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Product-Service Systems across Life Cycle

A Framework to Design Integrated Product-Service Systems based on the Extended Functional Analysis Approach

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Abstract

Despite the growing research interest in PSS design and development methods in recent years, there is still no fully stabilized and shared understanding of the PSS design process. This can be partly explained by two main gaps: the decoupled design of product and services and the lack of operational solutions. This research aims at outlining the main characteristics of a proposal for a new PSS design framework, expected to contribute answering these 2 gaps. The proposition is based jointly on a recently created PSS design methodology and an extension of the functional analysis (FA) approach (NF X 50-100), which is commonly used in product design. The proposed framework intends to smoothly integrate the whole PSS design process, including product-service design and the network configuration.

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Keywords: Product-service system (PSS); design method; functional analysis (FA) approach, PSS global offer, PSS value network

1. Introduction

The design of a PSS offer which maximizes the value for various stakeholders is a crucial stage to support the transformation of traditional manufacturing companies into integrated product-service providers. A 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 'services 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 products and services [2]. Although the quick increase of research interests in PSS design and development methods in recent years, it has been identified that the scientific understanding of the PSS design process both in the design community and in industries is still not fully mature. Several issues may hinder this scientific understanding, but this paper mainly puts forth the following ones. Firstly, an integrated design of product-service systems is not completely performed as services are mostly considered as add-ons to the product design. Secondly, existing PSS design methods are short of operational solutions to ensure their easy implementation in industrial context.

This research is motivated by the two above mentioned gaps and aims at outlining the main characteristics of a proposal for new PSS design method. 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 applicable to PSS design due to its potential to support this specific design context. First, a literature review of existing methods dedicated to PSS design is presented in section 2 in order to clarify the gaps mentioned above. Moreover, the potentials of the traditional FA approach regarding the design of an integrated product-service system are identified. In section 3, the conceptual formulation of the new framework is presented by highlighting the interdependent activities necessary to deliver the PSS global offer requirements specifications. The paper ends with a discussion on the strengths and limits of the proposition regarding services ideas generation and value network configurations, during the early PSS design phases. Perspectives for the future work will be then drawn.

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2. Research background

For helping manufacturing industries in their progressive mutation towards PSS offerings, any PSS project development team requires support in terms of design tools, techniques and methods [3]. The state-of-the art reveals that there are numerous methodologies developed to support the PSS design activities. Although their common intention to design integrated product and service systems which delivers value in use to the customer, it has been perceived that their visions were scattered in terms of scope and elements used to enhance the PSS design process. To illustrate this statement, some well-defined methods from the literature are described in the followings.

Alonso-Rasgado et al. [4] have developed the concept of 'total care products' consisting of architecture and business. Architecture refers to the physical product and the service support system (hardware) and the business refers to the market attributes. They proposed a fast-track design process, which breaks down the iterative process between the customer and supplier into distinct stages necessary for the creation of the 'total care product'. In that way, the product functional specifications integrate the customer's needs and they are simultaneously defined. Maussang et al. [5] targeted to provide engineering designers with technical product specifications linked with the whole system requirements as precisely as possible for the development of the physical object (O.P) and the related services units (U.S). They have exploited the functional analysis approach (NF X 50 100), where the graph of interactions (APTE ©) and the functional blocks are the elements used to bridge the gap between the system and the physical product. Shimomura et al. [6] have proposed an approach which 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/blueprint modelling is used. As a consequence, it is possible for service designers to model service activity while taking into consideration the customer value, the 'human process' (service function by human resource) and 'physical process' (service function by physical product). Based on industrial PSS projects, Medini and Boucher [7] have identified and analyze the 'usage' forms of each PSS offer in order to identify the value creation potential for the customer and stakeholders. They have characterized the customer's categories, their needs, in terms of goods and services. Then, they cross these usages with the service opportunities for a PSS offer. Afterwards, the under designed PSS are formalized by a mean of progressive transformation of creative PSS ideas into well-defined scenarios for its delivery.

