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Product-Service Systems lifecycle models: literature review and new proposition

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Abstract

The demand of global solutions to support customer's new expectations encouraged the development of the Product-Service Systems (PSS), which are complex solutions incorporating physical products and a non-physical services. PSS have been studied in many areas, among which data management is one of the most recent. A promising application in PSS data management is the use of its lifecycle information to improve PSS offer and related activities. In order to achieve this lifecycle approach, the first step is to identify a representative model of PSS lifecycle phases, which is the goal of this work. Pursuing this objective, a review on PSS lifecycle models was driven and compared to previous works on product and service independent lifecycles, leading to the proposal of an adapted PSS lifecycle model.

Keywords: Product-Service Systems, lifecycle models

1. Introduction

In the past 15 years, the research production around Product-Service Systems (PSS) have been increasing significantly [1]. The approach of the studies - at that time mostly focused in PSS origins, definitions and possible applications - are now being mainly explored on sustainability [2–4], circular economy [5,6] and data management [7–9] points of view. The current work has its basis in data management and particularly the use of PSS lifecycle information to improve PSS engineering and delivery.

Currently available solutions mainly support the single management of product (Product Lifecycle Management systems) or service (Service Lifecycle Management systems) but not the combination of them [10]. Other solutions, more suitable for PSS, support the integrated management of these three aspects but in unidirectional flow, providing data for the execution of PSS tasks, without considering the feedback information. These solutions do not allow exploiting lifecycle data to improve PSS.

The usefulness of PSS information to improve different activities realized during PSS lifecycle has been proved in many research works. Some of them pointed out the improvement of product and service design processes based on reported manufacturing problems [5,11], components failure data [12] and disposal knowledge [13]. Other works focused on manufacturing processes adaptation based on product use knowledge [14] and average lifetime [3].

In order to map and categorize the information exploitations that have already been addressed in literature, it is necessary to identify a representative model of PSS lifecycle phases. The first challenge in the current research about PSS lifecycle management consists of considering a PSS lifecycle model that fits with PSS characteristics (system dimension, integration between product and service) and PSS typology (product oriented, use oriented, result oriented). Having such a model allows highlighting information networks that can still be exploited in order to offer relevant information to PSS providers and customers.

In order to define an adequate lifecycle model, a literature review on models proposed to represent the lifecycle of PSS is conducted in section 2. Then, it should be possible to identify gaps and incompleteness in existent representations. Aiming to fill up these gaps, the lifecycle investigation is extended to Product lifecycle models and Service lifecycle models in

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section 3. This investigation allows identifying main activities and concepts that were not addressed in PSS lifecycle literature. The comparative analysis of the three categories of lifecycle (PSS, Product, Service) provides the necessary information to propose a new model able to represent the PSS lifecycle in higher detail in section 4.

2. Literature review on PSS lifecycle models

The review was centered on the identification of authors that have been making use of the concept of lifecycle in PSS, and the representation of how they structure and explain the different phases. In order to identify these works, a key-word research was conducted using the terms "product-service systems" and "lifecycle / life cycle", in the database Web of Science. This first search returned 176 publications in English, among which 119 were proceeding papers, 52 articles and 8 reviews. The final selection of papers was made by identifying which publications reached the central goal of presenting a PSS lifecycle model. At this step, six papers were selected. The six models were compared in order to clarify the similarities and the differences among the activities and concepts presented in the each phase.

In order to evaluate PSS lifecycle models, some criteria were established. The models need to represent the three categories of PSS: Product-oriented, use-oriented and result-oriented PSS [2]. The activity's sequence may vary inside each phase, but the phase's structure and content might be able to represent all types of PSS. The models also need to consider PSS as a holistic solution, in which product and service depend on and interact with each other. Depending on PSS type, product and service may have more or less importance in the representation. Finally, besides the main structure aspect, it is important to detail the activities included in each phase of the model to show the interaction points.

The PSS lifecycle concept was introduced in [15] according to two perspectives: manufacturer and customer.

