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Product-Service Systems across Life Cycle

Design for Product Service Supportability (DfPSS) approach: a state of the art to foster Product Service System (PSS) design

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Abstract

Product-Service System lifecycle is characterized by several phases from the initial concept to the final disposal. However, as for conventional products, the profit generation and the market success of PSSs critically depend on the decisions taken during the initial lifecycle stages, when PSSs are conceptualized, designed, developed and engineered. These are hence the phases deserving more attention in order to manage the intrinsic complexity of such systems, taking it in account during the entire PSS life cycle design phase. According to this, one of the main gaps detected in the PSS design process is the lack of methods able to support the early integration of service features during the product design. In this specific context DfX approaches, where X= x-bility stands for enhancing products design considering at the same time service features to be embedded on it (x) according to certain performance measures (-bility), are supposed to significantly contribute. The Serviceability point of view appears to be a critical aspect of the design of product-oriented PSS that has not been improving yet: significant enhancement in this products' characteristic will only occur if some changes will arise in the way they are designed. Indeed companies still need guidelines able to enhance the PSS design process in a more systematic way. On this basis, due to the main gap of integrating service features in the product design process, the paper presents and defines DfX approaches enlightening, among the several target properties they have been called to improve so far, the most suitable DfX streams detected to solve the reported PSS design issue and to define Design for Product Service Supportability (DfPSS).

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Keywords: Product Service System (PSS); Design for X (DfX); Concurrent Engineering (CE); Design for Product Service Supportability (DfPSS); DfX Guideline

1. Introduction

Different research communities [1] have already studied the transition from traditional businesses, based on the design and sale of physical products, to a new business orientation which considers a bundle of products and services able to enable a user to achieve the demanded functionalities [2]. Several terms can be referred to this new business orientation [3]: so far the main streams in literature are 'servitization' [4], 'Product Service System (PSS)' [5] 'Service-Dominant Logic (SDL)' [6] and Functional product [7]. This new business orientation has received increasing attention from manufacturing companies seeking competitive advantage opportunities. . Indeed, companies have started looking at the integration of products and services as a possibility for growth and competitiveness [8] instead of only offering services (e.g. aftersales services) in parallel to the "core" product sale. In fact, integrated solutions shift the customers' value creation process from the ownership of the physical product to the customer's interaction with the artifact. Therefore, all the activities and the knowledge associated with this interaction along all the solution lifecycle can contribute to the customers' value creation process [9]. In particular, the early phase of the PSS lifecycle is of central importance to develop well-integrated PSSs able to positively contribute to the customer value creation process, and various design strategies must be taken into consideration. To this purpose, concurrent engineering approaches, such as Design for X, have been suggested in literature as an effective way to integrate product and services since the design phase. As reported in Figure 1, [9] summarized

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these approaches. However, only few researchers have deeply investigated how to properly design the PSS product features in order to answer to the PSS goal. Thus, this paper aims at investigating though an extensive literature review how Design for X (DfX) approaches can support the early integration of service features already in the product design for product-oriented PSS. With this objective, the paper is organized as follow: section 2 reviews the literature describing DfX methods useful to enhance the design of integrated products and services in PSSs. Then, section 3 defines Design for Product Service Supportability (DfPSS) approach as a synergic use of the DfX criteria introduced in this SotA. Finally, section 4 concludes the paper and introduces the future research development.

2. State of the art: the Design for X (DfX) approaches in the PSS context

Product design influences the PSS offer and how the related services are provided and delivered. Therefore, it has a direct impact on the effectiveness and efficiency of the PSS along its lifecycle.

