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Towards a Lean Product Service Systems (PSS) Design: state of the art, opportunities and challenges

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Abstract

As for conventional products, the profit generation and the market success of Product Service Systems (PSS) critically depend on the decisions taken during the initial lifecycle stages, when PSSs are conceptualized, designed, developed and engineered. Successful cases show the adoption of lean techniques in the early stages of products development, impelling the authors to assess the application of the same approaches also to PSS development. For this reasons the paper aims to report the state of the art of PSS Design research, relating this strategic process to the Lean Thinking approaches typically applied in traditional Product Development and Manufacturing. The literature about PSS is classified and Lean Thinking evolvement from product manufacturing to design phases is described. On this basis, the paper defines which are the aspects of Lean Thinking already applied in PSS Development also uncovering gaps and lacks of the methods proposed by the scientific literature so far. This opens the way to new opportunities and challenges through many further research and industrial projects.

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Keywords: Product Service System (PSS), Lean Thinking, Lean Product Service System (LeanPSS).

1. Introduction

In 1968, Fuchs [1] defined the Service Economy as "*one in which more than half of the total labor force is employed by the service sector*". Today, the Service Economy is the reality, with more than the 70% of global workers engaged on service tasks [2] and manufacturing companies absorbed by the "*servitization*" revolution [3].

In this, Product Service System (PSS) is generally considered as a special case of servitization, in which a manufacturing company sets its market proposition on extending the traditional functionality of its products by incorporating additional services [4] for reaching new market competitive advantages [5]. These additional services are often enabled by interconnected and embedded technologies, which permit to trace, track, monitor and control remotely the physical artefact, creating "*intelligent, smart and connected*" solutions [5]. This "*PSS smartness*" is raising a new set of strategies for customer-focused value creation, long-standing productions [5], and sustainable consumption patterns [6], while the traditional boundaries between manufacturing and services are becoming increasingly fuzzy [2]. PSSs are nowadays supporting the development of a more sustainable economy [7], switching the emphasis from the "*sale of products*" to the "*sale of use*" [4], and reshaping the same concept of customer values, from "*possession*" to "*utilization*". 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. Notwithstanding the availability of a plethora of tools and methodologies for designing PSSs defined since the '90ies in the context of Service Engineering discipline [8], most of these methods are typically a rearrangement of conventional

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processes and lack a critical and in-depth evaluation of their real performance in practice [4].

This paper aims at contributing to this last issue, proposing a discussion on how the so-called Lean Product Development discipline could support the design and development of PSSs. With this objective, the paper is organized as follow:

- Par. 2.1 and par. 2.2 present a brief state of the art on PSS and PSS design and engineering, while par. 2.3 illustrates the main elements of the Lean Product Development, as a declination of the Lean Thinking approach in the design process;
- Then, par. 3 reports a specific state of the art on how lean approaches have been so far applied to PSSs context and it opens the discussion on how a Lean PSS development could be;
- Finally, par. 4 concludes the paper and introduces the next research steps.

2. State of the art

2.1. Product Service System

As reported by Baines, 2007 [4], Goedkoop [9] gave the first formal definition of a Product Service System (PSS) in 1999, defining its three constitutional elements:

- Product: a tangible commodity manufactured to be sold, capable of fulfilling a user's need;
- Service: an activity done for others with an economic value and often done on a commercial basis;
- System: a collection of elements including their relations.

During the years, many other definitions have been introduced in literature, adding some elements to the Goedkoop's one, but keeping it as the core. Table 1 reports some of the most important citations, on a four-section basis (*Definition, Focus, System Components, Objectives*). As suggested by Goedkoop [9], PSS could consist either on a system/combination [9]–[12], to be intended sometime "*pre-designed*" [13], or an "*innovation strategy/solution*" [14], [15]. When intended as a combination, PSSs are composed by products and services with an additional support of networks and infrastructures. When instead the concept of strategy/solution prevails, PSS are intended as merely made of products and services. In these definitions, generally PSSs are made to pursue industrial competitiveness, customer satisfaction and also sustainable development [16]. Different authors (e.g. [16], [17]) have highlighted how this win-win scenario can be realized only by a careful design of the PSS, involving all the significant stakeholders since the early phases of the design stage, as reported in the following paragraph.