Regarding research contributions for PSS design, various design methods focus on designing the PSS network, for instance [7], [8], [9], [10], [11], [12], [13]. Other relevant design methods are based on the specification of product criteria to perform the PSS design, for instance [4], [5], [14]. Additionally, researchers such as Shimomura et al. [6], Sakao and Shimomura [15], Komoto and Tomiyama [16] and Hara et al. [17] have proposed PSS design methodologies focused on services engineering. This underlines a large number of separate advances in this field. However, despite the spread of the PSS paradigm among academic and practitioners' communities, several issues still hinder a common understanding of the PSS design process. As underlined by this small classification, PSS design approaches remains focusing on specific targets with a lack of real integration among these distinct objectives and advances. Each methodology puts forth a pre-eminent focus and point of view on design, and the models and design methods proposed are induced by this point of view.

To tackle this integration issue, Cavalieri and Pezzotta [18] have suggested a generic design process for PSS. However this is a state of the art, with a restrained objective to underline the main PSS design phases and to present perspectives of research, more than potential solutions. Besides, Kim et al [19] have studied the usability of various design support tools for PSS for each stage of the PSS design process. McAloone et al. [20] have also tried to promote integrated product/service thinking across organizational boundaries through a systematic approach for user-oriented product and service development. Although integrating products and services is discussed as a target in PSS design, there is a lack of clear formulation for each detailed step involved in this integration process. Thus, the question still arises about the real and timely consideration of both the product and the services specifications during the earlier stage of the PSS design. Lastly, there is a weak diffusion of such academic tools and methods at the level of industrial practitioners. Many PSS design methods are little oriented on operational solution and thus very little adopted in industrial context. Consequently, there is a need to clarify what form of approach can support an integrated design of a PSS global offer, while ensuring its real applicability in industrial context.

3. Proposition

3.1. Overview

For the proposition, it was decided not starting from scratch. Specifically, this research consists in transforming an existing methodology (Figure 1) dedicated to industrial PSS scenarios identification, modelling and evaluation [7], [21] into a complete PSS design framework. The whole will be structured within the functional analysis approach layout. To reach this objective, there is a need to integrate a specific design step named "design the PSS global offer" within this initial methodology in order to obtain a framework covering the full PSS design process. In this section, the initial framework dedicated to the design of PSS scenarios is first described, followed by an overview of the proposition. Then, the precise interrelations between the functional approach used in product engineering design and the PSS engineering design are studied, in order to demonstrate the potential extension of the functional analysis approach to support the full PSS design process. Moreover, it we highlight how to integrate the step "design the PSS global offer" within this initial framework in order to perform simultaneously the

specifications of the technical system and the services opportunities, so as designing efficiently the PSS value network. Finally, the methodological contributions of the extended functional analysis approach in performing the step "PSS global offer design" are summarized. Brief insights for further steps of implementation within the whole framework are also described.

The initial framework (Figure 1) is composed of four steps: context analysis, usage analysis and scenarios prioritization, scenarios modelling, scenarios performance evaluation. The context analysis consists on understanding stakeholders' industrial context and competition factors. Strategic analyses such as SWOT or PESTEL are then suitable at this stage to identify the PSS opportunities and strategical issues for the stakeholders. Next, the usage analysis and scenarios refinement consist in analyzing different usages of the PSS offer in order to identify the value creation potential for both the customers and stakeholders. To do so, it is necessary to characterize customer's categories, their usages and needs in terms of product and services and cross these usages with PSS opportunities. Afterwards, the PSS needs to be formalized by a progressive transformation of creative ideas into well-defined scenarios. These latter provide good insights about PSS value chain. Scenarios prioritization is based on the experience of involved actors and consideration of external factors such as regulations and customer culture. The main challenge lies in identifying activities required to deliver the PSS and assigning organizational actors to them. The two last steps consist in building and implementing an evaluation model to assess the viability of the identified scenarios in terms of economic and operational performances. To do so, key performance indicators required by each of the actors involved in the scenarios are first defined. Then, data related to physical and financial flows needed to model the scenarios are collected before implementing the performance evaluation.