In such a competitive and fast changing environment it is important “doing right from the start” [10]: decisions in the early phase have been raised as important activities in the PSS design process, including considerations concerning several aspects (e.g. market needs, quality, manufacturing, life cycle). Indeed, considering since the design phase all the goals a PSS has to achieve along its lifecycle and the related constraints allows a company to produce better products. In this context, the adoption of the DfX approaches eases the consideration of these PSS goals and constraints [11], [12] allowing the designer to take into account the different X-dimensions [13]. At present, these design methods represent the most important attempt for enhancing product development according to certain characteristics or lifecycle phases during the design. Thus, “Design for X” methods support the PSS design process [14], redesigning or enhancing products in certain X-dimensions, in particular those ones related to “service supportability”. The main objective of the Design for Product Service Supportability (DfPSS) is to design a product more customer driven, maximizing the customer value of the solution provided and, at the same time, minimizing the cost of providing the solution during the whole lifecycle phases of the PSS. The main concept behind the DfPSS is that some services need to be supported by a specific DfX approach: the heterogeneity of the service brings to develop and enhance the tangible part according to different goals. Referring to service, Design for Product Service Supportability (DfPSS) encompasses all the DfX approaches aimed at systematically designing products able to deliver the following types of services (as reported in Figure 1) [9]: “Product use service” or operational services (e.g. maintenance, repair, spare parts, warranty), “Product life service”, namely the services encompassing the total product system and its full life cycle support (supplies, installation, auxiliary input, upgrade, disposal), and “Customer activity services” (training, planning, designing, specifying, operating, measuring).

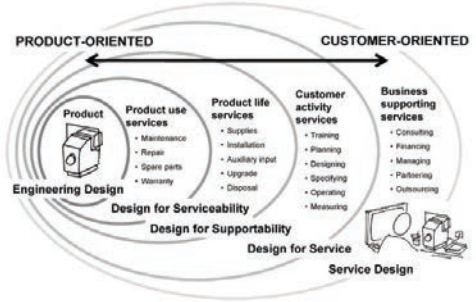

Figure 1. Development methods in relation to different types of services: from product to customer oriented services [9]

To this purpose, different available DfX approaches reported in literature have been analyzed and classified based on the sub-objective they could achieve if adopted. Thus, as reported in Table 1, the DfX making the solution more customer driven are Design for Usability and Design for Quality, while DfX minimizing the cost of providing the solution are Design for Manufacture and Assembly, Design for Validation, Design for Inspectability, Design for Testability, Design for Reliability, Design for Maintainability/Serviceability, Design for Modularity.

Table 1. DfPSS: Design for X for integrating products and services

Design for Product Service Supportability (DfPSS)	
DfX making the solution more customer driven	**DfX minimizing the cost of providing the solution**
Design for Usability (DfU) [15]–[19]:	Design for Manufacture and Assembly (DfMA) [25]–[29]
– Functionality [11], [15], [19]–[22]	Design for Validation (DfV) [17], [30], [31]
– Ease of operation and Aesthetic [15], [19]	Design for Reliability (DfR) [11], [25], [32]–[34]
Design for Quality (DfQ) [11], [23]–[25]	Design for Modularity (DfMo) and Customizability (DfC) [25], [35], [36]
	Design for Maintainability (DfMt)/Serviceability (DfS) [11], [25], [37]
	Design for Inspectability (DfI) [25], [38]–[40]
	3. Design for Testability (DfT) [25], [38], [39], [41]

As emerge from table 1, DfPSS entails a synergic use of DfX. Therefore, it is necessary to understand which are the guidelines and methods suggested by the different DfX approaches that are suitable for the PSS context and that can be adopted to satisfy both providers’ internal constraints and customers’ external expectations. In the following paragraphs, the DfX approaches listed in Table 1 will be presented in order to better define the “Design for Product Service Supportability” approach. For this purpose in the following, for each DfX, the definition, the main principles, the most relevant techniques and the main guidelines found in the literature are reported.