2.2. PSS Design

The scientific literature proposes several solutions and methods to design PSSs. We believe that the development level of PSS design is slowly evolving through a path strongly driven by the evolution of the technology and the progressive involvement of the industry in its application. However

Table 1.Characteristics of the main PSS definitions

Ref.	Definition	Focus	System's components					Objective	
[9]	'A PSS is a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models'.	system	products	services	networks of "players"	supporting infrastructure	comp etitive	satisfy customer needs	lower environmental impact than traditional business models'
[13]	'A pre-designed system of products, supporting infrastructure and necessary networks that fulfil users' needs on the market, have a smaller environmental impact than separate product and services with the same function fulfilment and are self-learning'.	pre-designed system	products	services	necessary networks	supporting infrastructure		fulfil users' needs on the market	have a smaller environmental impact than separate product and services with the same function
[10]	'A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models'.	system	products	services	supporting networks	supporting infrastructure	comp etitive	satisfy customer needs	lower environmental impact than traditional business models'
[14]	'An innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands'.	innovatio n strategy	physical products	services				jointly capable of fulfilling specific client demands	
[11]	'A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally PSS tries to reach the goals of sustainable development'.	combinat ion of	tangible products	intangibl e services				jointly capable of fulfilling specific customer needs	tries to reach the goals of sustainable development
[15]	'Product Service-Systems (PSS) may be defined as a solution offered for sale that involves both a product and a service element, to deliver the required functionality'.	solution	product	service				to deliver the required functionality	
[12]	'A product service-system is defined as a system of products, services, supporting networks and infrastructure that is designed to [be]: Competitive, Satisfy customer needs, & Have a lower environmental impact than traditional business models'.	system	products	services	supporting networks	supporting infrastructure	comp etitive	satisfy customer needs	Have a lower environmental impact than traditional business models

companies still need procedures/best practices able to improve the PSS development processes performances in a more systematic way. Hereafter, taking as reference point the state of the art on PSS design methodologies proposed by Vasantha et al., 2012 [18], we briefly report the solutions selected in this previous literature review:

- [19] proposed Service CAD, that supports design decision making evaluating the design concepts and suggesting alternatives to improve them, and ISCL (Integrating Service CAD with a life cycle Simulation), which aids quantitative and probabilistic PSS design using life cycle simulation.
- [20], proposed a method (Service CAD) and a SW tool (Service Explorer) for designing service activity and products concurrently and collaboratively during the early phase of product design, representing together human and physical processes in service activity through BPMN and evaluating them with QFD. A simulation tool has been also included enabling service designers to predict service availability [21].
- [8], using the UML 2.0, tried to introduce a systematic link between the technical-services design and the corresponding product design process.
- [22], considering any combination of product and service shares, presented a model-based approach to support an IPS² (Industrial Product Service System) designer generating heterogeneous PSSs concept models in the early phase of development, fostering the functional behavior of PSS artifacts.
- [23] proposed a methodology providing technical engineering specifications to complete precisely system requirements. Using SADT (Structured Analysis and Design Technique) representation, they used operational scenarios to fully describe the object-service system. [24] considered the different combinations of the two main aspects of Total Care Products, architecture (hardware and service support system) and business (markets, risks, partnerships, business chains, agreements, sales and distribution), trying to choose the most suitable combination of products and services to provide the best solution for all parties involved. From literature, [24] showed that the service design process is broadly similar to its equivalent in the hardware field. The proposed approach is the result of the integration of service design, simulation of services, hardware architecture, hardware and service support system costs.
- [25] introduced a design process for the development of a support service set in a two dimension space, problem space (often leading to new solutions) and design space.

Among these works, it is possible to find some common practices that are related to the typical methods and tools proposed by Lean Thinking. The next paragraph will identify these main elements, through a brief state of the art on Lean. Then, par. 3 will elaborate a comprehensive vision on how PSS design could be supported by Lean, evaluating at the same time if it could be the best candidate to operate in the development of such systems.