On the *manufacturer point of view*, four phases were proposed: (1) Organizational Implementation (building the necessary design and realization processes, as well as the organizational prerequisites), (2) PSS-Planning (identifying all PSS components), (3) PSS-Design (subsequent planning and execution of PSS project, integrating product and service design through modular design processes) and (4) PSS-Realization (procuring and processing customer information in order to support continuous PSS improvement and planning).

On the *customer point of view*, the PSS lifecycle includes Purchasing, Usage and Disposal. This perspective was mainly considered to promote an integrated PSS-Development, where the customer should be able to propose, during PSS-Planning, ideas of services that can be offered from PSS purchasing until its disposal.

The approach proposed in [15] follows the idea of a physical product core that is sold to a customer, to whom services are offered from purchasing to disposal. The services are, therefore, designed according to a predefined product, what represents only one of different possible scenarios of PSS implementation.

In [16], the authors created a PSS management model using three macro phases – Begin of Life (BOL), Middle of Life (MOL) and End of Life (EOL), with detailed intermediate steps, integrating both product and service development in a holistic solution. In this model, PSS BOL starts with the Ideation stage, followed by the Requirements and Design stages, for which the compatibility must be ensured through feedback loops between product and service design. Realization is the first step of the MOL macro phase and it comprises the manufacturing of the product and the implementation of the service, which are iteratively verified and adjusted. It is followed by Delivery and Support phases; point when the distinction between physical product and service no longer exists. In the EOL, also called Evolution phase, it may be decided if the PSS can be upgraded (product and/or service) or if it has to be decommissioned. In spite of considering product and service in a PSS as a holistic solution and presenting the exchanges between these two parts, this model gets to the same lack of details and specifications about which activities should be driven, in product and service modules, at each stage of the lifecycle.

Aiming to discuss different lifecycle management perspectives, [17] uses a model composed of five phases: planning, development, implementation, operation (delivery and use) and closure. In this model, the authors differentiate two stages of PSS: virtual, involving planning and development, and real, including operation and end of life.

This two-phased model is identified by the authors as a PLM (Product Lifecycle Management) approach for IPSS (Industrial Product-Service Systems). It means that they completed the traditional PLM approach (management of goods-related data and engineering processes) with the management of interdependencies of information and communication between all of the partners and customers involved in the PSS lifecycle. Besides this focus on PLM which neglects the service aspect, the work do not detail the main activities of each one of the declared phases. This lack of detail makes it difficult to understand which information could be collected in each phase from both product and service.

In [18], authors centered their work on identifying characteristics of PSS for each stage of the lifecycle, which were composed by the following concepts: requirements definition to meet specific customer demands; development of characteristics based on the requirements, implementation of these characteristics on usable resources; monitoring PSS through information obtained during its use and post use definition according to suitable situations.

This model is mostly focused on identifying conceptual elements of the lifecycle, without entering in specific details about the activities performed from PSS definition to its post-use. It does not go deeper in distinguishing needs and constraints specifics to a product or to a service in a PSS lifecycle.

The technology evolution map in [19] introduces PSS lifecycle management concept as the organic integration of services – such as product operation, maintenance, repair, parts replacement, recall and scrap recycling – and information management according to the product lifecycle. From this starting map, they propose a PSS lifecycle model explored in three main phases: Formation, Application and Reproduction. Formation includes PSS investigation, exploitation and design; Application goes from the implementation and sales to the use phase; and Reproduction involves maintenance and recycling activities.

Having an approach similar to the one presented in [17], the precedent work also highlights the product as the core part of the PSS, developing the other components, such as services and information management, according to the product lifecycle management. Therefore, the choice of this model limits its representation to one type of PSS, the one that is centralized in the product.

In a more generic view, [20] proposes a Product-Service Lifecycle Ontology integrating a PLM (Product Lifecycle Management), divided in the already introduced macro phases BOL, MOL and EOL, and a SLM (Service Lifecycle Management) composed by Service Design, Offering, Provisioning, Usage and Decommissioning. BOL phase is composed by design and manufacturing steps, MOL presents repair and maintenance and EOL presents reuse, remanufacturing and disposal activities.

Although this proposition considers product and service at the same level in a PSS, the model presents them as parallel cycles, overlapping PLM and SLM.

