Moving Integrated Product Development to Service Clouds in the Global Economy
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Functional and Ecosystem Requirements to Design Sustainable Product-Service

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Abstract. Product-Service (P-S) represents an innovative way to create highly sustainable solutions for both large and small enterprises. However, very few works propose structured approaches for P-S ideation and design in manufacturing industry. This paper presents a novel methodology to support ideation and preliminary design of sustainable P-S solutions within industrial chains involving Large Enterprises (LEs) as well as Small and Medium Enterprises (SMEs). It is based on a matrix-based approach and allows defining the P-S functional and ecosystem requirements according to the customer needs and sustainability principles. The research purpose is twofold: to effectively support industrial chains in P-S requirements elicitation, and to verify the benefits of P-S integration from the design stages in developing sustainable solutions. The research study involved an Italian company with its supply chains of SMEs, distributed in Europe, and aims at developing a new P-S idea in the white goods sector by exploiting Information and Communication Technologies (ICT).

Keywords. Design for Sustainability, Service Innovation, Product-Service Systems (PSS), QFD-based method, Requirements Elicitation.

Introduction

Proposing Product-Service (P-S) instead of traditional products represents an emerging trend for manufacturing companies to create new business opportunities and improve sustainability. Indeed, on one hand combining physical product and intangible services allows enhancing the product features, creating an added value by new functionalities, and bringing competitive advantages in a specific target market [1]. On the other hand, P-S moves the business from producing physical products to offering integrated systems of services and products, which are designed to be sustainable thanks to green principles such as dematerialization, better consumption patterns, innovative scenarios of use, more efficient use of resources, and cost savings [2].

However, a manufacturing company usually needs to involve other companies, usually Small and Medium Enterprises (SMEs), with diverse competencies and complementary skills to effectively develop and delivery P-S items as well as its infrastructure. As a result, the Large Enterprise (LE) generally designs the solution and SMEs contribute in its development, delivery and maintenance. In this context, to create a sustainable P-S all the network need to adopt integrated lifecycle approaches; but diversely, sustainable development is usually limited in SMEs due to lack of knowledge, awareness and investments, which are strong barriers for moving towards

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sustainable practices [3,4]. Indeed, SMEs usually lack of infrastructure, proper communication channels, ad-hoc mentorship, and this fact generates additional problems in developing SMEs' economies [5]. Therefore alternatives to support the strategic development of sustainable networks made up of LEs and SMEs are necessary.

In this context, the recent advances in Information and Communications Technologies (ICT) could give also to SMEs the competences required to develop sustainable P-S considering its three principles: environment, economy and social wellbeing [6,7]. Recent studies demonstrated that ICT could validly support sustainable business by the development of smart products, improved stakeholder communication, dematerialization, increased social inclusiveness, and consumer empowerment [8]. However, despite the potential of ICT in developing sustainable P-S, little is known about how such technologies should be integrated into products to create a sustainable P-S and which opportunities can arise [9].

The present paper proposes a methodology to design P-S by supporting manufacturing companies in ideation and requirements elicitation stages [10]. The method is based on Quality Functional Deployment (QFD) technique and starts from the ideation phase correlating customer promises generated by the marketing department with the market needs, and relating P-S functionalities with the ecosystem requirements in order to define a set of functional and ecosystem requirements to be respected by all partners, both LEs and SMEs. Requirements elicitation also takes into account sustainability principles in order to develop sustainable P-S. Finally, an industrial case study is used to describe the method application and to test its validity in practice.

1. Research background

1.1. Product-service and sustainability

Numerous manufacturing enterprises are moving from a product-oriented model to a new service-oriented model by adding service features to traditional products in order to increase the value perceived by the customers [11]. The result is a Product-Service System (PSS) that is composed by physical items, which are usually produced by manufacturing firms, intangible goods and a proper system infrastructure [12]. The introduction of PSS in manufacturing firms can bring to numerous advantages like new business opportunities and new market shares. It has been demonstrated that services can sensibly reduce the impact on sustainability in respect with its three dimensions: environment, economics and social wellbeing [5]. From the economical viewpoint, services can create higher profit margins and contribute to higher productivity by means of reduced investment costs along the lifetime as well as reduced operating costs for the final users [13]; from an ecological viewpoint, product-services can be more efficient thanks to a more conscious product usage, increased resource productivity and a close loop-chain manufacturing [14]; from the social viewpoint, services are able to realize a socially advanced scenario by ensuring knowledge intensive jobs and contributing to a more geographically balanced wellbeing distribution [15].