2.3. Lean Thinking and Lean Product Development

In "*The machine that changed the world*" in 1990, Womack, Jones and Ross introduced to the big audience the main concept of Lean Thinking [26]. Most of the book – and of the following literature for almost all the '90ies – focused on the application of the Lean philosophy to manufacturing and operations management, coining the main definition of the Lean Manufacturing concept, "*Doing more with less*" [26]. Over the years, Lean Thinking has been deeply defined and coded as a "*dynamic, knowledge-driven, and customer-focused process through which all people in a defined enterprise continuously eliminate waste with the goal of creating value*" [27], in which the costumer – and its satisfaction – should be always put in the first place, while everything not aligned to this should be considered as a waste (*muda* in Japanese). For this, Lean has been primary conceived as the practice (or group of practices) for eliminating and avoiding *muda*, adding more value to products and processes [28]. Today, after almost two decades of discussion, Lean Thinking could be well described by its main five principles (e.g. [28]):

- "*Specify value*": correctly specify value from the perspective of the end customer in terms of a specific product with specific capabilities offered at a specific price and time, indeed give the customer what he exactly want.
- "*Identify the value stream*": identify the entire value stream for each product or product family and remove the wasted steps that don't create value.
- "*Make the value flow*": make the remaining value creating steps flow continuously to drastically shorten throughput time.
- "*Let the customer pull the process*": design and provide what the customer wants only when the customer wants it.
- "*Pursue perfection*": strive for perfection by continually removing successive layers of waste as they are uncovered. Pursuing perfection refers to a process of continuous improvement.

Lean principles are nowadays diffused in a large quantity of companies, most of them at manufacturing level. The actual challenge has been to diffuse Lean Thinking all over the company, starting from creative processes, where the success of a manufacturing company is coming from. Only recently more attention has been given to the product development/engineering stage, on the motto that "*there is much more opportunity for competitive advantage in product development than anywhere else*" [29]. In their recent book (2006), "*The Toyota Product Development System*", Morgan and Liker [29] state that in high-competitive market the strategic differentiating factor is the excellence in product development, rather than the manufacturing capability. In the recent years, Lean practices in engineering have emerged as possible solutions for supporting the effectiveness (products quality improvements) and the efficiency (time to market and development costs reductions) of design and development processes. Today – after some years of debates – it is possible to identify Lean Product Development as a specific branch of Lean Thinking approach, which is based on three main elements:

- "*Waste Identification and Value Focus*" [29]: wastes need to be identified and eliminated, and non-value-adding activities kept to the minimum. The related core lean tools used can be *the 5Cs* (1. clear out, 2. configure, 3.

clean and check, 4. conformity and 5. custom and practice*), the 7 wastes* (1. Defects, 2. Overproduction, 3. Transportation, 4. Waiting, 5. Inventory, 6. Motion, 7. Processing), *visual control* and *standardization of processes*.

- "*Set-Based Concurrent Engineering*" (SBCE) [30]: in a lean design context more design alternatives are evaluated in parallel step-by-step, supporting the selection of the best solution along the process, taking care of constrains of the different involved actors and lifecycle phases (e.g. manufacturability, serviceability, environment, user experience etc.).
- "*Effective Knowledge Management*": as [31] pointed out, "*[knowledge management] is rapidly becoming an integral business function for many organizations as they realize that competitiveness hinges on effective management of intellectual resources*". IT collaborative systems (e.g. PDM, PLM, databases, web platforms) and authoring software (e.g. CAD, simulation tools, etc.) are the solutions for archiving and accessing the increasing volume and diversity of information types.

A relevant contribution has been done by [32], where Lean Manufacturing and Lean Engineering have been deeply compared on the main Lean principles (Table 2), inferring what follows:

- In the development process, "*value*" is harder to see and the definition of added value is more complex.
- In engineering activities, the "*value stream*" consists of information and knowledge, not the easy-to-track material flows.
- Due to uncertainties or interdependencies (e.g., between different analytical steps), during design stage branching or iterative flows may be beneficial (this is barely true in production).
- The "*pull*" to which the process should respond is not just the customer; in product development tasks are usually intermediate steps in an overall enterprise effort to create value.
- "*Perfection*" is even harder to reach, as simply doing the process very fast and perfectly with minimal resource used is not the final goal; efficient product development process is simply an enabler of better enterprise performance and better products.

