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State-of-the-art of design, evaluation, and operation methodologies in product service systems

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ABSTRACT

Product service systems (PSS) – integration of products and services – with aims to achieve economic profit and reduce environmental impacts, is a hot issue in academia. The purpose of this study is to comprehend the state-of-the-art in the field of PSS design, evaluation, and operation methodologies (PSS-DEOM) by conducting a systematic literature review. Up to 258 publications related to PSS-DEOM were reviewed and divided into three categories: PSS design methodologies (PSS-DM), PSS evaluation methodologies (PSS-EM), and PSS operation methodologies (PSS-OM). Based on the findings, future research trends were proposed and discussed.

Contents

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1. Introduction

The concept of product service system (PSS), also named as "functional sales" [1], or "functional products" [2], was proposed by the United Nations Environment Program (UNEP) in the late 1990s. Its core idea is to provide solutions to customers by integration of "products" and "services", meeting customers' requirements while reducing resource consumption and environmental impact at the same time.

Under traditional manufacturing modes, manufacturers usually spare no effort to promote product sales in order to earn more money and increase their market share. They seldom pay attention to the products' end-of-life, which usually results in waste of limited resources and environmental problems. With the approaching of economic globalization and much fiercer competition, more and more manufacturers realize that the possibility of making profit by selling products is rather limited and it is hard to maintain competitive advantage. In this case, they are considering business model transformation, integrating products and services which can not only improve efficiency but also result in positive economic and environmental impacts. In service-oriented business models, the way for service providers to make money is related to their services and in this case, products turn to be a part of operating costs. Therefore, they will try their best to prolong the life of products and increase use frequency. Undoubtedly, this will reduce material flow in the economic system and improve customer satisfaction.

Up to now, many scholars [3–5] have conducted PSS review through different perspectives. To implement PSS successfully, we need to present the bottleneck of research in this field very well. With the intention to understand state-of-the-art of PSS design, evaluation, and operation methodologies (PSS-DEOM for short), we would like to address this issue by conducting a systematic literature review to demonstrate how PSS is designed, evaluated, and operated in business practices. With the aid of Scopus database, we selected 258 publications related to PSS-DEOM. After a systematic literature review, we carefully analyzed the proposed methods in PSS and discussed future research trends.

This paper is organized as follows. Section 2 deals with methodology applied in the study, including selection and analyses of references. Findings and results are listed in Section 3 through the following three categories: PSS-DM, PSS-EM, and PSS-OM. Based on this, future research trends are proposed and discussed in Section 4, and Section 5 concludes the paper.

2. Methodology

2.1. Selection of references

Tukker [5] developed a method to search PSS publications with the help of Scopus database. We adapted his method and selected references in two steps. Firstly, we searched with different terms of product service system with the aid of Scopus database, which contains abstracts and citation information of articles published in scientific journals, books, and conference proceedings, covering a wide research range from science, technology, medicine, to social science, arts and humanities. It can also track and analyze particular paper intelligently with a visual presentation of the results. Compared with Web of Science and Google Scholar, as an ideal tool for electronic literature search, Scopus includes extensive journals and topics. Initial search with "product service system" (with quotation marks to restrict searching) generated 836 documents (status on 8 May 2015). To focus on high-quality articles, documents were refined to journal articles, which produced 281 articles. Besides, we focused only on English articles for easiness of comprehension, and this resulted in 251 articles. Moreover, citations of these publications were used as an important criterion under the assumption that articles with zero or only one citation would not be influential enough to be considered. This procedure reduced the amount of articles to 183. Since the purpose of this study is to focus on PSS-DEOM, these 183 publications were double checked on the basis of titles and abstracts to determine whether they were related to PSS-DEOM or not. This produced 125 articles ultimately. Full texts of these 125 articles were downloaded for further research. Similarly, we applied other search terms such as "extended products", "servitisation", "functional sales", "hybrid offerings", "product service bundling", and "value bundle" with an intention to be all-inclusive and repeated the above searching strategies. Note that different search terms may result in similar articles. It is quite necessary to pay special attention to those duplicates and omit them. Table 1 shows initial search results and filtered articles as to different search terms. The total number of filtered articles is 139, with 76 related to PSS-DM, 19 to PSS-EM, and 44 to PSS-OM.

