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Product–Service Systems Engineering: State of the art and research challenges

Sergio Cavalieri, Giuditta Pezzotta *

CELS – Research Center on Logistics and After Sales Service, Department of Industrial Engineering, University of Bergamo, Viale Marconi 5, I-24044 Dalmine, BG, Italy

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ABSTRACT

The design and development of a Product–Service System (PSS) raises new issues since the service component introduces further requirements than traditional product engineering. Compared to physical products, services are generally under-designed and inefficiently developed. For this reason, approaches such as New Service Development, Service Design and Service Engineering have emerged during the years to support the design and development of service either as a system itself or as a constituting element of a Product–Service System. However, only Service Engineering investigates service design and development with a systematic perspective and with a seamless integration of product and service contents. The purpose of this paper is to provide a holistic conceptualisation and an up-to-date review of the literature on Service Engineering with a specific focus on its adoption in the PSS context. A critical analysis is also performed with the aim to define a research agenda and the most prominent key actions that could give directions for future research.

1. Introduction

The evolutionary path of the business model of a manufacturing company from a pure product perspective towards an integrated product–service orientation is usually termed as *servitisation of manufacturing* [1]. A number of authors have discussed the servitisation phenomenon with a retrospective analysis by performing longitudinal studies on manufacturing companies which have endeavoured their journey along a "product–service continuum" [2]. As it is evident from the emphasis given by the related literature, servitisation is mainly motivated by a continuous strive to create new sources of value for the company, by either reactively fulfiling explicit requirements or proactively providing new integrated product–service solutions to the customer. There are several claimed benefits associated with the augmented content of services within a product [3–8]: an increase of revenues, as services tend to have higher profit margins and can provide a stable and countercyclical source of revenues; a differentiating weapon for competing in mass-markets characterised by commoditised technologies and products, a decrease of variability and volatility of cash flows throughout the life of a product, allowing for a higher shareholder value.

However, although services are thought to deliver higher margins, most organisations find it quite problematic to master the transition. A Bain and Co's survey revealed that only 21% of the sampled companies have experienced a real success with their service strategy [9]. When increasing their service offerings, they sometimes incur higher costs and eventually do not achieve the expected returns [10,11].

Overcoming this hitch represents a major managerial challenge [4]. Companies need to change their current structures and processes that are unsuitable for mastering this integrated offering. The development of a product–service solution raises new issues since the service component introduces further requirements, among which [12–14]: to go beyond the voice of the customer ensuring a connection with his emotional state of mind, his perceptions and preconceptions in a situated and changeable context [15–18]; to encompass a life cycle perspective [19,20]; to fulfil the expectations of a composite group of stakeholders calling for a more sustainable society [21,22].

A relevant stream of the literature, mainly rooted in the North-European research communities, has assigned an increasing emphasis to the role of Product–Service Systems (PSS) as a concrete response to these emerging pressures. The basic idea behind the Product–Service System concept is that it ensues from an innovation strategy, shifting the business focus from the design and sales of physical products to the design and sales of a system consisting of products, services, supporting networks and infrastructures, which are jointly capable of fulfiling specific client demands [23–25]. Several are the claimed benefits and barriers related to the adoption of Product–Service Systems, as Table 1 highlights [26].

The profit generation and the commercial success of the Product–Service System offering critically depend on its conceptualisation, design and development, even if this notion has

* Corresponding author.
E-mail addresses: sergio.cavalieri@unibg.it (S. Cavalieri), giuditta.pezzotta@unibg.it (G. Pezzotta).

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Table 1
Benefits and barriers to the adoption of PSS.

Benefits	Barriers
Setting barriers to competitors by creating a customer–supplier intimacy and mutual dependence	Need of reciprocal trust between provider and customer in shifting from a transactional to a long-term relationship
Releasing customers from the responsibilities of asset ownership	Low level of maturity and lack of engagement in the PSS market; consumers not enthusiastic about ownerless consumption
Differentiating the market offering, increasing the revenue by offering new services	Manufacturers concerned with increasing risks due to the adoption of new pricing policies, lack of expertise in designing and delivering services, change management of the organisation
Creating a more sustainable approach to business	Socio-environmental benefits not always significant

Source: Adapted from [26].

been largely ignored [27]. According to Baines et al. [26], despite the availability of a plethora of tools and methodologies for designing PSS, they are typically a rearrangement of conventional processes and lack a critical and in-depth evaluation of their real performance in practice.

This is the main motivation behind the upsurge since the '90s of Service Engineering as an emerging technical discipline whose foremost aim is to provide a "*systematic development and design of services using suitable models, methods and tools as well as the management of the service development process*" [19].

Given its increasing relevance in academic and industrial contexts with a resulting proliferation of scientific contributions and white papers, the purpose of this paper is to provide a holistic conceptualisation and an up-to-date review of the literature on Service Engineering with a specific focus on its adoption in the PSS context. A critical analysis is performed to ascertain the capability of the current literature to provide a valid response to the main issues and challenges marking this field. The final part of the paper delivers a research agenda with a list of the main key actions which in our opinion will drive relevant themes for future research investigations.