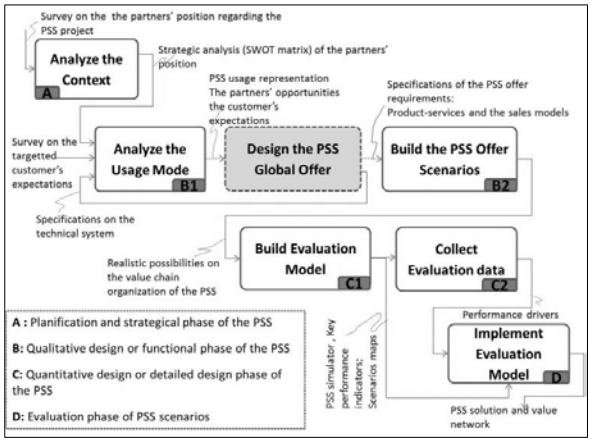

Figure 1. The intended PSS design framework based on the initial framework enriched with the step "design the PSS global offer".

The present research work assumes that if both the specifications of the technical system and the services opportunities are integrated within the initial framework for the PSS organizational scenarios design, a framework enabling the PSS global offer design while guaranteeing an operationalized PSS solution can be obtained. To achieve this objective, the initial framework is transformed as indicated in Figure 1, in order to encompass the design of the PSS global offer while following the philosophy of the engineering design process (A, B, C, D phases).

3.2. Extension of the functional approach to support the PSS global offer qualitative design

The functional analysis (FA) approach (NF X 50-100) which is commonly used in engineering design of products is chosen as a basis of the proposition, due to its consistency with many features of PSS design steps (for instance, expression of requirements, solution thinking, system architecture, etc.) and, additionally, to its strong utilization in industries. A system design approach (Figure 2) starts with an exhaustive formulation of the customer's expressed and implicit needs and constraints. The functional analysis translates this formulation during the 'analysis of requirements' step (external functional analysis) into requirements or functionalities to be fulfilled by the system. Once the analysis of requirements done, the functional specifications of the system are translated into technical solutions where only designers start thinking about solutions.

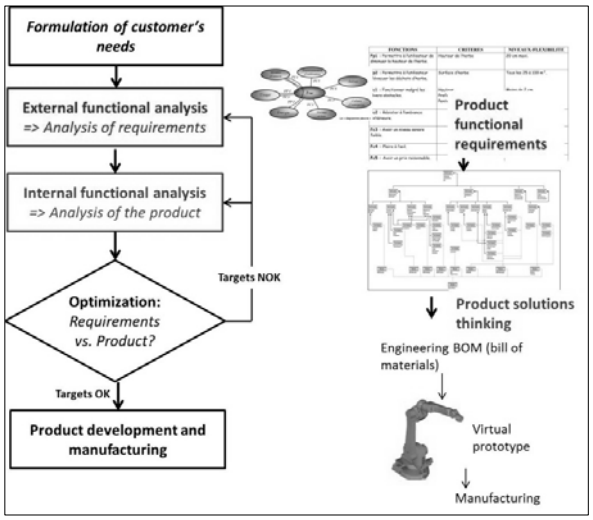

Figure 2. Standard functional analysis approach in the product engineering process

The proposition aims at using this framework for designing a PSS which would fulfill the customer's needs without compromising the opportunities of value creation for the stakeholders. However, until now, the functional analysis approach, in its standard form, covered only the initial design stage of the technical system. The focus was therefore on the system technical functions. Henceforth, regarding the PSS global offer design, there are distinct inseparable items to take into account in the functional specifications of the PSS: (1) the technical system, (2) the services opportunities and (3) the value network. Then, to answer to the requirements of PSS design, the traditional functional analysis approach must be transformed in order to cover larger design objectives than

only the specifications of the technical system. Thus, respective specifications of services opportunities and of the associated value creation network have to be managed by the design process (Figure 3).