Tukker [5] assumed that the authors with most frequently cited papers and most PSS publications would be the leading figures in PSS research. Based on this assumption, we conducted further search by checking the publication record of the authors of top 10 papers by citation ($\geq$55) in Scopus and top 10 authors who

Table 1
Initial search results and filtered publications for different search terms (status on 8 May, 2015).

Search term	Total publications	English journal articles	Publications ($\geq$2 citations)	Filtered articles			
				Design	Evaluation	Operation	Sum
Product service system	836	251	183	71	18	36	125
Extended products	295	155	118	1	1	0	2
Servitization	217	66	39	0	0	7	7
Functional sales	13	4	4	2	0	0	2
Hybrid offerings	16	10	5	1	0	0	1
Product service bundling	4	2	1	0	0	1	1
Value bundle	23	8	4	1	0	0	1
Total	1404	496	354	76	19	44	139

Table 2
Further search results and filtered publications for different search terms (status on 12 May 2015).

Name	Total publications	Publications with 2 or more citations	Filtered publications			
			Design	Evaluation	Operation	Sum
(a) Top 10 authors of most cited papers						
Mont, Oksana K.	32	22	1	0	5	6
Baines, Tim S.	50	43	6	0	5	11
Tukker, Arnold	53	43	1	0	0	1
Meier, Horst	107	43	4	1	2	7
Neely, Andy D.	62	46	1	5	2	8
Aurich, Jan C.	141	55	6	0	0	6
Maxwell, Dorothy	4	3	0	0	0	0
Morelli, Nicola	10	4	0	0	0	0
Roy, Robin	24	17	0	0	1	1
Sum 1	483	276	19	6	15	40
(b) Top 10 authors with most PSS journal articles						
Durugbo, Christopher	40	12	1	0	1	2
Roy, Rajkumar	145	69	8	0	3	11
Sakao, Tomohiko	69	35	13	3	5	21
Alcock, Jeffrey R.	70	48	1	0	0	1
Jiang, Pingyu	183	87	6	0	3	9
Shimomura, Yoshiki	143	48	15	5	2	22
Evans, Stephen P.	30	13	1	0	0	1
Huang, George G.Q.	251	160	3	0	0	3
Geum, Youngjung	30	14	4	0	2	6
Löfstrand, Magnus	23	10	1	0	2	3
Sum 2	984	496	53	8	18	79
Total (=sum1 + sum2)	1467	772	72	14	33	119

published most PSS journal articles. This resulted in 1467 publications in all (as shown in Table 2). To focus on more influential articles, we only took those with two or more citations into consideration. This reduced the amount of publications to 772. The titles and abstracts of these 772 publications were checked manually to determine whether they dealt with PSS-DEOM or not. This filtered 119 PSS publications, with 72, 14, and 33 related to PSS-DM, PSS-EM, and PSS-OM respectively. Therefore, a final list of 258 **(=**139 + 119) papers was obtained, in which 148 (=76 + 72, 57%) could be assigned to PSS-DM, 33 (=19 + 14, 13%) to PSS-EM, and 77 (=44 + 33, 30%) to PSS-OM. It is quite interesting to note that top 10 authors of most cited papers (a) are quite different from those top 10 with most PSS journal articles (b), as shown in Table 2. It is also noteworthy that among the top 10 most cited papers, 2 were published by Tukker [6,7]. Therefore, the repeated item was removed and there were only 9 rows in part (a) of Table 2.

2.2. Analyses of references

It is interesting and productive to analyze the selected articles including their publication time, author(s), cited information and journals in which they are published. Fig. 1 demonstrates the number of PSS-DEOM publications over the past 15 years. PSS-DEOM publications are increasing year by year, which proves that researchers are paying more and more attention to this problem. Before the year of 2005, PSS-DEOM research was at the initial stage of development and there were not many articles published. Between 2006 and 2008, there was a steady increase of PSS-DEOM related articles. The year of 2009 witnessed an obvious growth of PSS-DEOM publications, reaching three times more than the previous year. In the following three years from 2010 to 2012, it remained a rather steady development. From 2013 on, PSS-DEOM publications began to fall; most possibly, this can be attributed to the maturity of this field. Besides, it is obvious that publications in PSS-DM are much more than the sum of PSS-EM and PSS-OM. The reason of this phenomenon is that many proposed PSS-DM are evaluated in the same paper in which they are proposed, resulting in the rather limited number of PSS-EM.