2. Engineering integrated product–service solutions: an evolutionary path

There has been an evolution in the way an integrated solution is being engineered: from sequential stage-gate based engineering to concurrent engineering. The latter refers to a work methodology based on the parallelisation of tasks throughout product development between design, engineering, manufacturing and support functions in order to reduce the elapsed time required to bring a new product to the market [28–30]. According to Hara et al. [31], an integrated offering based on either of these two approaches suffers from two main problems: (i) an increasing gap between product function and customer value; (ii) a separation of product and service activity design, since these processes are normally performed by personnel with different skills and expertise.

What is nowadays clear is that product functions and service activities should be integrated seamlessly from the early stages of value and service content generation [32,33]. Both are means for value creation, and different combinations of them can fulfil the same needs of the potential customers.

Compared to physical products, services are generally under-designed and inefficiently developed [34]. Behara and Chase [35] quip that "*if we designed cars the way we seem to design services, they would probably come with one axle and five wheels*". Most publications emphasise the importance of the development of services, but they fail to provide specific assistance on how to embed these services into the strategic and operative management of enterprises.

For this reason, many approaches have been developed during the years to support the design and development of service either as a system itself or as a constituting element of a Product–Service System. The first scientific studies about service development were introduced in Anglo-American publications as early as the 1970s and 1980s, when terms such as "New Service Development", "Service Design" and "Service Engineering" appeared in the literature.

At that time, New Service Development (NSD) began to find its way as an overall process of developing new services, from idea generation to market launch. The first contributions were mainly marketing-driven focusing on success and obstacle factors [19,27,36,37]. Despite the flourishing of empirical studies, for many years there has not been consensus on a well-formalised development process, leading to contradictory results [38]. Hence, several efforts have been devoted to filling the evident lack of research with more systematic approaches finalised to the provision of a comprehensive framework which could be considered as a reference in the field [39–43].

Also the term Service Design finds its roots in the Anglo-American literature in the same years. Unlike NSD, which is mainly focused on a marketing and strategic level, Service Design specifically addresses the structure and content of a service operation [44]. Given the nature of service, research in this field is primarily based on interaction design, especially in terms of perceivable elements of a service (e.g. colours, sounds, odours) and interfaces with the customer [45–48]. Broadly speaking, Service Design is considered an exploratory enquiry with the aim to develop a proper understanding about what is being designed and to involve end-users in creating meaning through a creative process [49]. It differs from the other disciplines, since it looks at services from an outside-in perspective, privileging the user's context rather than the internal strengths, weaknesses and potential barriers of the organisation [37,45,46,50].

The inability of these two main research streams to approach service design and development with a systematic and extensive perspective (considering both user's and organisation's requirements) and with a seamless integration of tangible (product) and intangible (service) contents has impressed further interest on the potential of the Service Engineering (SE) field.

The discussion on SE became significantly relevant only in the mid-1990s, with research initiatives in Germany and Israel. Contrary to the prevalent marketing perspective of New Service Development, Service Engineering aims to apply the engineering-scientific know-how to develop Service Systems and Product–Service Systems in a systematic and methodological way [19,27]. It is a rational and heuristic approach based on the discussion of alternatives, goals, constraints and procedures, through the adoption of modelling and prototyping methods [45].

Despite the different perspectives, the fundamental research questions investigated by these streams are even more intertwined, thus motivating a strong interaction and overlapping of the relative research communities and witnessing an increasing difficulty to categorise a single contribution in a specific area.

3. A system perspective on service engineering

In a recent survey carried out with a panel of experts, one of the most compelling issues was the scant attention given to the qualification of PSS as a system [47]. A system theory view is fundamental for a proper conceptualisation of a Product–Service System and a better understanding of the role of Service Engineering [13,51].

A system can be defined as "a collection of real or abstract interdependent entities – hardware, software, people, facilities and procedures – organised as a whole in order to accomplish a common set of goals" [52,53]. According to INCOSE (the International Council on Systems Engineering), Systems Engineering is conceived as an interdisciplinary approach and means to enable the realisation of a system and its constituent entities, interacting with the most relevant stakeholders and actors throughout the system's life cycle [54].

Sharing this definition in the PSS context, the fundamental elements to be considered for a complete understanding of Product–Service System Engineering are:

- **Entities** – Real or abstract, tangible or intangible, whose relationship forms the PSS as a whole. In our understanding, system *content* (tangible, intangible) and channel are the main entities defining a PSS [55]. The channel is used to transfer, amplify and control the contents. Considering the PSS definition proposed by Mont [23,25], the channel can be further split into *networks* of companies, that may jointly fulfil customer needs, and existing collective and private *infrastructures*.
- **Life cycle** – A successful offering and realisation of a PSS extends the involvement and responsibility of the provider throughout the entire life cycle: from the design and realisation (Beginning of Life, BOL), to the usage and maintenance (Middle of Life, MOL) and the dismission (End of Life, EOL) [14,19,56–58].
- **Actors** – Engineering services require designing business architectures in which networks of customers, suppliers and alliance partners maintain consistent levels of quality, while allowing for minor variances in ends and means. To reach this purpose, the involvement of the value chain actors is one of the main pillars of the PSS development. It is also important to define and understand the role of different actors inside and outside the process development along the whole life cycle of a system [14]. The main actors to be involved in a PSS are [21,25,59–61]:
  - *Customer/End-User*: to engineer the Product–Service, customers' needs and diversity have to be known for the identification of the requirements throughout the PSS life cycle phases. The customer can be involved either in an active, as co-designer or co-producer, or in a passive way, as a mere source of information.
  - *Channel*: all the actors involved along the channel need to be considered within the engineering process due to their intermediary role between the manufacturer and the customer [62].
  - *Society and environment:* refers to the actors operating in the PSS business ecosystem. In our understanding, they can be related to laws and regulations, which allow a proper functioning of the ecosystem.