However the development of PSS forces product-centric firms to innovate their current business model and evolve their own processes [16]. For instance, optimizing the delivery process as well as creating new customer interface and new buyer-seller relationship [17] represents the core of service innovation and is fundamental for service implementation. However, compared to product innovation, there is a limited understanding about service and service innovation so far, especially in manufacturing industry [18]. Let think about sustainability: in industry product sustainability is a well-known practice that can be accomplished by lifecycle design techniques, such as LifeCycle Assessment (LCA) [19], LifeCycle Costing (LCC) [20] and Social LifeCycle Assessment (SLCA) [21]. Some recent studies have applied such techniques for sustainability assessment of PSS like [22], but the definition of the P-S features and design requirements is still unexplored. New methods to investigate the P-S sustainability and to design P-S according to sustainability principles are needed.

1.2. Requirements elicitation for P-S design

To be successful RE needs to start from the analysis of users' requirements: they first have to be captured and then translated into more formal system requirements. However, traditional approaches do not seem to be very suitable to elicit requirements for innovative services and products; they lack in understanding the tacit users' knowledge and formalizing user-centred processes [23]. About the investigation of customer needs to properly define service-based functions, the well-known approaches used for RE in industrial surveys, such as the multi-level analysis or the Design Structure Matrix (DSM), can be used to define the main P-S functions. After that, the Business Use Case (BUC) analysis can provide a more user-centred investigation. Indeed, multi-functional analysis and DSM can provide a simplified scheme and underline the main characteristics to understand and forecast the users' behaviour, while BUC analysis allows defining the business use-case model and the goal-oriented interactions between external actors and the P-S system [24]. Furthermore, the Quality Functional Deployment (QFD) technique [25] allows mapping the customer needs with the P-S functions to elicit the final P-S requirements for the solution to be developed by the correlation by means of a sequence of Houses of Quality (HoQ).

The offering of a P-S requires additional competencies for provisioning new associated services and a better understanding of the customer requirements [25]. In this context Requirement Elicitation (RE) is crucial: it implies the definition of the requirements of the P-S solution to be developed according to the target market, and the definition of the best processes to support an efficient and sustainable product or service development in an industrial network environment. For these reasons, RE is particularly critical because of the huge quantity of implicit knowledge to be elicited and the variety of actors involved [26]. As a consequence, RE needs to be faced in a structured and rigorous way [27].

2. A QFD-based methodology for P-S ideation and design

2.1. P-S ideation and design in manufacturing industry

Product design is usually well formalized and the ideation process is managed by each company according to guidelines defined by the marketing department to pave the way to the design process. Contrarily P-S ideation and design is not investigated at all and opens new issues for manufacturing companies. Indeed, a new P-S solution cannot be realized by simply adding services to a traditional product, but requires a deep analysis of the functionalities to be developed and the assets needed in order to discover the specific consumer needs, define the new design specifications, involve the right ecosystem partners and organize the network properly. For these purposes, defining guidelines to drive P-S ideation and design processes is necessary to create consumer-oriented PSSs and service-oriented networks.

The research focuses on household appliances sector and is carried out in collaboration with an Italian company that is world leader in designing and producing washing machines and dryers in particular. For this specific context, the ideation and design process workflow is represented in Figure 1: it usually involves several figures inside and outside the company and covers a time about 6 months. It starts with an operative workshop organized by the main company management team for brainstorming and idea generation about the new P-S solution. The initial scenarios are collected from the consumers though surveys or questionnaires, and the competitor analysis. After that, P-S ideas are generated from both internal company area (e.g. marketing, R&D, service, innovation & technology) and from the most strategic partners with the involvement of their research and marketing area during the workshops. The generated ideas are usually classified into different categories according to the main drivers defined by the company (e.g. market, technology, design). Moreover, in order to be assessed and compared, each idea is defined in terms of:

- *Insight*, that represents the abstract P-S concept from the consumer viewpoint and focuses mainly on the consumer needs' satisfaction;
- *Consumer promise*, that translates the insight into the first P-S concept to be proposed on the market.
- *Reason why*, that explains how the concept described from the insight and defined in the consumer promise will satisfy the consumer needs specifically.

