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Testing the methodology to generate Design for Product Service Supportability (DfPSS) Guidelines and Rules: an application case

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Abstract

The industrial world is today navigating from a traditional product-based business to a new more complex solution-based orientation, pushed by new technologies, a multiple functionalities demand and a change in the customer value perception. Several are the methods and tools proposed in literature to aid manufacturers to design those solutions in an integrated and systematized way but none of them is really able to consider together product and service components, according to both company and customer views. In this context, a methodology generating new Design for X (DfX) guidelines to support the early integration of service features already in the product design of PSS has been proposed by the authors. This methodology can raise engineers' consciousness in designing PSSs in a systematic and integrated way and provides insights into the link between the design process of PSS and the design knowledge generation in terms of guidelines and rules. In particular, the objective of this paper is to test this methodology through an application case. The test, following a theory building procedure, contributes to obtain the final methodology design, providing a double result: industrial experts' feedbacks, giving to the authors a major awareness of its strengths and weaknesses, and new industry-specific PSS design guidelines and rules.

Keywords: Product Service System (PSS); Design for X (DfX); Design for Product Service Supportability (DfPSS); Design Guidelines; PSS design and engineering

1. Introduction

The lack of methods and tools able to systematically bridge the integration of product and service in the design and engineering of PSS is acknowledged [1], [2]. There are however, up to now, as highlighted by the most recent literature reviews on this topic [3]–[8], several methodologies proposed to engineer a PSS. Most of them support this integration only at a strategic level during the concept phase [3] [9], neglecting the most detailed levels of design and engineering, when the solution is actually defined. Product and service are indeed managed as two separate silos without knowledge exchange. Different design strategies are proposed but they are actually either a product engineering approach (proposals and attempts from [10]–[13]) or, most of the time, a service one, while the PSS perspective as a single system is not still supported by a concrete method during the detail design phase. As a result, Service Engineering [14]–[18] revealed two main gaps [19], [20] for its practical adoption: its focus on the customer perspective (e.g. Value co-creation aspects) and the lack of a lifecycle view. Moreover, the scarce acceptance of these methodologies in the industrial context is strengthened by i) a limited development of tools (apart from [21]), ii) a rare demonstration of PSS methods and methodologies applicability in industry along all the PSS design process phases and iii) a lack in indicating the people

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responsible for each step (e.g. service manager vs product designer) with a consequent shortage of knowledge management during the design process.

In order to overcome some of the abovementioned issues, this paper presents a methodology developed to support the early integration of service features already in the product design of PSS, and reports an example of its applicability and its potential in generating new Design for X (DfX) guidelines and rules [22] according to the Design for Product Service Supportability approach [23] in a real context. In particular, this work aims at testing the applicability of the methodology generating DfPSS guidelines and rules through the conduction of an application case in a European machine builder producing automation solutions for consumer product production. Primarily, the application is willing to test if the methodology can be used to generate Guidelines and Rules not only for the design of the product feature of a PSS design but also for its supporting infrastructure. With this objective, the paper is organized as follows: section 2 presents the research framework briefly introducing the Design for Service Supportability (DfPSS) approach and the methodology for generating DfPSS Guidelines and Rules. Then, in section 3 the research methodology adopted and the application case characteristics are described. Finally, section 4 presents the validation results and section 5 concludes the paper and introduces the future research developments.

2. Research framework

The existing PSS design methodologies are not able to support manufacturers in focusing on both customer's perspective and company's internal performance and at the same time to properly support, also with a concrete tool, the integration of service and product design along their whole lifecycle [24]. In particular, some traditional PSS methodologies (e.g. [11], [25], [21]) tried to explain how to keep going with the traditional product design approach and to integrate it with proper service design, but often using a high level of abstraction or only proposing conceptual strategies to move in that direction [26]. In this sense, a lifecycle perspective on products and services in order to achieve good PSS performances is also needed [26]. To this purpose, concurrent engineering approaches, such as Design for X, have been suggested in literature, but only at a conceptual level, in order to adapt the physical products in various ways according to the PSS lifecycle, the service features and to address designers' lack of knowledge in important product and service lifecycle areas [27]. In particular, the DfPSS approach [23], by adopting a lifecycle perspective for integrating product and services, goes in this direction.