Following the Systems Engineering definition, in order to properly engineer a system, it is fundamental to lay down the whole process that drives the development of the system until its realisation. A **process** should be grounded on a robust and structured *model* whose role is to support the development of the system through the identification of its constituent phases and the interconnection between them. A process defines "WHAT" needs to be done, without specifying "HOW" each activity is performed [52,63].

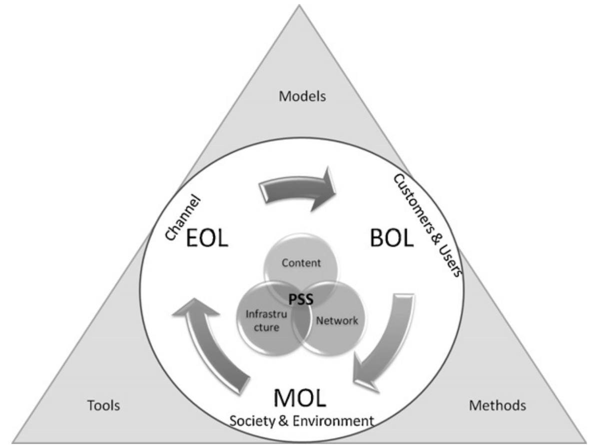

Fig. 1. A system view of PSS Engineering.

Moreover, structured practices are needed to enable each process phase to transform the inputs to valuable outputs and to manage the interaction with the different actors throughout the system life cycle. A **practice** defines, explains and integrates *methods* and *tools* in order to provide guidelines on "HOW" each activity should be carried out and "HOW" the system interfaces with its users and other systems [52,63].

A comprehensive view of the main constituents of PSS Engineering is provided in Fig. 1. They also represent the conceptual structure underlying the organisation of the literature review addressed in the following section.

4. Literature investigation on Service Engineering

To understand what has been developed in Service Engineering research and to identify open research gaps and future challenges, a research map on the most relevant literature currently available on Service Engineering and Product–Service System Engineering has been designed.

Journal articles were sourced from Scopus, ISI Web of Knowledge academic databases and web investigation. An initial keyword search for articles containing keywords such as "Service Engineering" and "Product–Service System" was performed. In addition, due to the blurred line among the adopted terminology, the keywords "Service Development" and "Service Design" were used.

From a first screening, 118 publications were selected, and a high level analysis of the abstracts and keywords was performed. At the end of this first round, a more detailed analysis was carried out on 79 publications. The selection was limited to those papers proposing models, methodologies, methods and tools under the Service Engineering perspective. For contributions related to the same research track, only one representative publication was considered. No publications older than 10 years were selected for the analysis.

In order to provide a systematic review of the articles and perform a critical analysis, each paper was classified according to the categories represented in Table 2.

Table 3 summarises a selection of the most relevant publications used in the analysis. The list does not want to be exhaustive, and it does not represent the entire list of papers reviewed. However, it aims to provide a good understanding on the topic. The selection has been performed considering the originality of the

Table 2
Main criteria adopted for classification of the papers.

Theoretical perspective	Analytical conceptual research
	Empirical experimental research
	Empirical case study
System perspective	Life cycle (phases and iteration)
	Entities (content, channel)
	Actors (society and environment, customer and user and channel)
System Engineering perspective	Process (frameworks and models)
	Practice (methods and tools)

contribution and the completeness both in terms of process development and adopted practice.

4.1. Theoretical perspective

Following the taxonomy proposed by Wacker [79], the research methods adopted by SE publications can be classified into analytical conceptual research, empirical experimental research and empirical case study.

Most of the current publications adopt *analytical conceptual methods*, since they develop new theories, models or frameworks based on a logical relationship among past theoretical assumptions, premises and axioms. These contributions typically use case studies to illustrate the proposed theories. Regarding this typology, only a few studies are available: a valuable example is the contribution by Jung and Nam [80], who attempt to find new design opportunities by qualitatively analysing relevant literature and existing cases in the contextual dynamics between service and product.