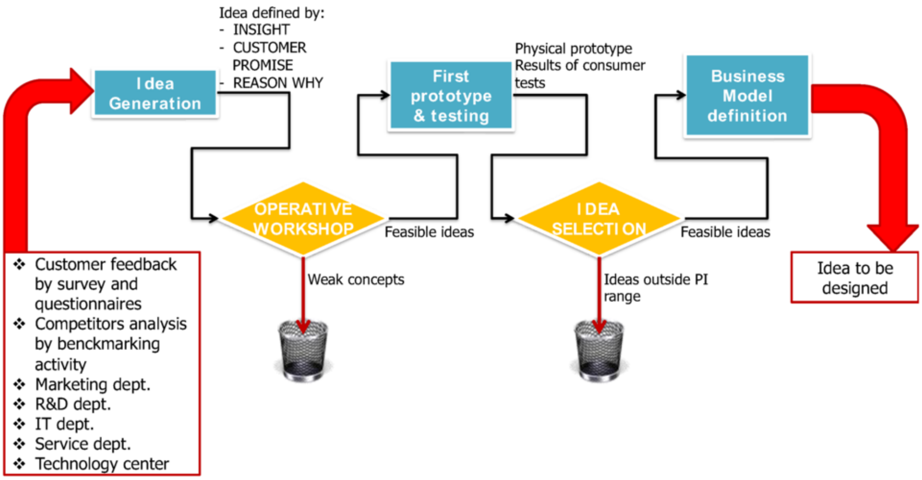

Figure 1. Ideation process workflow in household appliances

The most promising ideas generated thanks to this process are used for realizing the first prototype and compared during screening tests for idea selection. Such tests involve sample users and the company management team and allow the most feasible idea to be selected. Ideas are selected on the basis of a set of Performance Indicators (PIs) considering the economical-technical feasibility, sustainability, the innovation perceived, the consumer relevance, as well as technical risks. The ideas selected at this stage will be developed through the definition of a business model and completely defined thanks to a business use case that allows defining the stakeholders involved and the necessary sub-systems and system infrastructure (e.g. delivery channels, cost models, revenues).

After that, the final P-S idea has to be designed by the definition of the service functionalities, which are realized thanks to the P-S requirements and the involved assets, both tangible (e.g. re-design of some physical components, introduction of new sensors) or intangible (e.g. knowledge in product-service systems, software systems to support the physical product). Furthermore, product-centered and service-centered activities have to be integrated into a unique product-service lifecycle and interactions have to be properly managed. For manufacturing companies, activity organization and network management are the most critical stage; as a consequence, the resulting process is definitely unstructured and guided by non-objective drivers like subjective experience, particular opportunities of collaboration and business, specific technological drivers.

2.2. The research methodology

The methodology aims at supporting manufacturing industrial chains in P-S ideation and design by overcoming the main limitations of the actual process. Indeed, it aims at restructuring the actual process and correlating all data and information managed by the companies' involved, and their internal departments, to objectify the analysis and selection of the consumer promise, the investigation of the P-S insights, and the elicitation of the functional and ecosystem requirements for the following detailed design and manufacturing stages.

Such method allows structuring data and information to be easily used by designers to select the tangible and intangible assets for P-S design and co-creation and identify design guidelines for P-S. The structured methodology proposed also allows companies facing service innovation by designing P-S solutions on the basis of sustainability, feasibility, as well as technology feasibility and economic principles. These items are related each other by adopting a QFD approach that exploits HoQ (House of Quality) correlation to objectify the results at each stage (*a*, *b*, *c, d* and *e*) by relating the output from each step to the input of the following one. The method steps are represented in Figure 2. Each step contributes to fulfill the related HoQ by using data and resources as indicated in the figure; the process moves on by exploiting the obtained results in the next houses until the final House that allows estimating the product-service requirements to satisfy during the P-S design process.