Within the extended functional approach, a specific task dealing with the PSS strategical contextualization (context and usage analysis) must be performed (see § 3.1). It obviously linked to the collect and the formulation of the customer's needs in the standard approach. Then, the expression of the PSS functional requirements corresponds by analogy to the external functional analysis step in the standard approach. Particularly, it is important to mention that even if the technical specification of the PSS product must be already done at this stage, it is always considered as a part of the functional requirements of the PSS. The reason is that the technical system design attributes and its life cycle must be defined in order to explore the ideas of new services opportunities. It is particularly inherent to the PSS engineering and consequently requires strong iterative and collaborative tasks between people involved in the PSS design process.

Once the PSS functionalities have been defined, the configuration of alternative PSS economical and organizational scenarios can be performed. This stage corresponds to 'internal functional analysis' in traditional FA and, here, the full PSS solutions should be thought (PSS solution thinking) then designed. The internal functional analysis completes the qualitative design phase of the PSS before shifting to its quantitative or detailed design. The quantitative design phase consists in proceeding to comparative assessment of PSS delivery solutions. In product design, this covers various technical assessments of the product (e.g. virtual prototyping), to take detailed design decisions. Additionally in extended functional analysis, this covers the comparative evaluation of alternative PSS delivery scenarios. Such quantitative analysis should both assess the viability of the identified PSS scenarios in terms of economic, sustainable and operational performances, and provide decision-making support to choose the final delivery scenario to be implemented.

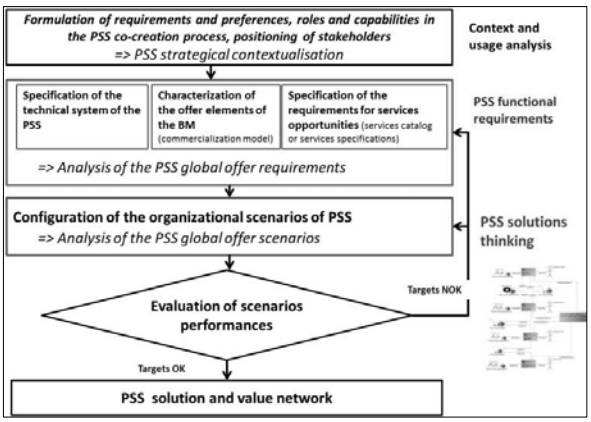

Figure 3. Extended functional analysis approach, supporting the PSS engineering process

In traditional FA, the final stage of design leads to the operational launch of product manufacturing. In the context of PSS design, it covers not only product manufacturing, but also concrete implementation of service delivery solutions and PSS value network integration. The very first step 'PSS strategic contextualization' directly corresponds to the 'context analysis' underlined previously in section 3.1. Thus, we do not come back on this phase and the following section focuses on the implementation elements for the step of 'PSS functional requirements'.

3.3. Implementation for the 'PSS functional requirements'

Within the PSS context, the activities required to design effective PSS start with the strategical context specification before performing the design stage itself. Then, the input of the PSS global offer design is composed of: (Figure 4)

- The customer's expectations and the stakeholders' opportunities, obtained from both the context and the usage analysis ;
- The PSS usage mode, obtained from the usage analysis;
- The functional architecture of the technical system obtained from its specification;
- The knowledge about the PSS whole life cycle stages.
- The strategical analysis of the stakeholders 'position'.