In addition, an evident effort has been produced in the adoption of *empirical experimental research*. While developing theories based on theoretical assumptions, researchers have also tried to understand whether direct experiments are able to confirm or falsify their theories [12,60,70,72,81–84]. Two of the main structured methodologies – MePSS (Methodology for PSS) [75,85] and Service CAD [55] – make use of experiments to elicit some best practices. In particular, MePSS has been experimented in two cases in order to investigate the level of effectiveness of the developed tools and to provide feedback to researchers for a further improvement of the methodology. Sakao and Shimomura [55], by the adoption of Service CAD, propose a way to design and redesign service. Applications in an existing hotel and for the design of renting home appliances are carried out in order to demonstrate how the presented methods and tools facilitate designers adding new value.

Few researches adopt *empirical case studies* with the aim to develop theory based on a limited set of companies. Burger et al. [86] derive part of their proposed maturity model on the results obtained in an industrial workshop where different companies were involved. The generic process model for PSS development

Table 3
A selection of major contributions on PSS Engineering.

Description	References
An Integrated Product and Service Engineering (IPSE) methodology for the development and production of an Integrated Product and Service Offering (IPSO).	[21,64,65]
A systematic design of technical services based on: (i) a service design phase model for the systemisation of service design on the basis of existing product design processes; (ii) a modular approach for integrating existing product and service design processes; and (iii) a method for life cycle-oriented process design.	[32,60]
A framework based on service life cycle where product life cycle is integrated into service life cycle. A basic structure for a Service Process Model (SPM), which integrates customer behaviour factors, is proposed. The output of the SPM is a set of parameters to evaluate the quantitative performance of a PSS in terms of costs, resource consumptions and a set of product or customer receiver state parameters.	[66]
A design process for total care product creation that seamlessly integrates hardware and service by proposing a robust design methodology and a process model with the definition of the design stages and of the structure supporting the decision-making process at each stage.	[33,15]
A service product engineering methodology (Service CAD) for: (i) the identification of value realisation structures; (ii) parallel design of services and products. A generic service has three elements: service goal, service environment and service channel. The content of service is delivered through service channel. By adopting the same methodology, a computer-aided service design system, named Service Explorer, has been developed.	[31,67,55]
A frame of reference for the progress of a PSS development model is proposed. FPD (Functional Product Development) is chosen to represent an engineering development point of view, thus focus is to bring in service aspects in early phases. It considers three perspectives, namely people, process and product. Taking these perspectives, the engineering team is able to combine, build on and refine ideas for new PSS solutions.	[13]
An inter-enterprise Service Engineering platform for integrating business as well as technical stakeholders in the e-service development process and supporting them in the selection and adoption of appropriate models, methods and tools.	[68]
A model which emphasises the importance of customers and their information feedbacks within an engineering process. A systematic approach based on the use of methods to identify customer needs and compare them with the skills available in the company. Role of change management and customer information to improve the strategic orientation of the so-called hybrid producer.	[69]
An engineering methodology for realising product-oriented PSS and use-oriented PSS for consumer products. Product life cycle data are acquired and transmitted to a service enabler, whose role is to make proper use of product life cycle data for the creation and delivery of effective services during a product life cycle. A software toolkit, namely Service Enabler Software Framework, has been also formulated.	[70]
A generic process model for PSS and IPS2 development, which is part of a PSS development methodology. Main features: make service development explicit, synchronise product and service development, and explain methods for an integrated development.	[71]
An architecture that comprises steps to be taken to successfully design and develop professional services. Main focus is on service planning and service conception. For each process step, the methods and tools useful to properly engineer the system are detailed.	[72,73]
A product–service design process developed through an iterative sequence of problematic and propositional phases. The problematic phases acquire as much information as possible in order to implement the conceptual and operational structure of the service, while the propositional phases are temporary configurations of the service. Problematic and propositional phases generate a process of co-evolution, which suggests that service design is an exploratory activity.	[74]
A modular methodology or 'toolkit' to guide companies through the innovation process to develop product service systems. The MePSS (Methodology for Product–Service Systems) methodology highlights the key factors of success for innovative PSS and offers a systematic framework for innovation so as to ensure that all issues have been considered.	[75]
A process model for developing product–services articulated into six broad phases. With the aim to support the testing phase, the ServLab platform has been developed. It is a holistic platform of techniques supporting the development of new services.	[76,77]
A methodology providing engineers with technical specifications in relation to the whole system's requirements as precisely as possible for the development of the physical objects involved in those systems. The proposed methodology is based on tools and formalism based on function-oriented activities and a functional analysis approach.	[78]

proposed by Müller and Stark [71] has been elaborated considering both theory and empirical findings undertaken to compare as-is processes in German industry. Pezzotta et al. [87,88], by means of a multiple case study investigation, provide some guidelines for selecting the most suitable engineering process model for a PSS.

4.2. System elements

A system is composed of real or abstract entities that have a set of interdependency that forms a whole [53]. Those entities interact along the different life cycle phases of the system with the main involved stakeholders in order to fulfil the overall system goals. Three main elements characterise a PSS. How these elements are considered in the Service Engineering literature is the core of the following analysis.