2.1 Design for Usability (DfU)

During the 1980s, the user friendliness of products began to be a strategic point for designers that started to incorporate requirements such as product-user interface and safety [15] in a complex design process [42]. A system designed to be used by people should be easy to learn and remember, useful (thus encompassing functions people really need) and easy and enjoyable to use [16]. Usability deals with assuring to the user the correct and safe use of the device in order to avoid errors during the product's use: errors could result in injuries to the stakeholders or damages to things [17]. Indeed also the most skilled users can incur in an error if the user interfaces are ambiguous or irrational. This further demonstrates the relevance of usability to develop a PSS aligned with the customer needs. The involvement of the users in the design process can improve human performance in the use of products as well as bring to a higher level of usability (so contributing to better define some aspects related to systems specification and development [18]). In this context, [19] highlights Human-Centered Design (HCD) and Activity-Centered Design (considered as an extension of HCD) as powerful tools belonging to Design Thinking which can be used to foster usability. [16] gave three main principles of design for usability: early focus on users and tasks, empirical measurement and iterative design.

According to the paradigm of usability and related concepts, usability is placed in balance with utility and likeability in order to satisfy users in terms of human and financial costs [22]. Utility directly involves the product functionality that is hence linked to its usability. Functional design plays a central role in ensuring design quality and solution innovation. According to [20], [21], "*function is a set of causal relationships between physical parameters, as described by the outward physical action of a device*". Product functionality was usually purely fulfilled through engineering design [11]: value engineering and producibility engineering approaches aid designers to shrink product costs after design conclusion [43]. A generic guideline based method for functionality is given by [15]. DfU also includes making devices easier to use [15]: constraints, discoverability and feedbacks are detected by [19] as the elements needed to the user to operate in a correct way with the device. The discoverability of the device depends on the combination of the knowledge available in both the world and the human head. The first consists of perceived affordances and signifiers, the mappings between the parts to manipulate and the resulting actions and the physical constraints. The latter includes conceptual models, cultural, semantic and logical constraints on behaviour, and analogies between the current situation and previous experiences with other situations. Thus, designers have the practical problems of understanding how to design things to make them understandable.

Wrapping up, we can shortly define usability as the capability to be used by humans easily (to a specified level of subjective assessment) and effectively (to a specified level of performance) [22]. Some steps in order to obtain usability guidelines were done by [43], who focused on the design of mobile device interfaces, widening the "Golden Rules of Interface Design" [44], aimed at guiding the design and implementation of interfaces for desktop machines and their applications. Furthermore, the ten Usability Heuristics for User Interface Design [46], excellent to explain previously found usability problems, are reported: visibility of system status, match between system and the real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, and helping users recognize, diagnose and recover from errors.

2.2 Design for Quality (DfQ)

DfQ deals with concept generation and selection: given a function, many solutions are generated and the best is chosen according to determined criteria, mainly those closely related to quality. DfQ is directly linked with the functionality aspect, more specifically with the measurement of how efficiently and effectively the product function can be achieved. Moreover, quality can be also defined as "compliance with requirements" of the characteristics of a machine [23] being able to improve the product's reliability, performance and technology in a continuous way [11]. According to ISO 9000, related to quality management, design involves products and services: it is indeed composed by traditional design and the design of procedures regarding each phase of the product life. [11] and [24], with MFD (Modular Function Deployment), identified QFD (Quality Function Deployment) as a strategic method for DfQ, enabling the shift from customer requirements into consistent technical specifications. Furthermore, TQM (Total Quality Management), Six sigma and standards ISO9000 are other methods developed to support quality management, emphasizing the process role to achieve quality, shrinking defects rate to a target rate (six sigma standard deviation) or enhancing customer satisfaction.

2.3 DfMA: Design for Assembly (DfA) and Manufacturability (DfM)

DfMA is a systematic procedure supporting companies in optimizing the use of the existing manufacturing processes as well as reducing to the minimum the number of parts in the assembly. It should be considered in the early phase of the development process, in parallel with the product concept and prototype development [25]. The analysis begins conducting DfA to simplify the structure of the product and to obtain the cost estimates of the different design solutions, also evaluating the best materials and processes. Then, DfM is implemented on the single parts of the product. Three are the main DfA evaluation methods: Hitachi AEM [26], Lucas [27] and Boothroyd-Dewhurst ([29], [47]) methods. DfM cost estimating process starts analysing how each part is manufactured. Design teams can gauge alternative designs and production processes, quantify manufacturing costs and make the necessary trade-off decisions between parts consolidation and increased material/manufacturing costs.