Table 3 lists PSS articles by journals. Journal of Cleaner Production ranks first with 36 PSS articles, which is followed by International Journal of Production Research and Journal of Manufacturing Technology Management with 17 PSS articles respectively. Table 4 shows the top 10 PSS journal articles by number of citations. "Clarifying the concept of product-service system" by Mont O.K. ranks first with a citation of 395 and "State-of-the-art in product-service systems" by Baines T.S. ranks second with a citation of 384, representing their dominant places in PSS research.

3. Progresses in PSS-DEOM

The purpose of this study is to promote our comprehension of PSS-DEOM through a systematic literature review. However, the great number of selected publications makes the analysing process somewhat difficult. It is therefore quite necessary to categorize these 258 publications into three categories: PSS-DM, PSS-EM, and PSS-OM. To be objective, we assigned three different people to read titles, abstracts, and key words of the 258 downloaded articles and

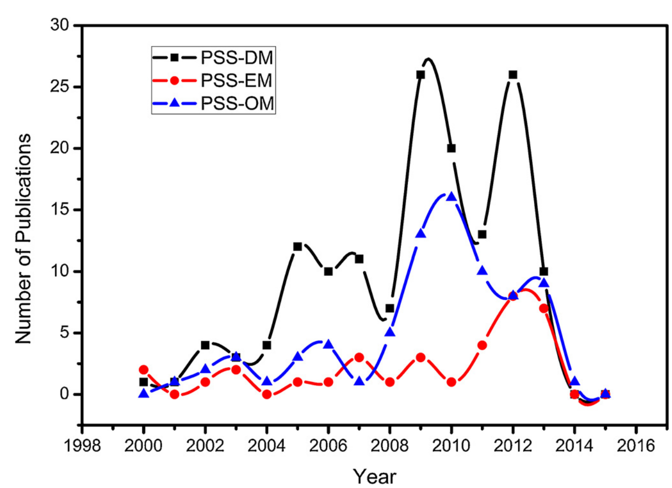

Fig. 1. Distribution of PSS-DEOM publications over time (status on 8 May 2015).

Table 3
PSS articles by journals (status 8 May 2015).

Ranking	Source title	Number
1	Journal of Cleaner Production	36
2	International Journal of Production Research	17
3	Journal of Manufacturing Technology Management	17
4	CIRP Journal of Manufacturing Science and Technology	14
5	International Journal of Advanced Manufacturing Technology	11
6	CIRP Annals Manufacturing Technology	9
7	Computers in Industry	9
8	International Journal of Internet Manufacturing and Services	7
9	International Journal of Product Development	7
10	International Journal of Operations and Production Management	5

decided which category they fall in. Besides, the analyses were established on inspection of each articles' conclusion and discussion section. Each of these three categories incorporates different perspectives according to number of articles found in that particular perspective. It is easy to foresee that there may come out contradictory opinions. Under this kind of circumstances, all the authors were required to read the whole article, and discuss in order to reach a satisfactory conclusion. After this step, we found six perspectives in PSS-DM: customer perspective, modeling techniques, visualization methods, modularity, TRIZ, and system dynamics. We discussed PSS-EM through three perspectives: customer value, sustainability, and trade-offs between perspectives. And PSS-OM can be divided into five perspectives, i.e., knowledge management, barrier analysis & fault monitoring, business models, technology, and policy perspective. Fig. 2 demonstrates the hierarchy system of this review.

3.1. PSS design methodologies (PSS-DM)

In the transition process toward PSS, manufactures need the assistance of tools, techniques, and methods to provide superior service to customers. Researchers have proposed many PSS design methodologies with similar intentions and different ideas. It is of great importance to study them and make an appropriate choice. After a systematic literature review, we found that design methodologies in PSS fell into six perspectives: customer perspective, modeling techniques, visualization methods, modularity, TRIZ, and system dynamics. Table 5 shows some PSS-DM and their contributions.

Table 4
Top 10 PSS journal articles by number of citations (status on 8 May 2015).