2.1. The methodology for generating DfPSS Guidelines/Rules

A methodology (Figure 1), for generating Design Guidelines/Rules suitable with the DfPSS approach, is proposed in order to enhance the design of the product features enabling the delivery of excellent services. In particular, Guidelines provide a proper basis for considering generic, non-company-specific, lifecycle oriented information to be followed during the design phases. Rules become concrete and quantitative instructions for PSS developers to be followed during their daily specific design activities, representing hence the characterizing knowledge belonging to the company. The methodology has been inspired by different methods and research area such as: the method proposed by [28] to generate functional-driven guidelines, the PARIX model procedure to define DfX tool [29], the DFX Shell framework [30], [31] and the Hoshin Kanri X-Matrix, deriving from the Lean philosophy, a tool used to perform strategic plan in "a detailed, documented course of action" [32]. The methodology is composed of 4 main sections. In particular, a first preliminary step is followed by 5 additional phases. In the following, a brief description of each section is reported:

Section 1: before starting with the content guideline and rule creation procedure, preliminary activities need to be performed in order to collect the basic information to be used through the adoption of the methodology. All the Design for X approaches that could be involved during the PSS design are collected: they represent the possible Abilities (A) the PSS under design could achieve and represent the starting point for the guidelines/rules definition. The DfX Ability concept is based on the "function" concept defined by [28]: they are those principles through which the PSS functions can be explicated and explained and represents what exactly the guideline addresses.

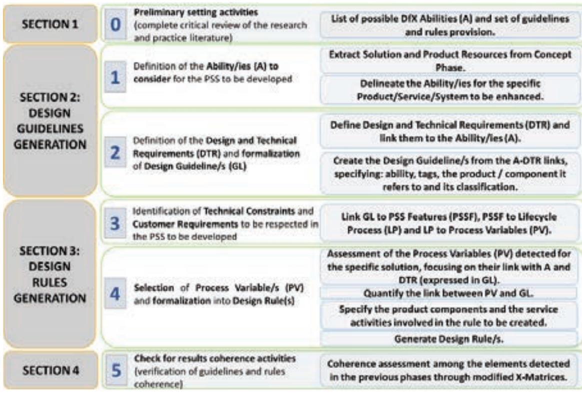

Figure 1 The PSS design Guideline/Rule methodology (adopted by[22])

Section 2: The design process can start when a PSS concept is already available. Once defined in Phase 1 the Ability(ies) (A) that the product under design has to achieve, an analysis must be conducted in order to create, if not existing, new suitable content guideline(s). Thus, Design and Technical Requirements (DTR) are defined: they represent the practical and technical recommendations to be followed by designers and engineers, through which abilities could be achieved. Therefore, the new DTR has to be linked to the Ability/ies, also specifying the importance degree of the relationships. Based on the identified links between A and DTR, guidelines able to guide the designer/engineer activities in the Product/Service/System development must be formalized in text and made available as company knowledge.

Section 3: in this section design rules are created. Here, the methodology must lead the designer/engineer to focus on the specific company context. In order to create a bridge between the functionalities of the PSS to be achieved and the related lifecycle variables that need to be managed, an extended version of the Function Transformation Matrices (FTM) methodology [28] is used. A series of them, all based on the same structure, is adopted to document and gauge the relationships among various factors such as:

- PSS Features (PSSF), those characteristics of the PSS components to be considered to act on DTR expressed in the Guidelines (GL);
- PSS Lifecycle Processes (LP) represent all those activities of the PSS lifecycle (from the design to disposal phase);
- PSS Process Variables (PV) are those variables which need to be detected since they affect LP. They can belong to any process of the several phases composing the PSS lifecycle.

Finally, Design Rules are systematically developed based on the links found in the previous steps. Their aim is the ability-driven control of lifecycle variables in order to better manage the design activities to achieve the PSS Ability/ies enabled by the introduction of a new service on a physical product.

Section 4: In this last section, the coherence of all the elements considered during the design process is verified, supporting designers and engineers in finding the right connections between the obtained high level Guidelines and the more operative Rules. For this aim, two modified X-Matrices [32] are used.

3. Research methodology and application case

The research has been conduct using the following research methodology.

3.1. Research Methodology

The application case has been conducted with the aim of testing the methodology for the generation of DfPSS Guidelines and Rules and receiving relevant practical feedback by the company side. A face-to-face workshop has been organized to test and collect the information. Before it a video has been shared with participants to train them about the methodology. The interactive session was led by two academics and involved two additional academics with which the company has long term relationship, the head of the design and engineering division and a software engineer (usually developing machines software including GUIs, data management and control programs): after a discussion regarding the actual use of DfX methods in the company, DfPSS approach was introduced as the basic concept related to the methodology for Guidelines and Rules generation.

Hence, a solution, the remote maintenance on machines supported by knowledge database (DB) and intelligent search, has been detected through a concept design brainstorming [33] to enhance the company business. The methodology has been tested by generating guidelines and rules to support the design of this new PSS. The aim was to test the applicability and to collect useful feedbacks to improve the methodology.