Wrapping up, through DfMA simpler and more reliable products, less expensive to assemble and manufacture, are obtained. All of these factors have an important effect on overheads, which in many cases form the largest proportion of the total product cost. Moreover, several guidelines for DfM and DfA already exist [25]. Here some examples are reported for both DfM (simplify the design; design to minimize the labor cost; avoid generalized statements on drawings; dimension form surfaces, not from points in space; etc) and DfA (reduce part count and types; modulirise the design; strive to eliminate adjustements; design parts for ease of feeding or handling; etc).

2.4 Design for Modularity (DfMo) and Customizability (DfC)

Modular design is a technique used to develop complex products using similar components. These are parts of the product with discrete functions that, coupled together, provide a variety of functions. DfMo aims at the minimization of interactions between components [36] following the two main important challenges of decomposition and integration [35]. This can be strategic in the assembly/disassembly process for the whole PSS lifecycle. A DfMo technique is Modular Function Deployment (MFD) [25]. It is a systematic technique composed of five steps. It begins with QFD analysis to define both customer requirements and technical solutions focusing on modularity. Then modular concepts are generated and chosen. The Module Indication Matrix (MIM) is used to identify, through the use of a questionnaire, possible modules by gauging the contact points between module drivers and technical solutions.

2.5 Design for Reliability (DfR)

Reliability is defined by the IEEE Advisory Group on Reliability of Electronic Equipment (1957) as the time/probability of failure of a device performing its intended function under defined conditions. DfR enables designers to detect potential failure areas and to obtain a reliable design configuration [11]. Product reliability is of key importance to customers and is strictly related to design, manufacturing and maintenance as well as to customer expectations. The improvement of reporting and of the information flow among the different stakeholders should be strategic to improve reliability during the use phase of the solution [25].

A method, aimed at defining guidelines to enhance reliability from the beginning, is to detect the interfaces and components that may cause failure. [32] identified three general design principles: simplicity, clarity and unity. They can be seen as internal properties of a mechanical system: a mix of them can determine the external properties of performance, economy and reliability [25]. These criteria seem to be directly linked to the more relevant design concepts of affordance, signifiers, mapping and constraints, furtherly confirming the relationship between reliability and usability.

[34] provided a list of guidelines for Design for Reliability (DfR) which are (1) simplicity, (2) use of proven components and preferred designs, (3) stress and strength design, (4) redundancy, (5) local environment control, (6) identification and elimination of critical failure modes, (7) detection of impeding failures, (8) preventive maintenance, (9) tolerance evaluation, and (10) human engineering.

Finally, [48] defined eight elements of DfR for medical devices: 1) Design realistic product requirements and constraints, 2) Define the product life-cycle environment, 3) Select components with the requisite level of quality, 4) Identify potential failure modes, sites and mechanisms, 5) Design to the usage and process capability of the product, 6) Verify the reliability of the product in the expected environment, 7) All manufacturing and assembly processes must have requisite capability, and 8) Use closed-loop management for product life-cycle usage.