Neglecting the interaction between product and service lifecycles, it is difficult to predict how a process driven in product affects the ones in service and vice-versa. In order to summarize the information acquired in the previously presented models, Fig. 1 schematizes the lifecycles described. The phases correspond to the phases named by the authors and they were overlapped according to the similarity among the concepts describing the phases in each model. The phases were distinguished by different colors, using a pattern that will be maintained in the following sections.

Comparing the models in Fig. 1 it is possible to identify some common concepts in PSS lifecycle, which enables the definition of phases. In order to fill the gaps pointed out for the lifecycle models, such as the lack of details in the activities of each stage, the missing information about service lifecycle, and the difficult to integrate product and service aspects as a holistic solution, it is necessary to visualize the particularities on Product lifecycle and Service lifecycle separately.

The next step consists of comparing and completing the PSS models studied above with the models proposed for product lifecycles and service lifecycles separately.

[15]	Organizational Planning		Planning	Design		Realization		
						Purchase	Usage	Disposal
[16]	Idea	Requirements	Design	Realization	Delivery	Support		Evolution
[17]	Planning		Development	Implementation		Operation		Closure
[18]	Requirements		Development	Implementation		Monitoring		Post use
[19]	Investigation	Exploitation	Design	Manufacturing	Sale	Execution	Maintenance	Recycling
[20]	BOL					MOL		EOL
	PSS ideation [16] Opport. creation [18] User requirements [19] Mkt. investigation [19]	Processes bulding [15] Req. definition [15, 16] Plan [17]	Design [15, 18, 19, 20] P-S compatibility [16] Development [17] Actors, infra [18] Service resource [19]	PSS Execution [15] P-S Integration [15] Manufacturing [16, 19, 20] Implemen. [16, 17, 18] Assembly [19]	Deliver [16] Sales [19] Logistics [19] Mkt [19] Offering [20]	User train. [15] Use, oper. [15, 17, 20] Monitor. [15, 16, 19] Improv. [15, 18, 19]	Maintenance [15, 16, 19, 20] Support [16]	Take-back [15, 16, 17, 18, 20] Repair, upgrade [16, 18, 20] Reuse, renew. [18, 20] Recycle [18, 19] Disassembly [19]

Fig. 1. PSS lifecycle models and concepts associated to each phase.

3. Product lifecycle and service lifecycle models

The investigations about product lifecycles have started many years before the advent of the PSS. Therefore, at this point, some models representing Product lifecycle are already consolidated. Service experts also found important to clearly represent the lifecycle structure of this kind of offer. Although it is still less consolidated than product models, some authors have proposed lifecycle stages in order to improve the service lifecycle management. Analyzing the specificities of product lifecycle and service lifecycle independently should help on completing the current models of PSS lifecycle.

3.1. Product lifecycle models

According to the review on product lifecycle in [21], covering the works published from 1950 to 2009, the expression "product lifecycle" dates from the end of 1960s, but it not always represented the same idea. The first concept, which prevailed until the middle of the 1980s, was focused on the market life of the product, i.e. market development, growth, maturity and decline steps.

After this period, another type of product lifecycle has raised and it was mostly interested on the complete life of a single product, from product conception to decommissioning. In this topic, we are interested in analyzing the propositions on the second concept of product lifecycle, also called Engineering Product Lifecycle.

Detailing the contemporary perspectives of this concept, the authors in [16] presented the evolution of product lifecycle models during the studied period. These models will be presented in the next paragraphs.

The model proposed in [22], focused on product design, was composed by six phases: Needs recognition, Design/Development, Production, Distribution, Usage, and Disposal/Recycling. The author argued that all the six phases should be considered for designing the product.

In their analysis of product lifecycle cost, [23] distinguish between only four phases: Design and development, Production, Use and Disposal. On the other hand, [24], in the analysis of lifecycle cost and lifecycle assessment represent it in five phases: Concept, Design, Manufacturing and assembly, Use and support, Reuse and/or recycling.