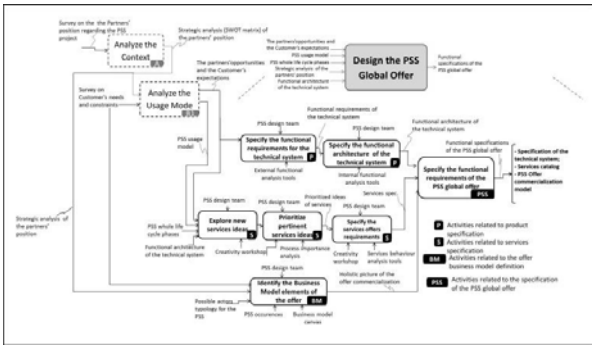

Figure 4. Overview of interdependent activities for specifying the PSS global offer requirements

In this context, there is interdependence between activities required for the technical system design and the services opportunities specification. At this stage, the functional analysis approach must be enriched with tools for supporting service design. Service design encompasses a collaborative task implying all the PSS design team. It goes from the ideation by exploring new services opportunities, through evaluating their organizational impacts (risks anticipation) for each PSS actors, till the specification in a catalog of the services packages offered with the PSS. The outcomes expected at this stage regarding the PSS specifications are composed of:

- The functional architecture of the technical system (for instance, hierarchical functions tree such as FAST, SADT diagram, etc.)
- The services opportunities catalog. The services catalog provides the functional specifications of services opportunities. It is expected to specify the service typology (for instance added services, reconfiguration,

pre-sales, sales and after-sales…), the various service levels considered and importantly the required skills to deliver each of these proposed services.

- A qualitative model of the PSS commercialization, which describes the offer core area regarding the value proposition and the key partners of the business model (BM) elements.

Table 1 below summarizes the expected outcomes and the supports of detailed activities described in figure 4, which are required for specifying the PSS functional requirements. In other words, it underlines how the integration of relevant tools dedicated to product engineering and additional methods developed more specifically for PSS engineering can support the extended functional analysis approach to perform a full PSS qualitative design.

Table 1. Interdependent activities to specify the PSS global offer requirements.

	Activities (figure 4)	Expected outcomes	Possible supports of the activities
Technical system (product)	Specify the functional requirements	Functional specification	Graph of interaction (APTE ©); functions characterization table
	Specify the functional architecture	Technical specification	Functions hierarchical tree (FAST ©), SADT diagram or Functional Blocks diagram
Services Opportunities	Explore new services opportunities	Ideas of services per life cycle stage of the PSS	Creativity tools (e.g. mind maps, post-its…); Functional block diagram enriched with services functions [5]; Functions hierarchical tree enriched with services functions; Extended services blueprint [6];
	Specify services opportunities	Services opportunities catalog	Services functions categorization table; Process importance analysis…
Offer BM	Characterize the BM elements related to the offer	Picture of the PSS offer selling mode	The Business model canvas [22]
PSS	Specify the PSS functional requirements	Functional specifications of the PSS global offer(product-services; offer BM)	PSS Functional specifications document

Coherent and timely specifications of the technical system, the services opportunities and the offer characterization are crucial regarding the PSS value chain determination. These allow having good insights for characterizing the value network. Indeed, when the needs and the skills of each actor are identified and crossed with the service requirements, the range of possible relationships between the actors will be refined, and they will form a value network of stakeholders. In the limits of the current paper, it is not possible to give a full presentation of each of the further steps of 'Extended functional analysis for PSS'. However some brief insights are underlined below. Two major points can be considered for the next step called 'PSS solution thinking'. First, the existing internal functional analysis models and tools for product design remain necessary, but have to be enriched by integrating a service view. Secondly, the method and tools used are required to go beyond product analysis, and analyse the potential configurations of PSS scenarios. Concerning the evaluation step, many very mature evaluation approaches for product assessment and prototyping are available for the material part of the PSS. The issue consists in extending the evaluation to service providing and value creation network delivery, taking into account the various performance points of view of the stakeholders. Our research work leads to propose 2 sub-steps: a step of configuration of the evaluation system (compliant to the evaluation specificities of each PSS), then a final step of comparative analysis of the alternative PSS scenarios, using simulation approach to answer multi-actor performance analysis needs [7]. The final design step should lead to the concrete implementation. As a complement to product industrialization, for the PSS dimension, interoperability risks among the various activities contributing to PSS delivery should be anticipated to help the implementation of the value creation network.