3.2. The application case

The application case has been conducted in Company A, a B2B European machine builder producing automation solutions for consumer product production. The company operates worldwide thanks to its partnership with some of the most important industries of the sector. It has a mature and consolidated product portfolio, supported by a strong and experienced design and engineering division. Their intent is to go through the servitization process: in this sense they want to enhance product monitoring, achieve an efficient production and minimize the downtime through the improvement of the already existing services or establishing new ones. Indeed, so far, they provide with their machines only some basic services (maintenance, training and consultancy): the company is thus considering new PSS projects like organization of the production, machine monitoring and remote maintenance supported by knowledge DB and intelligent search.

3.3. The design process in Company A

The methodology was applied in the company throughout all its steps, as described above. Therefore, starting with Section 1, some preliminary setting activities, assessing the AS-IS of the company design procedures, were performed. Automation solutions are very complex and specific machineries: special skills, combined with a certain background and experience, are needed to manage the high number of requirements and to arrange them into a design project. Engineers have of course a lot of requirements to cope with during the design of their products and services. Requirement engineers have also to understand how to test requirements and verify their fulfillment. In particular, when a new machine is commissioned, the type of requirements to be followed basically depends on:

- the characteristics of the final product the machine is going to deliver for the customer: this defines also the connected production process.
- the type of company commissioning the machine. The customer asking for the machinery can be an international player, an OEM or a family home business. Big companies have strict standards to be followed: they have a lot of requirements to fulfil and need experts for every aspect, like automation and safety.

They do care of a lot of topics and they try to systematically follow the requirements during all the design of their machines: the approach is similar to DfX even if a different name is used. In particular, a bullet point list, checked from time to time during the design process, is used for requirement management to inform every designer about the target of each project. Those requirements are not written down to be protocolled and linked to design projects: indeed, design guidelines and handbooks are not developed in the company. However, some procedures are followed during the design phase: guidelines defined by international associations of engineers, are customized according to company procedures. Moreover, some European laws are followed, having to consider misuse of the product: the machine have to be safe according to the European regulations and to consider both intended and unintended use.

Furthermore, the design of new machines is often based on feedbacks and customer care reports collected by company's sales and service personnel. It is important to highlight the already existing collaboration during the design process among designers, service and sales but also manufacturing and other company departments: this is aimed to manage and satisfy customer requirements, also combining them with the company technical constraints. However, being a small company, this procedure is not codified.

For these reasons and the characteristic of the company design process the company is an interesting case for the application of the proposed methodology to create DfPSS Guidelines and rules to support the design of the supporting infrastructure of the Knowledge DB and Intelligent Service solution, is reported. The application has the main objective to verify if the methodology can really support companies in creating design rules able enabling a better design of a PSS. In particular, the intention is to test if the methodology can be used not only to support the product design but also for the infrastructure needed. In order to have a complete understanding of the solution under investigation, its service delivery process is described.

3.4. The service

As previously mentioned, in order to strengthen the maintenance service delivered to their customers and reducing the idle time of their machines, through a conceptual design brainstorming using the PSCT [33], the company detected a new solution: the Knowledge DB and Intelligent Search.

The service, in the company's intention will be structured as follows: the customer, after the discovery of a problem on the machine, contacts the call center and is recognized by the Customer Relationship Management (CRM) Tool. A company expert, thanks to the proprietary software, is able to view all the data related to the machine(s) with issue(s). Data contained in the DB covers all the aspects of the apparatus. From the DB, the operator retrieves a list of the possible causes previously entered by technicians: the customer verifies them trying to identify the problem's root cause. Otherwise, new causes are added to the system. Once detected the right cause, the system provides a list of possible solutions. Depending on them, the customer can require or not the intervention of an on-site operator. The intervention is documented in the system through a photo. If necessary, the maintenance procedure on the machine, can be guided by the tele-service operator through a telephone and a camera. The big benefit for the customer is that most of the times he solves by himself in the fastest way his issue. Young and new technicians have thus the DB in the background and for the company it is possible to send someone with basic knowledge and not so experienced. Indeed, the experience is shifted on the DB: the result doesn't depend on the operator on the phone or on the technicians you send to solve the issue.

3.5. Guidelines and rules generation in Company A

Once analyzed the current design approach of the company, according to the methodology procedure in Section 1, and detected the solution to be developed, DfPSS Guidelines and Rules were developed following the steps described from Section 2 to 4.