The methodology can be summarized into four steps as follows:

Step 1) *Selection of Consumer Promises*. It starts from the analysis of the target market with regards to the conceptual P-S idea to elicit the customer needs. A weight is assigned to each need according to a 5-point scale (1 = low importance, 5 = high importance); then, the consumer needs are related to the consumer promises coming out from the P-S ideas operative workshops during which ideas are discussed by marketing and management teams from the entire ecosystem (usually one representative for each company and area). The relationship between the consumer needs (CN_i) and the consumer promises (CP_j) is expressed by a 0-3-9 scale correlation (c_{ij}) (0 = no correlation, 9 = high correlation); the result is to highlight the most relevant consumer promises to be further analyzed on the basis of the Promise Importance index (PI) that is obtained for each CP_j by equation (1):

$$PI_j = \sum_i (w_i * c_{ij}) \tag{1}$$

Step 2) *Identification of P-S Functionalities*. According to the main consumer promises resulted by the previous step, marketing and technical staff defines a set of P-S insight (I_i); indeed, each consumer promise can be easily transferred into a specific insight by proposing a specific set of functionalities (F_j). Each insight is then weighted according to the promises importance normalization (n_i). After that, the functionalities are ranged in order to define how they satisfy the P-S insight using a 0-3-9 scale correlation (i_{ij}) (0 = no correlation, 9 = high correlation). Finally, the most important functionalities can be selected according to the Functionalities Importance (*FI*) that is obtained for each F_j by equation (2):

$$FI_j = \sum_i (n_i * i_{ij}) \quad (2)$$

Step 3) *Elicitation of P-S requirements*. In this context both functional and ecosystem requirements are identified considering the relations between the selected functionalities (F_j) as identified and weighted (w_j) in the previous step, and the ecosystem requirements (ER_z) that consider several drivers: from sustainability to technological constraints, to feasibility, and many more. The ecosystem requirements are weighted (e_z) by experts from both Academia and Industry according to a 5-point scale (1 = low importance, 5 = high importance) and related to the selected P-S functionalities by a 0-3-9 scale (f_{jz}) (0 = no correlation, 9 = high correlation). At the end the functional requirements needed to start the P-S design process are elicited in the basis of the functional requirements importance (*FRI*) and ecosystem requirements importance (*ERI*): in both cases the highest values will indicate the most important ones. *FRI* and *ERI* are calculated by respectively equation (3) and (4):