[25] introduced the concept of system lifecycle, integrating product, processes and logistics lifecycle. Their product lifecycle model is composed by Conceptual design,

Preliminary design, Detail design, Production, Usage and End of Life and Recycling.

The last lifecycle highlighted in [16] is the one proposed by [26] at the occasion of PROMISE project. This model is characterized by the macro phases: BOL, including design and production, MOL, including use, service and maintenance and EOL, characterized by various scenarios such as reuse of the product with refurbishing, reuse of components with disassembly and refurbishing, material reclamation without disassembly, material reclamation with disassembly and, finally, disposal with or without incineration

Besides the models listed by [21], others lifecycle have been proposed in the last years. With the advent of the servitization concept, some product lifecycle models started considering the services on the product lifecycle, without integrating both concepts as a PSS.

[27] divided the product lifecycle in four main parts: Design, Manufacturing, Servicing and Remanufacturing. The servicing phase includes three activities: purchase, usage and disposal, from a customer perspective. For the purchase phase, the proposed services would be sales, counseling and commissioning; for usage, services are maintenance, retrofitting and teleservice; and for disposal, services include take-back and refurbishing.

The product lifecycle model proposed by [28] follows the same standard phases proposed by [27], but it details the manufacturing phase in components acquisition and manufacturing, and the servicing phase in distribution, use and maintenance.

[29], that was used as a guideline to the PSS lifecycle model proposed in [16], introduced the concepts of BOL, MOL and EOL. In his first proposition about product itself, BOL is the macro phase where the product is imagined, its ideas are converted into specifications and it is finally manufactured. In the beginning of the MOL phase, the product is already in the possession of the customer, who exploits it and who is assisted by the provider through maintenance. Finally, in EOL the product loses usefulness and it has to be retired or upgraded by the manufacturer and disposed for eventual reuse or recycling.

The lifecycles explained in the previous paragraphs are resumed in Fig. 2. According to the description of the lifecycle phases and the key concepts associated to each of them, it is possible to overlap the models and to find the correspondence between the phases of different lifecycle models.

Comparing and mixing the elements of these lifecycle, it is possible to inform the specificities of the product in the PSS lifecycle. The product lifecycle starts with the idealization of a product, responding to customer needs. Then, the design is driven, defining all the requirements and specifications to launch the production and eventual assembly.

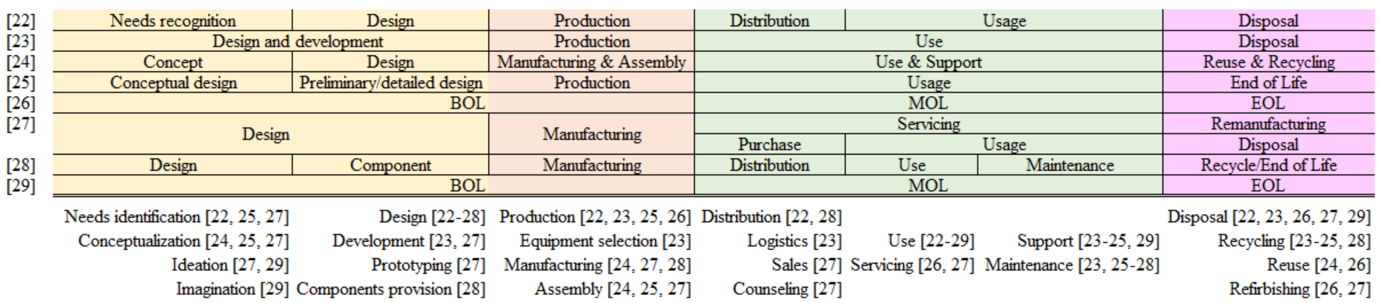

Fig. 2. Product lifecycle model and concepts associated to each phase

When the manufacturing is finished, the product is distributed and sold, arriving in customer's possession. During the use phase, support services can be offered. In the end of life of the product, it can be took back, retired, reused, recycled or remanufactured

3.2. Service lifecycle models

Service lifecycle management (SLM) is a concept derived from PLM (Product Lifecycle Management). SLM aims at managing all service data relating to its design, implementation, operation and final disposal. As well as the PLM, there are many different SLM (Service Lifecycle Management) models. However those existing models are mainly focus on IT related services or deal with the management of services after its implementation [30].