- **Entities**: According to Sakao and Shimomura [55], service content is supplied by a service provider and delivered through a service channel. Physical products can be either part of the service contents or the service channel itself. The combination of these two elements makes up the added value to the final customer. This vision, adopted from the Japanese school, is not far from Meier and Sadek [56], where the existential origin of a PSS artefact is a function, and could be represented by the constructs "IPS2-object" (Industrial Product Service System) and "IPS2-process". An IPS2-object represents the material or immaterial operand of an IPS2 artefact, while IPS2-processes complement IPS2-objects. Only the combination of the two elements can generate a functional behaviour [17].
- **Life cycle**: An exact separation between product and service elements is no longer feasible, neither during the design and development nor during the delivery and use phases. In this sense, over the life cycle a PSS creates a win–win situation for all the stakeholders involved in the process [17,19]. Manufacturing firms, in order to increase revenues, have to provide services during the complete life cycle of the physical product, such as operations on the installed base [2]. A successful offering and realisation of a PSS extends the involvement and responsibility of the provider throughout the entire life cycle [14,19,21,56,58,71]. This means that companies have to shift their focus from merely designing and selling products, to supporting and accompanying their usage and end-of-life. What is really evident from the analysis of the approaches, and the phases they consider during the engineering process, is that they are focused mainly on an in-depth and detailed investigation of the Beginning-of-Life phase (e.g. [12,33,55,72,74,83,84,89]). Only a few approaches have been conceived with a whole life cycle perspective of the development process and of the related methods and tools (e.g. [20,21,32,58,64]). An example is the Integrated Product and Service Offering (IPSO) concept [21,57] and the contribution by Aurich et al. [19,32,60] in the application of the Life Cycle Engineering and Life Cycle Assessment theory to the PSS development.
- **Actors**: Product–Service Systems are forcing a new understanding of relationships, and many stakeholders are involved in the provision of sustainable and ecological solutions [17,19,25,59,65,90,91]. However, to consider customers and stakeholders as key resources, the development process has to be redefined, and new activities must be encouraged throughout the life cycle phases. The aim in service development is to create prerequisites for long-term profitable customer relations, and to attract and keep customers who are satisfied and loyal along the different life cycle phases.

  Several contributions claim the utmost relevance of involving customers and users as co-designers and part of the service results [16]. However, their role is often confined to being a source of information through a dialog process, and their active participation in the engineering process is limited to the definition of the requirements.

  The other stakeholders (internal and external to the organisation) are even less committed. Main relevant exceptions are the role of internal stakeholders in the engineering process developed within the MePSS [75] and of supply and service chain actors involved in Service CAD [92].

4.3. System Engineering perspective

Research in the engineering environment is traditionally grounded in those contributions whose main purpose is to define "WHAT" (as a process) needs to be performed, and those elaborating "HOW" (as a practice) to support each single activity.

A Service Engineering process model specifies the sequences and the iterations of the process phases and the related engineering activities. In Systems and Software Engineering, a number of process models has been proposed, mainly based on three seminal models [52,54]: the Royce's Waterfall model [93], the Boehm's Spiral model [94,95], and the Forsberg and Moog's "V-model". A detailed description of these models is reported in Table 4.

Even if the proposed models have been conceived specifically for the PSS development, most of them are based on the classical system engineering process model structure. Almost all the acknowledged Service Engineering process models [15,33,58,60,68] can be classified under the "waterfall" heading. Due to their straightforward nature, waterfall models are currently the most widespread ones among theoreticians and professionals [27].

Starting from a different perspective, Muller and Stark adopt the V-model TX engineering process [71]. Its main peculiarity is the stronger emphasis on the planning and project definition at the left branch, while after the verification and validation phases on the

Table 4
Development process models.

	Definition	Main references in the PSS literature
Waterfall model	A sequential design process in which development is supposed to proceed linearly through the phases of requirements analysis, design, implementation, testing (validation), integration and maintenance. The Waterfall model is a step-by-step method. Eventual feedbacks involve only the immediate previous phase.	[15,33,58,60,68]
V-model	A product-development process which describes the sequence of steps in a project/solution life cycle development. The left side of the "V" represents the decomposition of requirements and the creation of system specifications. The right side of the "V" represents integration of parts and their verification.	[71]
Spiral model	The original spiral development model [94] is defined as a risk-driven process model generator that is used to guide a multi-stakeholder concurrent engineering of systems. It has a main distinguishing feature: a cyclic approach for incrementally growing a system's degree of definition and implementation while decreasing its degree of risk.	[82]

Table 5
Analysis of engineering process models.