$$FRI_z = w_j * \sum_z (e_z * f_{jz}) \quad (3)$$

$$ERI_j = e_z * \sum_j (w_j * f_{jz}) \quad (4)$$

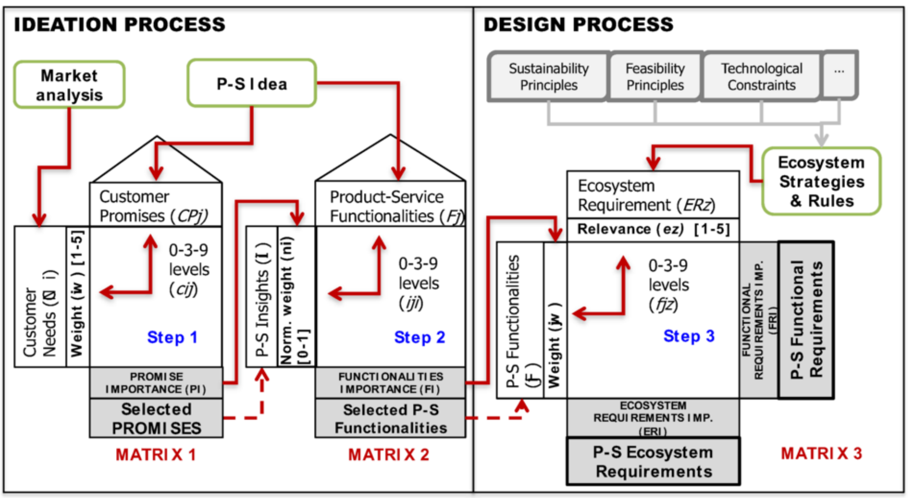

Figure 2. QFD-based methodology to support P-S ideation and design

3. The research case study: method application in the white good sector

3.1. Motivation

The white good sector is one of the most traditional manufacturing industries in Europe. It realizes machines enabling common activities within a domestic environment (i.e. washing dirty clothes, drying, freezing food) and characterized by high human-product interaction. Furthermore, in this field companies usually collaborates with numerous partners due to the multidisciplinary activities to be carried out. As a consequence, companies generally have a huge ecosystem that is one of the most strategic elements of success, based on the contribution that each partner can provide according to its specific knowledge and skills. In particular, the case study ecosystem is composed by technology suppliers as well as research institutes and consulting companies involved in specific activities. For these reasons, white goods are perfect candidates to be enhanced by services; however, in this field innovation mainly refers to aesthetical and technological aspects and do not include service and contrarily products are still sold in traditional manner. It is mainly due to the lack of structure methodology to conceive and design a new P-S. For these purposes, the authors applied the proposed methodology to this specific sector: attention has been focused on the definition of the final requirements to satisfy the consumer expectation and needs for new P-S project ideas. In particular, the P-S solution considered in the study aims at innovating washing machines, that are probably the most spread appliance in traditional homes all over the world.

3.2. Method application and results

The first step is the selection of the most promising ideas answering the customer needs. Such ideas are described in terms of “Consumer Promise” that express the benefits by the development of a specific P-S solution for the final consumer. Table 1 describes the ideas proposed and analyzed (in columns) and how they satisfy the consumer needs (in rows). The last row contains the PI (Promise Importance) calculated according to equation (1). The highest values indicate the better ideas. Table 1 contains only the most important promises due to space limit.

The second step refers to the identification of the P-S functionalities. In particular, the ideas collected in the previous step are translated into a more technical description by identifying the P-S insights, which describe in a more detailed way exactly what the machine will do to realize the consumer promises considered before and to satisfy the consumer needs. AS a consequence, the insights contain the first technical description of the P-S and are inevitably connected with the system functionalities. For this reason, the relation between insight and functions can be mapped to better highlight the technical features of the new solution. Table 2 shows such correlation for the case study. Results from equation (2) are highlighted in the last rows.

The third step focuses on elicitation of the P-S functional requirements to design the new P-S idea to develop a specific idea of P-S solution. On one hand, it allows eliciting functional requirements to understand which functions should be effectively integrated and considered also considering external factors such as their availability in the ecosystem, their impact on costs or environment, etc. On the other hand, it supports the creation of the right ecosystem thanks to the ecosystem requirements that elicit the system needs from the company involved in the study. Table 3 shows the achieved results. For the specific case study, it can be stated that offering ad-hoc marketing actions is the first functions to implement as well as smart detergent supply and appliance monitoring. Even if appliance monitoring did not achieved the higher value from step 2, however it has a positive impact on sustainability and environmental issues, and it can be easily provided by the ecosystem. Such a method also allows eliciting such factors and carry out an integrated approach. About the ecosystem, addressing the target customers and cooperation and data sharing among the partners are fundamental to create the new P-S. Other important factors are new sensor development and measure of the p-S profitability.

Table 1. Main ideas answering the identified consumer needs (MATRIX 1)

		CONSUMER PROMISE					
CONSUMER NEEDS	**Weight (wi)**	Certainty in removal obstinate stain	Autodose	High performance cycle	Colour catcher integrated	Ultrasonic device for pre-treatment of stain	Automatic recognition of the garments colours
High cycle performance	4	9	9	9	9	0	9
High machine performances	4	9	9	9	3	9	9
Energy efficiency	5	0	3	0	0	0	0
Other resources efficiency	5	3	9	3	0	0	0
Balance between quality and price	4	3	3	0	3	0	0
High quality of components	3	0	3	9	3	9	3
Easy to use	2	0	3	0	3	3	0
Safety and security	2	0	0	0	0	0	0
Function personalization	1	9	3	3	0	3	3
Reliability and Durability	3	0	3	9	0	0	0
Attention to environmental theme	4	0	9	9	0	0	0
Appliance control	2	0	9	3	0	0	0
PROMISES IMPORTANCE (PI)		**108**	**225**	**186**	**75**	**72**	**84**

