requirements for the PSS and its organizational structure, the identification of involved actors, the possible scenarios of PSS use cases and the sequences of actors' roles, as well as the representation of the PSS in all of its components [16]. If most of the methods have proved clear advances on integrating product and service design processes, the full integration of organizational design aspects remains questionable [18].

(2) Later, Cavaliere and Pezzotta [19] underlined the necessity to cover the whole Product-Service-System lifecycle when, at the same period, Ref. [4] emphasized poor specification of the detailed intricate steps occurring within each process stage. Such advances on deep integration have to be reviewed in the recent literature.

(3) Further, Tran and Park [20] underlined the necessity to further develop generic PSS design methodologies, addressing all types of PSS (product, usage or result-oriented PSS) and which should contain detailed design stages for providing operational guidelines to the PSS designers depending on the type of PSS considered.

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