The work presented in [31] divided the Service Lifecycle in 6 main parts: Analysis, Design, Implementation, Publishing, Operation and Retirement. On the other side, Wiesner et al. (2014) in [16] proposed a model composed of 7 phases: Ideation, Requirements, Design, Implementation, Testing, Deliver and Evolution.

The Ideation phase is represented only in the second model and it corresponds to the opportunity recognition. Both Analysis and Requirements phases are related to the requirements definition as well as Design follows the technical and business specifications definition. Implementation presented by [31] is detailed in Implementation and Testing by [16]. On the other hand, Deliver phase can be related to Publishing and Operation that include activities from the deployment and dissemination to the service use. Finally, Retirement and evolution both represent the moment when the service reaches the end, having to be decommissioned or re-designed.

In [30], a work on servitization in a manufacturing environment, eight phases are identified in the service lifecycle: Ideation, Requirement, Design, Implementation, Test, Delivery, Operation and Decommission. This model is oriented by the servitization concept, what means it aims to develop a SLM linked to a predefined PLM. In this approach, the Ideation phase, whose steps are considered optional by the author, would include assessing the servitization level and identifying the servitization objective; the Requirement phase would define service engineering activities and the links with PLM; and Design phase would be composed by modeling the service system and simulating service.

In the next phases, service has its components identified and it is implemented, tested and delivery to operation until its decommissioning. In the figure that follows – Fig. 3 – it is schematized the main structures of a service lifecycle and the most import concepts of each stage.

From this comparison between well-accepted service lifecycle models, it is possible to notice that even without having a standard model for SLM, the proposed lifecycles share almost the same structure. The activities presented in the different phases must be used to complement the service details in the PSS lifecycle.

[31]	Analysis		Design	Implementation	Publishing	Operation		Retirement
[16]	Ideation	Requirements	Design	Implementation	Testing	Delivery		Evolution
[30]	Ideation	Requirements	Design	Implementation	Testing	Delivery	Operation	Decomissioning
	Oportunity, ideas [16] Service objective [30]	Feasability [31] Requir. [31, 16]	Design [31, 16, 30] Modelization [30] Simulation [30]	Building [31] Training [31] Implem. [31, 16, 30]	Register [31] Assessment [16] Test [16,30]	Delivery [31, 16] Value prop.[16]	Operation [31, 16, 30] Maintenance [31] Monitoring [31, 16]	Retirement [31] Sucession plan [31] Re-design, re-engineering, re-think; re-purpose [16]

Fig. 3. Service lifecycle models and concepts associated with each phase

4. PSS lifecycle proposal

The proposed model aims to represent the PSS as a holistic solution in which product and service are highly integrated.

Starting from the well-known and recently proposed lifecycle based on the macro phases Beginning of Life, Middle of Life and End of Life, it is possible to compare activities that were already assigned to the PSS with the ones detailed in Product and Service lifecycles, structured through the same structure.

As pointed in section 3.1, in the product point of view, BOL starts with the product ideation and it is finished when the product is handed to the customer, ready for use; The MOL, as consequence, includes product use and support; followed by EOL and the product disposal, remanufacturing, reuse or recycling.

According to [16], it is also possible to represent service lifecycle management through the macro phases of BOL, MOL and EOL, though the interfaces would not be so clear as the ones in PLM. BOL would include service ideation and requirements definition; BOL would include design and implementation; and EOL, testing, delivering and evolution.

With this comparison, it is notable that BOL and MOL phases from product and service represent different activities that in terms of PSS should be aligned; e.g., product and service design should be thought together, but they are identified in different macro phases. In order to reduce incongruence between product and service it may be necessary to create new macro phases able to represent product and service concepts simultaneously. In this sense, the macro phases proposed for this model are: Ideation and Design, Realization, Use and End of Life, as presented in Fig. 4.

The Ideation and Design phase includes the activities of identifying Product and Service opportunities, selecting the best alternative for both, and converting the holistic alternative in requirements and specifications through designing.