Table 2. Correlation between the selected P-S functionalities and the P-S insights (MATRIX 2)

		P-S FUNCTIONALITIES								
P-S INSIGHTS	**Norm. Weight (nj)**	Appliance connection	Appliance monitoring	Best practices proposal	Marketing offers	Coaching actions	Preventive maintenance	Ubiquitous service	Smart detergent provider	Needed water for the cycle
Autodose	**0,94**	9	9	3	9	3	0	0	9	3
High performance cycle	**0,83**	0	3	9	9	9	9	9	3	9
Certainty in removal obstinate stain	**0,40**	0	0	3	0	3	0	3	3	0
Automatic recognition of the garments colours	**0,26**	0	3	0	0	0	0	0	0	3
Colour catcher integrated	**0,22**	0	0	0	3	0	0	0	0	0
Ultrasonic device for pre-treatment of stain	**0,21**	3	0	0	3	3	0	0	0	0
FUNCTIONALITIES IMPORTANCE		**9,07**	**11,72**	**11,45**	**17,17**	**12,07**	**7,44**	**8,63**	**12,12**	**11,05**

Table 3. P-S Functional and Ecosystem Requirements (MATRIX 3)

		ECOSYSTEM REQUIREMENTS									
P-S FUNCTIONALITIES	**Weight**	Ecosystem partners cooperation	Involvement of SW systems providers	Involvement of HW systems providers	Involvement of research centre in P-S design	New sensors development	Addressing the target customers	Definition of the dependencies between product and service	High degree of P-S maturity company index	Measure of the P-S profitability	**FUNCTIONAL REQ. IMPORTANCE**
Relevance		**5**	**3**	**3**	**4**	**5**	**5**	**3**	**5**	**4**	
Marketing offers	**17,17**	9	3	0	0	3	9	0	0	9	**2575**
Coaching actions	**12,07**	3	3	0	0	3	9	0	0	3	**1159**
Smart detergent provider	**12,12**	9	0	9	0	9	3	3	0	3	**1854**
Needed water for the cycle	**11,05**	0	0	3	0	9	0	0	0	0	**597**
Appliance monitoring	**11,72**	3	9	3	3	0	0	3	9	3	**1512**
Best practices proposal	**11,45**	0	3	0	0	3	9	0	0	9	**1202**
Appliance connection	**9,07**	3	9	3	3	0	0	3	3	0	**789**
Ubiquitous service	**8,63**	3	0	3	3	0	3	3	9	0	**906**
Preventive maintenance	**7,44**	3	3	3	3	0	0	0	3	0	**60**
ECOSYSTEM REQ. IMPORTANCE		**2052**	**994**	**758**	**442**	**1653**	**2142**	**374**	**1163**	**1461**	

Such a method represents the first step for realizing a structured P-S ideation; obviously it could be further develop also in the design stage to support also detailed design and assets selection. The method has been adopted in household appliances but it can easily translated to other industrial sectors by properly changing weights, needs and functions considered. Elements about the ecosystem are quite general and could be used also for different scenarios.

4. Conclusions

The present paper investigate the main issues of product-service design in manufacturing sectors and proposes a methodology to support this process from the earliest ideation stages. The methodology has been defined starting from the analysis of actual product design methods in manufacturing industry, focusing on white goods sector, and proposes a structure approach to overcome the main limitation. The method allows matching market needs and technical issues within the company network by considering all partners involved with their assets, both tangible and intangible (i.e. products, services, infrastructures, knowledge, people). The proposed method has been applied to an industrial case study to check its validity and demonstrate the concrete support provided not only to the main company, but also to the entire ecosystem of LEs and SMEs. The case study ecosystem comprehends a household appliances manufacturer (LE) that wants to design a new P-S solution by exploiting ICT technologies and involving a set of suppliers (SMEs) as strategic partners. The paper presented the main results and highlighted the main advantages connected with the method application for manufacturing companies, enforcing the research objectives.

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