Year	2002	2007	2004	2010	2008	2006	2003	2006	2006	2000
No. in reference list	[8]	[3]	[6]	[9]	[10]	[11]	[12]	[7]	[13]	[14]
Citations	395	384	234	185	162	160	147	138	108	94

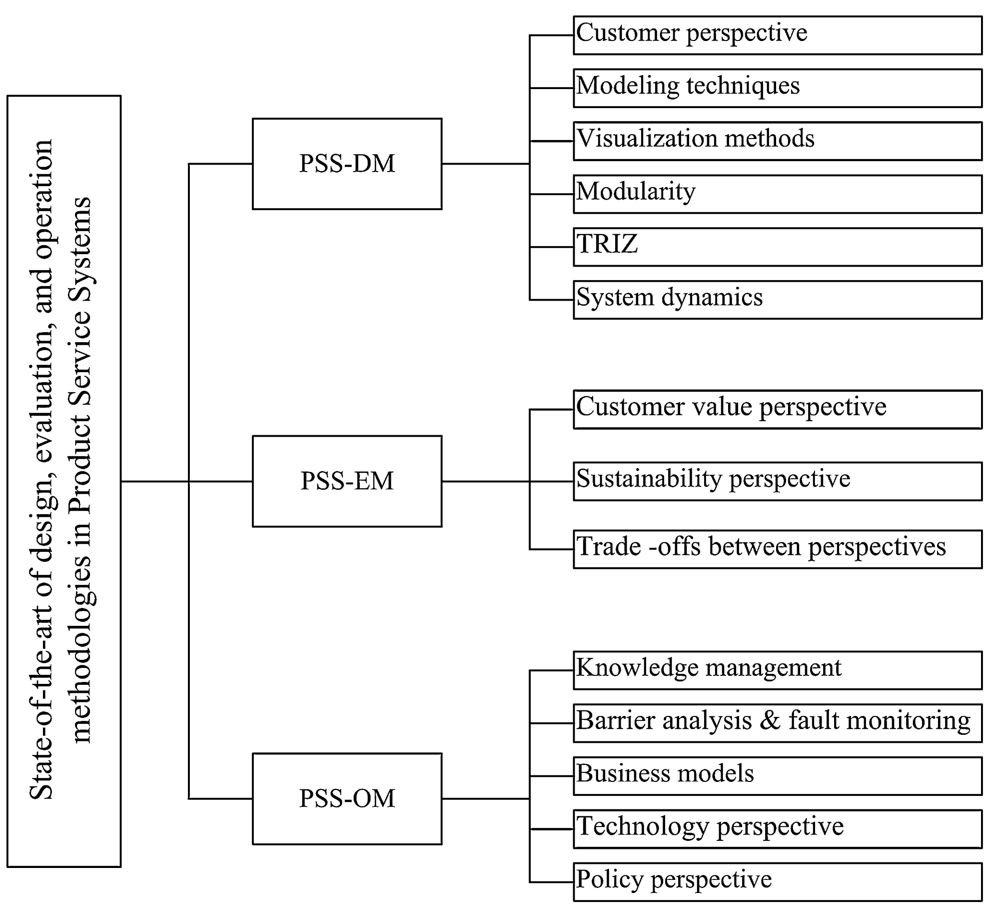

Fig. 2. Hierarchy system of the review.

Table 5
Some PSS design methodologies.