2.6 Design for Maintainability (DfMt)/Serviceability (DfS)

According to [11], DfMt is aimed at assuring the product availability maintaining it throughout its lifecycle without excessive costs and difficulties. Customers expect service procedures to be carried out with the absolute minimum disruption of product use. Reliability and serviceability are strictly linked for both the manufacturer, determining the cost of the product warranty, and the user, being part of the continuing ownership cost. The analysis of service tasks should be conducted concurrently to the design for assembly studies, that is at the early stage of product design. DfA contributes to DfS reducing both part counts and the use of separate fasteners: when products are simplified in this way, a potential to execute service tasks in an easier way exists [25]. Related to DfR, the URI Design for Service procedure [37] has been developed, aiming at estimating the cost of servicing an item either not functioning correctly or being replaced for routine maintenance. The serviceability efficiency of the design is determined considering each disassembly operation and item removal, assessing if they are necessary, relating it to the functional cover part concept. The task of optimizing a design to ease initial assembly focusing on minimizing assembly time and cost, is fundamentally different from that of optimizing a product to ease service provision [27]. In this last case, different service tasks create conflicts because applied to the same product at the same time [25]. The perfect design for service would have all the items replaced without the disruption of the device use and all the service operations performed immediately being accessible on the outer surface of the product. This is very often not possible, so it must be decided which item must be the most easily accessible and understand the ease of the service tasks to be performed.

Some qualitative guidelines have been reported by [11] to describe DfMt requirements: (1) accessibility, (2) ability to detect and isolate failure, (3) weight limitations of replaceable units, (4) dimensional limits to allow replaceable units to be transported, and (5) design requirements to make replaceable units compatible with robots.

2.7 Design for Inspectability (DfI), for Testability (DfT) and for Validation (DfV)

DfI is a consequence of the growing customer demand for high product quality and continuing safe service: in manufacturing this means fast and precise feedback in process check (DfV), in service safety of use and fast assessment of function deterioration (DfI-DfT). Product, process and person can be designed together to improve inspectability. The product must be designed so that defects can be easily inspected and process decisions should be taken in a clear way. DfI [37, 38] deals with both manufacturing inspections and in-service inspections (checks during service life of the product). Complex products can deteriorate during their use phase: inspection during service life must be considered as well as manufacturing inspections. The product-process-people system must together fit human needs through inspection design. During the design phase, a trade-off between reliability and inspectability must be considered by the designer: if inspectability is not considered into design, variability in both manufacturing and service use must be avoided ensuring structural integrity of components and preventing the failure before replacement but this is very costly. This principle is called Damage Tolerance [40] allowing systems to work unless defects are detected.

DfT ([25], [38]) is similar to DfI, extending more its action framework at the circuit board level [39] and allowing the isolation of certain parts of the circuit to discovery and detect faults [41]. Indeed, DfT covers functional test rather than visual inspection [25]. Dealing with electronic equipment design, its principles are isolation of components, boundary scanning for boards, removal of feedback paths, synchronous logic to allow timing of test signals.

DfV follows the same stream of DfI and DfT but involving the design phase: it includes the verification of the design as it evolves [17]. The early work on DfV methodology [30] was aimed, through a literature review of good design practices, at making the validation process easier and more economic, assuring the satisfaction of user needs and conformity with the intended use [30], [31]. With their work six design guidelines were formulated: (1) capturing implicit and explicit requirements, (2) having verifiable requirements, (3) using a risk-based approach for design and verification, (4) considering the effects of re-design on requirements, (5) considering the effects of device development on process requirements, and (6) considering the effects of process re-design on device requirements.

3 Towards a definition of Design for Product Service Supportability (DfPSS)

This paragraph aims at discussing and summarizing the results of the above conducted State of the Art in order to introduce the DfPSS concept. To properly understand the current state of development of this concept, an assessment on the literature analyzed has been performed. One driver has been selected to model the available DfX guidelines against the DfPSS areas defined in Table 1: the lifecycle phases affected by the DfX (Table 2). Starting from the PSS lifecycle phases defined by [14], the following phases have been considered: Requirement Definition/Concept; Manufacturing/ Assembly; Validation; Service Delivery; Use; Disposal (due the length limitation of this paper, the disposal phase has not been considered here). Table 2 summarizes the conducted State of the Art and reports the main general principles characterizing each DfX composing DfPSS, revealing the fuzzy contact points among the different criteria. For example DfMA, DfQ, DfV and, in a minor way, DfMo/DfC are more related to the early phases of the lifecycle. By definition, they do not focus on service delivery and use phases: their range of action is indeed until Validation stage. Even though these DfX appear to be not so much significant for the enhancement of service supportability, some contact points can be found. They contribute to improve the solution availability in the use phase and to make the service delivery easier and faster from the service provider point of view. Design and manufacturing are strictly related: improvements in operations directly depend on product design [10]. However, also the service delivery and use phase are strategically related to the design, bringing together the decisions taken for the production and assembly phases: a solution that is designed to be easily assembled, manufactured and tested also through quality, modularity and customization concepts, is supposed to improve its availability also after the manufacturing phases. Thus, the resulting solution is supposed to be more prone to satisfy the remaining DfPSS criteria during the service delivery and use phase.