Figure 2 (from solutions in the bottom part of the figure following a clockwise direction) summarizes the results obtained through the application of Section 2: it begins with Phase 1, focused on Abilities definition, the five most important abilities to develop the solution desired have been identified. They were mainly related to the supporting infrastructure needed for the PSS provision: three of them were linked to the infrastructure User Friendliness (operations speed, graphical user interface and intelligent search), while the remaining two were linked to its Serviceability (possibility to use the DB with different platforms and scalability of the DB size). In Phase 2, eight DTRs were defined such as: the use of company's corporate design, the response time, the information contained in one page etc. Then, the relationship grade between each Ability and DTR was defined. As result, nine Guidelines (GL) were obtained since only the relationships with a weight higher than "3" were investigated and translated in operational guideline for the designer. Later Section 3, summarized in Figure 3 (from guidelines in the bottom part of the figure following a clockwise direction), was carried out in order to create detailed rules. In Phase 3 the PSS Feature were defined such as: powerful hardware, good coding and good search algorithms. Then, the team brainstormed once again to define the relationship between the Guidelines and the PSSF. Also, in this case for some of the Guidelines and PSSFs was not possible to define a relationship grade. In Phase 4, the designers' attention moved on the Lifecycle Process (LP) steps identification, in particular six phases were identified (Concept & Design, Programming, Validation, Implementation & Testing, Use and Disposal). The definition of the relationships between the PSSF and the LP, aided engineers in understanding the value of the PSSF in all the phases of the solution lifecycle.