Perspectives	Author(s)	Contribution to PSS design methodologies
Customer perspective	M. Berkovich et al.	A Requirement Data Model (RDMod) for PSS.
	W. Song et al.	"Industrial Customer Activity Cycle" and rough group AHP.
	M. Rese et al.	An IPS2 framework and a method of combining the Net Present Value (NPV) Approach and the Real Options Approach (ROA).
	R. Carreira et al.	Combining customers' experience requirements with the extension of Kansei Engineering.
	K. Kimita et al.	A model to express the changes in customer demands from the perspective of service design.
	X. Geng and X. Chu	Revision of the importance-performance analysis (IPA) method and application of vague sets and Kano's model.
	O. Rexfelt and V.H. af Ornäs	A conceptual developing process for PSS on the basis of user-centered design approach.
	N. Morelli	A method to design PSS on the basis of customers' active participation.
	H. Long et al.	A PSS configuration method on the basis of support vector machine and customer perception
Modeling techniques	P. Marques et al.	A novel methodology for the development of product-service systems (PSS).
	J. Lindström et al.	A conceptual development model to manage the developing process of FP.
	N. Morelli	A tool named IDEF0 (Integration definition for function modeling).
	R. Hussain et al.	A capability-based framework of utilizing system-in-use data to develop PSS.
	J. Becker et al.	Strategies to create reference models and modeling language for PSS models.
	R. Maull et al.	A product service supply chains (PSSC) model.
	T. Alix and G. Zacharewicz	Developing PSS models on the basis of G-DEVS/HLA.
	J. Aurich et al.	A framework for PSS configuration, containing all necessary activities.
	X. Geng et al.	A three-domain PSS conceptual design framework based on QFD.
	C. Durugbo	A co-design approach on the basis of multi-methodology.
	H. Komoto and T. Tomiyama	Integrated Service CAD and Life cycle simulator (ISCL) for product design in PSS.
	X. Yang et al.	A methodology of combining product life cycle data, IDU (Intelligent Data Unit) and the service enabler.
	C.-J. Chou et al.	A framework and innovative tool for service models construction.
	Y. Geum and Y. Park	A product-service blueprint, an innovative way of illustrating how PSS facilitates sustainable production and consumption.
Visualization methods	A. Bertoni et al.	A lifecycle value representation method named LiVReA.
	C. Durugbo et al.	An information flow modeling technique related to key features of a PSS.
	C.-H. Lim et al.	A structural tool named PSS Board.
Modularity methods	N. Shikata et al.	Adoption of modularity to extend services and add value to products.
	P. Wang et al.	A modular development framework.
	M. Dong, L.-Y. Su	A modular modeling and configuration approach based upon ontology.
	H. Li et al.	An interactive module design process by analyzing the relationship between products and services.
TRIZ	S. Kim and B. Yoon	An innovative method to develop PSS by applying TRIZ to solve the contradictions between products and services.
	J. Jiang et al.	A PSS functional model based on service blueprint and functional system diagraphs.
System dynamics	C. Lin et al.	A generic modeling technique with enough details of an SD generic model.
	N.P. Bianchi et al.	A qualitative system dynamics to improve the product-oriented market mode.
	M. Afshar and D. Wang	A system dynamics approach for sustainable product service system to solve the complicated structure in PSS design.
	T.S. Baines and D.K. Harrison	Application of the SD model.

3.1.1. Customer perspective

Customers play an important role in the process of PSS and we have identified many PSS researches with a customer perspective. Berkovich et al. [15] proposed a Requirement Data Model (RDMod) for PSS, describing various requirements and their inter-relationships and a detailed classification of the related requirements according to PSS design process. There are 6 levels in the proposed model: goal, system, feature, function, component, and supporting activities. A limitation of their work was that they conducted application of the RDMod retrospectively. Moreover, they restricted their attention to the conceptual stages of PSS life cycle, excluding the analysis of requirements implementation. Song et al. [16] discussed the assessment of customer requirements in the early stage of industrial product service system (IPS2) and proposed the concept of "Industrial Customer Activity Cycle". The rough group analytic hierarchy process (AHP) method was applied to deal with the subjectivity and vagueness in a fuzzy context, providing an easy and effective way of requirement elicitation and evaluation. The limitations of their work mainly lie in the difficulty of passing the consistency test and industrial stakeholders' lack of rough logic knowledge. It would be helpful to develop a computerized rough group AHP model and apply rough group Analytic Network Process (ANP) in future research. Rese et al. [17] established an IPS2 framework to meet the needs of both users and markets, which also took the subsequent changes of these needs into consideration. They also developed a method of combining the Net Present Value (NPV) Approach and the Real Options Approach (ROA) to determine the quantified value of an IPS2. Nevertheless, they did not explore the estimation of IPS2 value from the supplier's perspective with a focus on economic value, especially on costs of flexibility. They [18] developed a user preference driven method for IPSS and identified nine main preference drivers to help IPSS providers choose an appropriate IPSS model. These were customer resources, know-how, number of employees, core competences, value-based figures, process complexity, process standardization, process frequency and process significance. However, they did not take the strength and interdependency of the above-mentioned drivers into consideration.

Carreira et al. [19] combined customers' experience requirements in the design of PSS with the extension of Kansei Engineering by an in-depth study of the customer experience and active participation of inter-company experts. However, they only focused on esthetic experience requirements (ERs) at later stages of the extension, instead of other ERs including social environment or entertainment. What is more, they did not construct physical prototypes to validate the proposed method.