4. Discussion

The approach presented in this paper is under construction. The method specification presented in previous sections will be enlarged in coming publications in 2 directions: first, to provide a full specification of whole "Extended functional analysis for PSS design" beyond the first steps described in section to 3.3; second, to apply the method to industrial case studies.

In fact, to carry on the development of the method, a validation protocol appears necessary. We suggest structure it with two complementary objectives:

- A validation task dedicated to a systematic comparative analysis of the last PSS design methods produced by the academic literature. The state of the art presented in section 2 has made possible to position the key orientations and requirements for the method proposed. However, after the upcoming specification of the whole method, a comparative analysis to position (and if necessary integrate) the models and tools for PSS design proposed by a larger panel of contributions would be particularly interesting. To avoid creating redundant methods and tools, the objective of the 'Functional Analysis' framework is to try and integrate the added-value of several contributions.
- A validation task dedicated to the confrontation and assessment of the method on industrial case studies. In that objective, a first industrial consortium has been created, with the French national FUI project CLEAN Robot. The objective of this consortium is to apply the full method of 'Extended functional analysis for PSS' on an active project of design of a Robot dedicated to industrial cleaning functionalities. Beyond the design of the technical device, the design of services along the

whole life cycle together with the organisational design of the whole value chain, are covered by the project partners. This industrial validation should answer additional questions, like: 'is the application of the method adapted to industrial use?'; 'which modelling and decision-aid tools are required to make the application efficient?' etc.

This validation protocol remains to be applied: it should bring interesting additional results for the framework building.

A second discussion would be to reconsider the initial hypothesis: to use the 'Functional Analysis' approach for PSS oriented design. Of course, in such discussion we have to keep in mind a second hypothesis of our work: the objective is to integrate PSS design advances in concrete methods and tools used by industrial engineers. Currently, better than giving a theoretical answer, we have adopted a constructivist position in this research work: we try and answer this question by building, concretely, a technical solution to this problematic issue. The validation protocol mentioned will also make possible to assess correctly the industrial applicability. However, this constructivist answer does not close the door to further discussions: there are also alternative design methods, distinct from functional analysis. So, could a method, built on a different framework, bring more efficient results when concretely deployed in industries? This question remains an open perspective for further work.

5. Conclusion and future work

This paper outlined a complete PSS design framework to support the integrated products and services design in the PSS context. Additionally, the framework considers the requirements of the PSS stakeholders from the very beginning of the design process so as to ensure an efficient design of the PSS network. The large scope of the framework and the integration of product and service design and value network configuration are expected to fill the gaps identified in the paper, such as the scattered visions of most of the PSS design methods and tools, the decoupled product and service design. Furthermore, the framework provides a practical support for the PSS designers through extending a commonly used approach that is the functional analysis, and building on an existing operational and tested method.

The framework needs however to be applied to several case studies in order for it to gain maturity. In addition, it needs to be supported by practical tools for easing its implementation and traceability. Another relevant dimension of the framework can be strengthened further is about the decision making support. This can be improved through integrating different assessment of the design alternatives with regard to predefined criteria (e.g. customer satisfaction, economic output, environmental impact) at different steps.

In this perspective, research objectives include i) the use of the framework in a real PSS design project in the field of industrial cleaning, ii) supporting the framework with proper modelling tools so as to provide designers and decision makers at large, with a visual support during the early design steps, and iii) simulation based tools to support the decision making during the last PSS design steps (e.g. configuration of the PSS scenarios).

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