From the table it results evident that even though most of the assessed DfX approaches focus on the design of the early phases of the lifecycle, their effects can reveal advantages also in Service Delivery and Use phases. However, according to the so far considered criteria, guidelines aiding the service delivery and use phases do not still exist: this gap can be filled through a concurrent and synergic use during the PSS design process of these different criteria belonging to DfPSS. Finally the main concept behind the DfPSS is that some services need to be supported by a specific DfX approach: the heterogeneity of the service brings to develop and enhance the tangible part according to different goals.

4 Conclusions and further researches

This paper has reviewed the most suitable DfX approaches fostering the integration of services in the PSS design. Service Supportability is defined as a synergic use of several criteria that should be satisfied during the PSS lifecycle in order to meet the different stakeholders' needs. This impels designers towards DfX practices since the early phase of the PSS design. This is also supported in literature by the opening of PSS design and development to lean philosophy and principles [49].

Table 2. Design for Product Service Supportability: contributing DfX and their objective lifecycle phases

Design for Product Service Supportability (DfPSS)		**Lifecycle phases affected by the DfX (where to apply DfX)**					
		Requirement Definition/ Concept	***Manufacturing/Assembly***	***Validation***	***Service delivery***	***Use***	***Disposal***
DfX making the solution more customer driven	**DfUsability**	- Focus on systems specification and development [18]. - Product-user **interface** and safety requirements; **Functions** people really need [15].					
	- Functionality	- Traditionally used **engineering design** [11]. - **Value engineering** to define product functions/costs [43].	**Producibility engineering** to attune product specifications to available tools and equipment [43].				
	- Ease of Operation					**Design things understandable** [19].	
	DfQuality	Shift from customer requirements into consistent **technical specifications** [11], [24]					
DfX minimizing the cost of providing the solution	**DFMA**		**Optimize** the use of the **existing manufacturing** processes and **minimize** the number of **parts in the assembly** [25][49].				
	DfValidation			Make the **validation process easier and more economic** [30].			
	DfModularity and Customizability	Identify modules: **contact points between module drivers and technical solutions** [25].	Modular design to be **attuned with assembly process** [25].				
	DfReliability	Relationship between reliability, usability and ease of operation: **interface components design** [11].		Validation should also be aimed at in-service reliability improvement [25]	**Reporting and information flow** among the different stakeholders **to improve reliability in the use phase** [25].		
	DfMaintainability/ Serviceability		**DfA contributes to DfS** reducing both part counts and the use of separate fasteners [25]		Design for ease of initial assembly is different from one for ease of service [25].		
	DfInspectability and Testability				Consider a **trade-off between reliability and inspectability** [25]		

Firstly, a systematic method to integrate products and services, able to guarantee the respect of both customer requirements and technical constraints, is still missing but also strongly required for the so far proposed PSS development methodologies [50]: DfX approach could support designers and engineers to solve this issue. Moreover, an assessment of the different DfX approaches reported in literature has been conducted (Table 2). The next step will be to integrate properly those criteria in order to obtain DfPSS guidelines useful for PSS designers.

Finally, in product design literature some methods already exist for guidelines creation. Further researches will be conducted to elaborate a new methodology fostering the integration of the different criteria belonging to DfPSS: it will be likely inspired by both the method aimed at generating functional-driven guidelines [15] and the procedure, deriving by PARIX model [51], to develop and implement DfX tools, DFX Shell [25], [52].

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