Lean Principles	Manufacturing	Engineering
Value	Visible at each step, defined goal	Harder to see, emergent goals
Value stream	Parts and material	Information and knowledge
Flow	Iterations are waste	Planned iterations must be efficient
Pull	Driven by takt-time	Driven by needs of enterprise
Perfection	Process repeatable without errors	Process enables enterprise improvement

Table 2. Lean Thinking from Manufacturing to Engineering [31]

Starting from this state of the art, the next paragraph will debate how Lean Product Development could consider and support the design of Product Service Systems.

3. Towards Lean PSS Design

PSS design and development is a process that requires a huge effort, also in terms of technical specialization, business organization, data and knowledge management. This is due by the intrinsic complexity of such PSSs and to the different needs and expectations they are supposed to satisfy in a fast and adaptive way. The majority of the methodologies proposed in literature for PSS design and development "*have a clear heritage in Concurrent Engineering and Lean Product Development methodologies: identification of customer value, early involvement of the customer in the system design, effective communication, information sharing, and continuous improvement*" [4]. The next step to do is to understand in which way and how much this existing approach could be able to improve the development level of PSSs.

Actually, in the current literature, some contributions already applied Lean principle into PSSs context exist, even if in many cases these links have been not explicitly described. Among them, it is useful to quote and comment the followings:

- [33] focused his attention on the application of the Lean Thinking on service operations. He detected the main differences between service and industrial production, introducing some general criteria that could be provided in service companies in order to attune them with the lean approach.
- [34] concentrated their efforts on how to systematically configure PSS through a lifecycle-oriented management. The challenge laid on the development of a tool able to obtain an appropriate combination of products and services in order to develop consistent procedures for the lean continuous improvement of the PSS configuration model as well as of the material and immaterial entities composing it.
- [35] focused their attention on PSS design, starting from the statement that in the creation of a PSS, services are generally under-designed and inefficiently developed [36]. For this reason new methods emerged during the years to support service development, either alone or embedded in a PSS. [35] recognized in the Japanese discipline of Service Engineering ([19], [20]), the potential to work as a reference framework for PSS development able to integrate product and service contents with a systematic perspective. This discipline is aimed at intensifying, improving, and automating the whole framework of service generation, delivery, and consumption. Moreover, [35] ended up observing that few are the methods conceived exclusively for services (e.g. service blueprinting), while many lean-oriented tools from product and software engineering are transferred to services.
- Keeping on the same research way, [37] tried to understand how to support PSS design and development: they proposed a lean-oriented platform connecting Service Engineering methods to a support tool of LCS (Life Cycle Simulation), based on four requirements: Modularity, Stochastic Behaviour of Modules, Life Cycle Cost perspective, Social and Environmental Impacts).
- [18] did a review of 8 of the most referred PSS design methodologies and harmonised all the different points they faced, defining twenty design dimensions grouped

into six categories, most of inspired by Lean Thinking.

- Again in 2014, [38] studied the technical discipline of Service Engineering, realizing once more that most of the existing methodologies for service were mainly adapted and derived from the traditional engineering, business and computer science approaches. The proposed *SErvice Engineering Methodology* (SEEM) is aimed at balancing company's internal performance and customer satisfaction.

Table 3 maps how Lean Product Development elements (as defined in par. 2.2) are mentioned and used by the PSS design methods commented above. The most upsetting result is that all the methods involve Lean Thinking approaches even if they don't refer to them directly. In particular, *Set-Based Concurrent Engineering* (SBCE) appears to be the most appropriate approach to manage the PSS design process, even if almost none of the papers quote SBCE directly! In its essence, SBCE process should support the identification and the definition of the most appropriate integration of components and services, aiming at the resolution of the possible design trade-off along the whole development process, stage-by-stage.

PSS Design	**Lean Product Development**			
	Waste Identification and Value Focus		*Set-Based Concurrent Engineering*	*Effective Knowledge Management*
	5C	*Standardization*		
[19]	X	X	X	X
[20], [21]	X	X	X	
[8]	X	X	X	X
[22]	X		X	
[23]	X	X	X	X
[24]	X		X	
[25], [39]	X		X	
[37]	X		X	X
[38]	X	X	X	X

Table 3. PSS Design and Lean Product Development elements

Some authors have addressed the relevance of an effective knowledge management, generally proposing the adoption of IT solutions, even if just one contribution [37] proposes the adoption of a collaborative design platform typically used in engineering processes, while other authors suggest the adoption of simulation IT-based tool specifically defined for Service Engineering.