Phases	Models										
	Alonso-Rasgado et al. [15]	Alonso-Rasgado and Thompson [33]	Bullinger et al. [27]	Magnusson [97]	MePSS [75]	Morelli [74]	Aurich et al. [60]	Aurich et al. [19]	Sakao and Shimomura [55]	IPSE [57,64]	NSD Fraunhofer [68,86]
BOL											
Requirements generation				Initiation	Strategic analysis	Value proposition		Planning	Making a preliminary flow model		Idea management
					Exploring opportunities						
Requirements identification							Customer demands identification		Describing the target receiver Describing the value		
Requirements analysis			Requirements analysis		PSS idea development	Material analysis	Feasibility analysis			Need and requirements analysis	Requirements analysis
Concept generation and evaluation	Concept creation			Idea creation						Concept generation	
Concept development and evaluation	Identification of subsystems	Concept	Idea generation and concept development		PSS concept development	Definition of the product/service structure	Concept development			Check and contract	
Embodiment design and evaluation	Integration of subsystems					Use-case development (use hypotheses)			Generating a realisation structure		
Detailed design	Modelling service systems					Prototype architecture	Service modelling	Development			Service design
Test (prototyping/simulating)						Test					Service test
Final design		System design		Delivery	Development and implementation of PSS design	Final definition	Realisation planning		Modifying the flow model		
Implementation and measure	Testing service systems implementation	Testing and implementation	Implementation	Evaluation			Service testing	Manufacturing		Concept realisation	Service implementation
MOL											
Middle of life			Market launch					Usage		Use and maintenance	Market launch
Monitoring and evaluation			Post-launch interview								
EOL											
End of life support								End of life		Take back	
Monitoring and feedback analysis											

right branch, the phases fade out from development into use and delivery.

Regarding the Spiral model, its adoption in the Service Engineering area is still quite negligible [27,82]. As an example, Boughnim and Yannou [82] proposes a model, based on the service blueprinting taxonomy, for the development of PSS. The potential relevance of this approach resides on the formal relevance given to the iteration process [96].

Both the V-model and the Spiral model can be classified as iterative models. They present a high number of testing phases and therefore are suitable for complex services because in each step there is the possibility to return to a former step. Another type of iterative process model is the Aachen Quality Management Model, whose aim is to harmonise corporate skills with strategic objectives in order to achieve a highest possible overlap with customer requirements. It has been used as a reference model by [89] to support the service orientation of companies and to make product–service solutions profitable.

Going more into the detail of the main process phases and of their mutual logical relations, it is apparent how there is still a plethora of proprietary process models, each providing a different nomenclature and a specific relevance to the engineering phases. As a result, a common taxonomy of the steps needed to engineer a PSS is not yet available (e.g. [21,27,32,33,58,64,71,72,74,81]).

An analysis of the most renowned Service Engineering process models is provided in Table 5. An extensive list of phases along the life cycle has been elicited by merging the single proposals. As it is possible to infer from the same table, the most relevant phases investigated by these models are mainly related to the Beginning of Life with a great emphasis on all the requirement activities. Phases, such as Use, Maintenance and End of Life, have been considered only by recent publications, showing their increasing relevance in the development process [19,57,64].

Another significant part of the literature has provided contributions on "HOW" the process phases and related tasks have to be carried out through the adoption of appropriate practices, in terms of methods and tools required to perform the single activities and phases.

However, a small number of methods have been developed specifically for service and PSS design, development and engineering (e.g. Service Blueprinting and ServQual). The most adopted ones derive from traditional engineering, business and computer science disciplines. Table 6 provides a list of the most acknowledged methods.

In the last years, several authors have tried to systematise the different available methods with the aim to elaborate a normative model and to give a complete view on how the different phases of the engineering process can be carried out by the usage of an

Table 6
Most adopted methods in the PSS Engineering literature.

Method	Main supported phase	Purpose of application
Quality Function Deployment (QFD)	Requirements generation Requirements identification Requirements analysis	To translate customer requirements into engineering characteristics in product or service design [98] To measure the contributions of new service ideas to strategic service objectives and to detect gaps in the existing portfolio [12] To design a service that meets customer's needs [99]
Critical Incident Technique (CIT) and Sequential Incident Technique (SIT)	Requirements generation Requirements identification	To use a procedure for collecting respondents' previous observations or experiences and then classifying them [100] To identify individual process steps along the service creation and to analyse where customers and suppliers are in direct contact [72]
TRIZ	Requirements analysis Concept development and evaluation	To identify, generate and evaluate possible solutions to service problems in the engineering process [84] To optimise the idea generation process to support the shift from "intuition" to "formal development" [91] To reduce the risk in the service development phase to deliver breakthrough sustainability concepts [101] To predict what are the most likely improvements that can be made to a given PSS [102]
Analytic Network Process (ANP) Analytic Hierarchical Process (AHP)	Requirements analysis Concept development and evaluation	To evaluate new service concepts [83] To determine the initial importance weights of engineering characteristics considering the complex dependency relationships between and within customer requirements, product and service engineering characteristics [98] To measure the degree to which a receiver recognises value or cost of a PSS offer [67]
Pairwise Comparisons	Requirements generation Requirements identification Concept development and evaluation	To evaluate the feasibility of new service concepts with an ANP model. Pairwise comparisons are made to define the importance of the goal [83] To support the rating of engineering characteristics' final importance [98] To prioritise customers' requirements [72]
Service Blueprinting	Embodiment design and evaluation Detailed design Final design	To clarify the influence of service processes on the receiver [31] To model all processes, actions and interactions inside and outside the company [82] To transfer functions into service processes [72]
FMEA (Failure Mode and Effects Analysis)	Test (prototyping/simulating)	To provide a detailed analysis of potential risks associated with service delivery processes [72]
Functional Analysis	Detailed design Test (prototyping/simulating)	To map all the elements of a particular solution. Both physical elements and service units are detailed and linked [103] To define the sequence that allows precision of the specifications of the product–service to deliver [104]
ServQual	Concept generation and evaluation Implementation and measure	To uncover different kinds of gaps in the service offers and to explain the perceived quality of service as deviation between expected service outcomes and perceived service outcomes [105]

appropriate set of methods and tools. Kim and Meiren [58] in their analysis provide a list of phases and related methods for service development. Luczak et al. [72] propose an architecture that comprises steps and the related methods and tools to be taken and used to successfully design professional services. Kett et al. [68] develop a framework with the aim to elicit key design practices and artefacts to the planning of e-services. Torney et al. [106] present an activity-based framework for the classification of service development and implementation methods and tools.