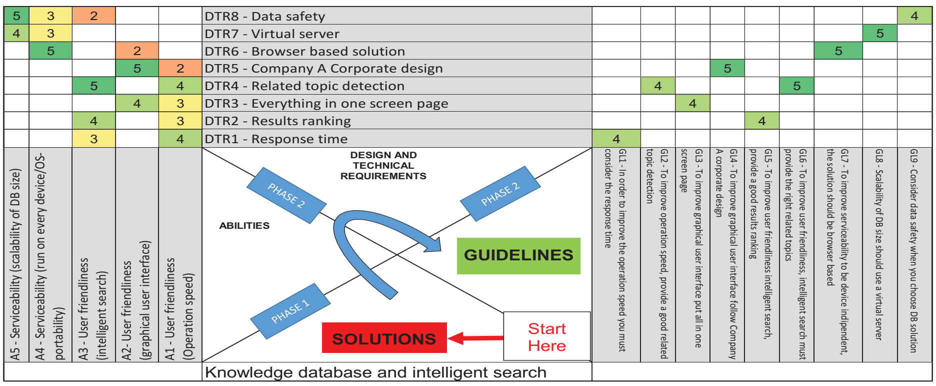

Figure 2 FTM – X Matrix from Solution to Guidelines

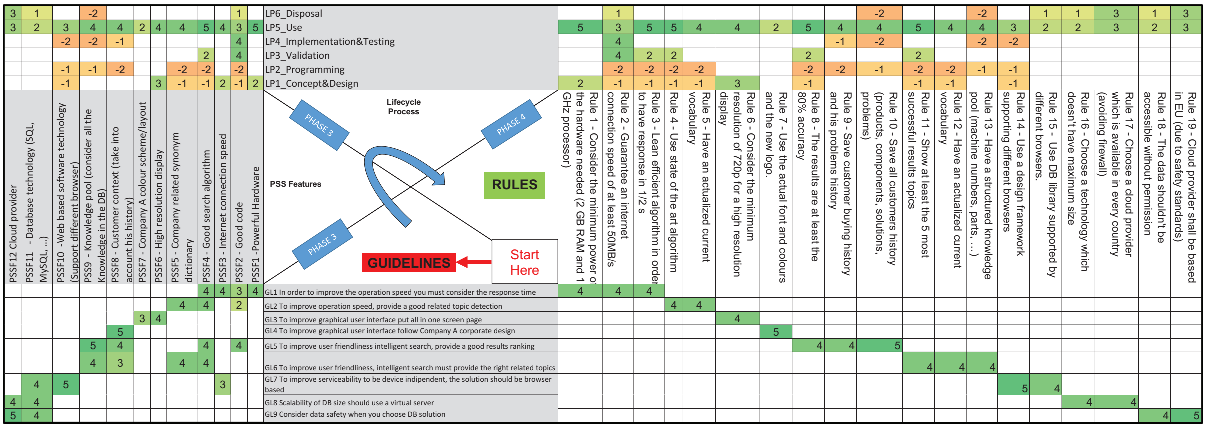

Figure 3 FTM - X Matrix from Guidelines to Rules

Once again, the resulting links fostered the creation of the Design Rules to be followed by the designers. 19 specific new Rules have been created (listed in Figure 3). Finally, in Phase 5, the team checked the coherence between all the information created along the methodology implementation thanks to the analysis of the two X-Matrices. No contradictions emerged and all the abilities initially listed were successfully explored. For example, in order to achieve A3, *User Friendliness (intelligent search)*, DTR4, *Related topic detection*, was considered. This relation was explicated in GL2 ("*To improve operation speed, provide a good related topic detection*"). To act on this, two PSSFs were considered. (i) PSSF4, *Good Search Algorithm*, requires a little effort in the beginning of the PSS lifecycle but makes the validation phase easier and gives a huge improvement in the use of the solution. (ii) PSSF5, *Company related Synonym Dictionary*, requires a little effort for programming and filling the DB but gives advantages in the use phase. Indeed, both Rule 4, "*Use state of the art algorithm*", and Rule 5, "*Have an actualized current vocabulary*", contribute to GL2's aim.

4. Discussion

Several and different results have been obtained through this application case. The main evidence is that the proposed methodology is able to foster not only the design of the product component [22], making it more suitable to support the service, but also the PSS' supporting infrastructure (in this case the needed software and of the connected hardware). In particular, following the methodology, 9 new Guidelines (Figure 2) and 19 connected Rules (Figure 3) were obtained and checked.

Besides, according to company's employees, the most useful possible improvement in the methodology concerns the time required to complete it and the level of detail that is possible to obtain. In fact, they reported the risk to have, for most of their design projects, a high number of requirements that can lead to a very high number of Guidelines and connected Rules. This also implies spending on it a considerable quantity of time that can affect the normal work of the designers. However, this issue can be partly managed by the design team itself through the weights given to the relationships between Abilities and DTRs. In this way, complexity can be reduced at the top of the procedure and the focus is shrunk only on those DTRs that are functional to the target Abilities previously chosen.

Generally speaking, the methodology adoption requires a high effort from the company's employees since the concepts involved in the methodology are new and not deeply known. Notwithstanding, throughout its adoption, the more knowledge is collected in the company, the easier the design process gets and more detail design knowledge is created. However, from the application case emerged that designers can't always use this methodology in an extensive way, especially for those design projects presenting a very high number of requirements.

Furthermore, company's experts found useful the application of the X-Matrix to verify the coherence between the Guidelines and Rules. Automatic warnings about the correctness of what have been done is considered a good feature, however hints supporting the designer in developing new connections and thus new design knowledge have been suggested as a further improvement. Regarding variables the application case highlighted that the step for their detection in the methodology (with the related FTM) is useful only when the solution design is very complex and requires a very specific issue analysis. Regarding the organizational issues connected with the adoption of the methodology in an industrial context, one of the main issues emerged is related to the identification of who is in charge of protocolling and managing the produced knowledge. Depending on the company and on the design projects, designers are in charge of creating Guidelines and Rules but an approval is required by the design manager. In this way, the different sub-departments, focused on specific topics of the same design project, can be aligned on every aspect every time a design modification on the design project is needed.

5. Conclusions and further developments

This paper copes with how to support companies in properly design a PSS by integrating the service features already in the product and infrastructure design of the PSS. For this reason, due to a scarce adoption in the industrial context of the existing PSS design methodologies, the methodology

generating DfPSS guidelines and rules, proposed in [22], is tested through the conduction of an application case in a European machine builder producing automation solutions for consumer product production, willing to pursue its servitization process. Thanks to it, the authors were able to validate the applicability of the methodology also to the design of the PSS supporting infrastructure and not only of the product component. The work enabled authors to better understand strengths and weaknesses of their methodology, unveiling how to improve the steps for the generation of the DfPSS Guidelines and Rules. All the methodology has been gauged in each of its phases and the consistence among them has been confirmed. In this paper the methodology has been tested: designers/engineers were allowed to use it and then an assessing questionnaire/interviews was performed. A further test will be conducted in future in order to evaluate the effectiveness of the design method, dividing participants in two groups and assigning the new methodology to one group and an existing one to the second (in the case of the presented company the already adopted agile development).
The most important action needed to foster the adoption of the methodology, once ascertained its value for designers and engineers developing PSSs, seems to be the development of a supporting software tool able to manage the knowledge produced through the methodology and to automatize its different steps: a first prototype has already been developed to solve the issue. In fact, considering the main challenge to keep all the requirements and guidelines in the designer mind during the design phase, it is important to consider how the adoption of the methodology and a connected tool can contribute to save time and effort if compared to other traditional methodologies.

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