From Table 4, it is also possible to see how PSS design methods are focused to the waste elimination and value identification. All the quoted papers propose the application of methods and tools for eliminating *muda*, like the 5C approach (*Clear out, Configure, Clean and Check, Conformity, Custom and Practice*) or similar. At the same time, most of the works suggest and support standardization practices in the PSS design process. Generally, they propose to adopt common process (e.g. BPMN [20], [21], UML 2.0 [8], SADT [23], etc.) as well as standard models (e.g. QFD [20], [21]) and templates (e.g. *View model* [20]*, Service Requirement Tree* [38]). These standardization practices are normally considered as the basis for promoting continuous improvement consciousness.

A part what it is mentioned, it is interesting to notice also what it missing in the analyzed contributions, in a Lean Product Development perspective:

- At first, none of the contributions has clearly and systematically identified which are the typical *muda* to be considered in a PSS design process, while also the definition of what is a *value-added* activity is often vague.
- Second, none of the contributions is quoting SBCE, even if all of them are proposing/suggesting a design process structured according to the SBCE archetype [29].
- Third, practically no contribution is investigating/mentioning the role which could be played by computer-aided design and engineering tools already existing in the normal engineering practice.
- Fourth, the application of the proposed PSS design methodologies is most of the time at a prototype/piloting stage and no detailed guidelines on how lean-inspired mechanisms should be implemented are given.

The above open issues support a first remark: in order to improve PSS design with the support of the Lean, knowledge sharing among different academics communities (e.g. experts in PSS design, lean, computer aided engineering, etc.) is needed. Then, industrial practitioners should be as well involved in this debate, for considering the real state of practice of design processes. In an industrial context rigorous definition and representation of technologies are important: issues related to service design are increasingly being recognized by designers and managers as relevant, even though the knowledge on how to develop a PSS and who should design it is still marginal [40]. The conducted state of the art can generally confirm that most of the existing PSS methodologies have a clear heritage in Concurrent Engineering and Lean Thinking, even if there is still the need of a comprehensive approach, which groups the elements and provides powerful guidelines. Being often PSS design more or less implicitly structured according to some core Lean pillars, we believe that Lean Thinking could be the best candidate to operate in the PSS design systemization.

4. Conclusions and further researches

This paper has reviewed the state of the art in the application of Lean Thinking to PSS design. Firstly has been cleared what is a PSS and what Lean Product Development is and it differs from Lean Manufacturing. Next, an analysis of the methods presented so far in the scientific literature has been proposed: lacks and gaps have been identified uncovering the opportunities related to the design of PSSs. Former, it was possible to notice how Lean Thinking approaches are popular among the various attempts of the scientific literature to systematize PSS design, even if none of them cites it explicitly. Latter, it was possible to identify the Lean methods already adopted in PSS design and the existing gaps.

Despite of the great involvement of the academic context in PSS design, the scientific contributions as well as the industrial experiences considering also the potential role Lean Product Development methodologies and tools are still few. This means that there is room for performing further studies and which could be the challenges to be addressed. According to the performed analysis, it is possible to identify at least four of these potential research challenges:

- Which is a proper definition of what is waste and what is value in a PSS design process? How *muda* and value-added activities should be detected? Thus, what are the best practices for eliminating wastes in PSS design?

- How the SBCE paradigm should be implemented in a PSS design process? Which are the constrains and the trade-off to solve along such a design process?
- How computer-aided tools could support the PSS design process? How IT tools available in the market of engineering solutions should be used or reshaped to support the PSS design process in a lean-oriented way?

These challenges open the way to further researches. With this purpose, the just-started DIVERSITY project, a research consortium funded by European Commission, is testing and experimenting the proposed PSS design methodologies and lean principles. DIVERSITY aims to support PSSs designers, putting in place a detailed guideline for managing the process according to the Lean principles and also re-shaping market-available computer-aided tools (PDM / PLM platforms).

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