Moreover, the whole service development process needs the support of life cycle methods such as general project management methods (i.e. time and work scheduling or team coordination) [67,104] and strategic management methods [68,75].

To deploy these methods in the real context, tools are also needed. It is evident that there is still an evident gap in this domain [19,58]. The two most known and structured IT tools that are already used in practices are ServLab [76] and Service Explorer [67]. They are really different in terms of perspective and objective, even if both of them are mainly focused on the Beginning of Life and on the integration of the customer requirements and needs in the creation of value.

ServLab offers a new approach to Service Engineering. It is a holistic platform of techniques for the development and design of innovative services [76]: acting out a new service using a virtual reality (VR) environment; planning and testing work organisation methods and measures; developing, demonstrating and communicating new concepts of interaction between service providers and service clients; visualising new service concepts through projecting an appropriate VR backdrop to create and manipulate an environment that is as close as possible to actual or intended reality. The applicability of such a tool has been proven by some in-depth studies performed by the Fraunhofer Institute in different sectors, among which are digital systems and hospitality management [76,86,107].

Service Explorer [67] is a computer-aided modelling tool for Service Design. Designers can describe services and register them in a database. They can operate the service in the following ways: express a service model; edit the models; evaluate the total service by means of assigning each value of the components; search suitable service models in the database such as analogous services and partly related services. An application in the tourism industry demonstrates how the designed solution increases customer satisfaction while the environmental burden is reduced. Another smaller-scaled application proposed by the authors regards the design of renting home appliances.

Only a minor group of authors has developed consistent methodologies both in terms of ''WHAT'' and ''HOW'', such as the MePSS, the Service CAD and the IPSE [54,64,75,108]. These methodologies have also identified the need to support their theoretical approach with the creation of a specific IT tool with the aim to transfer the theoretical knowledge into concrete industrial applications.

An unambiguous vision is not yet disclosed. What underlines the bewilderment around the subject is the complete absence of established *reference process models*. So far, there are no methodologies, models or frameworks developed under the PSS Engineering label that have become either an ISO standard or a globally recognised reference. Conversely, this evolution has already occurred in adjacent fields such as IT service management and software development and engineering with ITIL (Information Technology Infrastructure Library) [109], DSDM (Dynamic Systems Development Method) [110] and CMM/CMMI (Capability Maturity Model) [111]. Contributing is also the fact that manufacturing companies have no explicit service development processes but they mainly adopt intuitive and rudimentary approaches [60].

Finally, relatively few service-specific methods exist (e.g. service blueprinting), while methods and tools from product and software engineering are transferred to services instead (e.g. TRIZ, QFD, FMEA). However, due to the high degree of intangibility available in every PSS and the relevance of customer involvement and interaction, the adoption of product and software engineering approaches seems to not achieve the goals in many cases [47].

5. Discussion and conclusions

The critical analysis so far performed had the main purpose to recognise the level of understanding of the current literature of the most prominent aspects characterising this novel research field. Service Engineering has been deconstructed into its basic elements: the history and origins, the research methods, its main elements and relationships. The analysis has allowed a conceptual restructuring of the topic for a clearer comprehension and to assess how it is addressed in the literature.

A list of the major critical points identified along the review is reported in Table 7.

Manufacturing companies still adopt approaches based on a traditional engineering perspective to design and develop their integrated solutions. They engineer the ''tangible'' part and then adopt intuitive processes and methods to develop the ''intangible'' elements. The value obtained is therefore not optimised because it is an un-structured combination of ''*something methodologically and systematically approached*'' [27] and ''*something rudimentally developed*'' [47,112,113].

Why does it still happen? Is it a problem of the research field, which is far from being a mature discipline providing complete and concrete solutions? Or is the company mindset, still affected

Table 7
Main evidences and issues.

Evidences and issues	Motivation
Ranking of publications	Few publications have been published in high-ranking journals, even if a step-wise increase is evident. Due to the novelty of the field, most interesting publications reporting new ideas are mainly available in conference proceedings
Terminology	A common terminology in the design and development of integrated solutions is not yet available, since an overlapping of meaning among terms is evident
System elements	A comprehensive approach able to encompass all the different system elements of PSS Engineering process is missing, even if several efforts have been produced in this direction. A multi-disciplinary orientation is one of the core aspects for embracing and integrating the different perspectives of the system elements
Reference frameworks and models	A common understanding on how it is possible to systematically deal with the field is not yet available. Due to the absence of a reference model and framework, most of the literature still dwells on their definition and on the identification of the most suitable supportive methods
Methods and tools	A strong effort is evident in the development of specific IT tools able to support the practical adoption of the Service Engineering methods. However, few working tools are available and also adopted in real contexts
Industrial practice	The practical application of existing theories in industry is really occasional, as the absence of empirical applications demonstrates. Few of the existing theories and researches report detailed practical implications

by a technocratic culture, which overlooks the need of a methodological and systematical engineering of the intangible elements?