Realization includes both product and service prototyping, manufacturing of the physical product as well as service implementation and testing. It is finished with the delivery of the PSS to the market.

Detailing the main activities pointed in Idea and Design and Realization, it is reasonable to highlight that the order in which product and service specific tasks will happen might depend on the category of PSS.

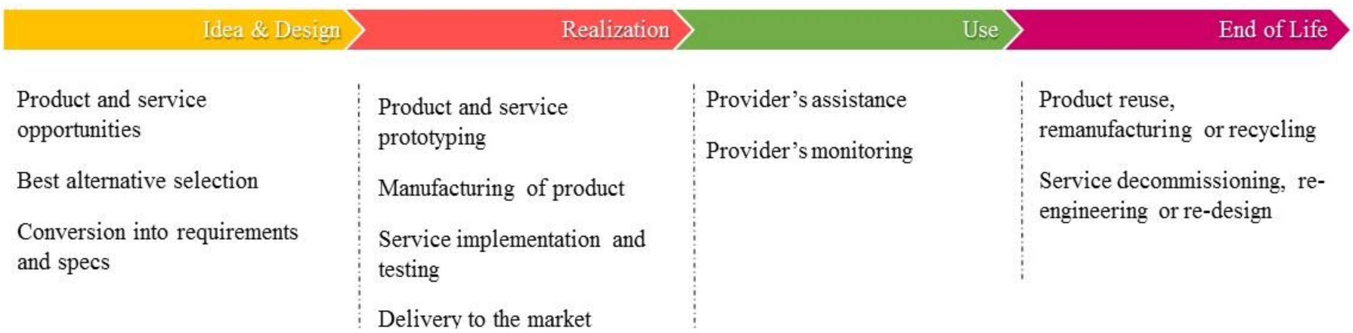

Fig. 4. Proposed PSS lifecycle model

We refer to the typology proposed by [2] to classify the PSS: Product-oriented, Use-oriented and Result-oriented. In the first one, business is still mainly geared towards sales of products with certain functions, but extra services are added. In use-oriented PSS, the product is still a central point, but the core business is not the product selling: the product stays in ownership with the provider, and its use and functions are made available and sometimes shared by a number of users. For the last category, result-oriented, the provider and the customer pre-define a result the PSS must reach, but there's no predefined product linked to this decision.

Having the definition for these different categories, it is possible to modularize the processes in the Idea and Design and in the Realization phases of the PSS according to the classification in [18].

A parallelizing approach is translated by the design and realization of product and service being conducted in parallel. They are both developed from the same idea but the activities driven in product lifecycle are not necessarily connected to the ones in service lifecycle. This approach is possible in all categories of PSS.

In an integration approach, the product and service activities have to be driven not only simultaneously but also in an integrated and iterative way. This means that there is no product without a service and vice-versa. This schema is only possible for use and result oriented models where may not configure the core part of the PSS. On the other hand, the linkage is really specific to PSS where the product is predefined and the service is developed according to it.

For the use phase, the PSS is already in possession of the customer, when the product and the service are simultaneously delivered, and it is being assisted by the provider's support. This support can be offered to the product or to adapt or change a service.

The End of Life does not change comparing to other PSS models and it includes the loss of usefulness of the PSS, making it to be retired or upgraded, what can happen through reuse and/or recycle of the product and/or decommissioning, re-design or re-engineering of the service.

5. Discussion and conclusions

This work proposes a new model to represent the lifecycle of a PSS, identifying all phases and presenting the activities that are related to them.

It was planned as a first step to formalize the exploration of data generated during product-service systems life. A structured and representative model allows a consistent mapping and categorization of current works involving data management throughout PSS lifecycle.

Being able to reset the lifecycle representation considering PSS as a system, where product and service have both important milestones, will facilitate the discovery of improvements linked to specific activities planned for the PSS.

Comparing first PSS cycles with product and service ones, we could identify the main gaps specially related to the non-alignment in the lifecycle of the two parts of this system and to the lack of details considering the service aspects, that are a more recent field of study comparing to the already stablished product and manufacturing subjects.

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