An additional investigation has been performed by adopting the framework proposed by Harland et al. [114] for assessing the evolution of a research field from its first theoretical hypothesis to the development of a structured discipline. The framework considers three main parameters of evolution: coherence, quality and impact. Starting from the methodology developed by the same authors and drawing on the outcomes reported in Table 7, the following evidences can be summed up:

(1) *Coherence*: this driver evaluates the existence of a common focus in the research field, as opposed to a multiplicity of paradigms. Nowadays, the Service Engineering field cannot be defined as "coherent", mainly due to the absence of a common terminology and of a shared framework which can be considered as a standard in the field.
(2) *Quality*: among others, this parameter relates to the quality of publications, considering also where they have been published. From the extensive literature review conducted in this paper, it is evident how a high number of contributions origin from conference proceedings rather than from well ranked scientific journals.
(3) *Impact*: this measure refers to the grade of application of the existing theories both in the research field and in the industrial context. From our analysis, the majority of contributions are mainly paper-based with scattered applications in real industrial contexts.

From these evidences, it seems apparent that Service Engineering is still at an infancy stage of the discipline life cycle and many definitional elements are still under development. One of the main difficulties is that Service Engineering mainly adopts models, methods and tools originally applied in other research fields, either from traditional engineering or pure service marketing areas. As already discussed in Section 2, the dividing lines among Service Engineering, New Service Development and Service Design are weak due to the strong co-habitation of marketing, engineering and design knowledge in all three fields. This is fascinating because it can support new ideas through cross-fertilisation and breakthrough innovation. However, at the same time, the consolidation of Service Engineering as a discipline, integrating seamlessly such a variety of fields, knowledge and perspectives, requires the coverage of a long evolutionary path. Researchers involved in this exploration should be aware that they are embracing a plurality of disciplines, in most of the cases distant from the "traditional" engineering perspective.

As it has already happened in other disciplines considered at a good level of maturity (as for example Systems Engineering), the integration of different perspectives is also needed in order to identify a reference framework of processes and practices based on real problems. A reference framework has the aim to harmonise the research actions and the industrial investigation of the scientific community. Moreover, it is even an important means for taking over the cultural difficulties and barriers of the stakeholders and their lack of engagement. They are fundamental actors in their crucial role as co-designers and co-producers of the PSS solution.

Several are the challenges for the scientific community working in this area. In order to empower and recognise Service Engineering as a discipline, five relevant key actions will cast a prominent position in the formulation of a research agenda:

- to overcome the blurriness between the various disciplines involved in Service Design and Development, a sound and unambiguous statement of their boundaries should be formalised;
- to support the consolidation of research on a common ground and to foster a factual application of the Service Engineering discipline in the industrial world, all the research efforts should converge towards the definition of a shared reference framework (in terms of processes and practices) which could turn into a recognised standard for the community;
- to provide an effective and immediate return of research findings into pragmatic knowledge, there is the compelling need to elicit good practices with a clear understanding of the applicability of the methods; this would pave the way for their subsequent deployment into commercially available IT tools;
- to overcome the technocratic culture in the industrial organisation, the emerging profile of the Service Engineer should find its proper location in the organisational chart with the same level of decision-making responsibilities and prerogatives as the traditional product engineers;
- the professionalism and competence of such a profile should be grounded on a solid academic background; this requires a further consolidation of the Service Engineering knowledge through the delivery of purposely designed graduate and post-graduate courses.

In our opinion, these research lines will contribute to a better understanding and clearness of the scope of research in the Service Engineering domain and will provide a common identity for the scientific and industrial community operating in this promising field.

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Sergio Cavalieri is Full Professor of Operations and Supply Chain Management at the University of Bergamo. He is Director of CELS (Research Center on Logistics and After-Sales Service), former coordinator of an Italian joint industry-academic After Sales Service Management Forum and Co-Director of a post-graduate Executive Master on Industrial Asset Management. He is author of 4 books and more than 90 papers published in international journals and conference proceedings. He is member of IFAC – TC 5.1, member of IFIP – WG5.7 and former member of the Technical Development Steering Committee of the Supply Chain Council.

Giuditta Pezzotta is Research Fellow at CELS (Research Center on Logistics and After-Sales Service) at the University of Bergamo. She received her PhD degree in Management, Economics and Industrial Engineering from Politecnico di Milano in 2010. Through her work at CELS, she is involved in several industrial and research projects related to the Product-Service field within the Automotive section of the ASAP Service Management Forum. Her current research interests are Service Engineering and Product-Service System.