Nor did they apply the method in other public transportation systems such as airplanes and trains, which may broaden its application. Aiming at responding to mass production and increasing the added value of products, Kimita et al. [20] applied the methods proposed through a marketing perspective to service components through an engineering design perspective. They developed a model to express the changes in customer demands from the perspective of service design. However, they did not consider changes in customer importance over time and they limited the scope to a single service, which may be quite different from the real case. Kimita et al. [21] consequently proposed an approach for designers to estimate customer satisfaction and compare design options at conceptual stage. A model representing PSS features related to customer's condition and a non-linear function named the satisfaction-attribute function was utilized to quantify customer satisfaction.

Schotman and Ludden [22] pointed out that users and manufacturers need to change their habits to put forward the successful implementation of PSS. They maintained that PSS designers must address the problem of lost habits to gain more user acceptance of PSS due to users' reluctance to change their behavior. Geng and Chu [23] revised the importance-performance analysis (IPA) method to evaluate customer satisfaction in PSS design. They employed vague sets to deal with uncertainty and vagueness in the evaluation process and Kano's model to solve the nonlinear relationships between attributes performance and customer satisfaction. Moreover, decision making trial and evaluation laboratory (DEMATEL) was applied to discuss the mutual relationships among attributes. Rexfelt and af Ornäs [24] identified the conditions for users to accept a PSS and proposed a PSS developing approach. They settled factors influencing user acceptance of PSS by group discussion and individual interviews and proposed a conceptual developing process for PSS on the basis of user-centered design approach. The limitation of their study was that they only used hypothetical PSS offers. No real case about commercial development project was developed to validate the proposed methodology. Morelli [25] developed a method to design PSS on the basis of customers' active participation in the value creation process. She also presented techniques to comprehend local context and individualized requirements. The tools developed in this study were meant to be used in a multidisciplinary context and to target problems and conditions without a detailed description. Long et al. [26] proposed a PSS configuration method on the basis of support vector machine and customer perception. They constructed a multi-level support vector machine model to configure a particular PSS which can be used to meet customer requirements. The following can be regarded as the limitations of their work. Firstly, customers may refuse the proposed solution and call for reconfiguration, which should be addressed in further research. Secondly, the authors only dealt with two kinds of constraints, which was far from enough. Thirdly, they should also identify conditions under which manufacturers could apply a new PSS to satisfy customers with consideration of customer value and operation cost.

3.1.2. Modeling techniques

Modeling techniques are of great significance in PSS design, and there are 17 papers addressing this problem. Marques et al. [27] proposed a novel methodology for the development of product-service systems (PSS), which was divided into four phases: organizational preparation, planning, design, and post-processing. It can shorten the time to market of product-services and ensure compliance with the early requirements. To coordinate, monitor, control, and share information among stakeholders involved in the development of functional products (FP), Lindström et al. [2] proposed a conceptual development model to manage the developing process of FP, including hardware, software, service support system and operation of an FP. They also proposed challenges and difficulties related to the integrated development of FPs. Morelli [13] defined the partnerships between companies and stakeholders as Solution Oriented Partnerships (SOP). He introduced a tool named IDEF0 (integration definition for function modeling), which allowed for continuous detailing of the functions and actions in the system, while keeping the link between each element in it. Hussain et al. [28] proposed a capability-based framework of utilizing system-in-use (rather than just product-in-use) data to develop PSS at conceptual stage. There are 10 steps in the proposed model: depict the system; define the desired overall capability parameter values; define the actual overall capability parameter values; find the overall capability parameter gaps; define the desired sub-capability parameter values; define the actual sub-capability parameter values; compare different instances of the overall capability; propose solutions; appraise the solutions; and conceptual design. For providers, the proposed framework calls for a detailed and transparent customer's process, which is often difficult to obtain. However, it is simple enough for a learned customer to master and apply it. Becker et al. [29] developed strategies to create reference models and modeling language for PSS models. Reference models can conceptualize cooperation contexts of service providers and manufacturers. They also introduced some characteristics in constructing modeling languages by integration meta-models with features from service blueprinting.

Maull et al. [30] proposed a product service supply chains (PSSC) model for integration of supply chain and an IDEF0 model to highlight the importance of coordinating product and service concepts for integrated PSSCs. A limitation of the study was that they focused on one single organization instead of considering a supply chain. The proposed a model only related to illustrations of single suppliers in service supply chains, in which no service elements were outsourced to a third party. Alix and Zacharewicz [31] proposed to develop PSS models on the basis of G-DEVS/HLA (generalized discrete event specification/high level architecture) to help decision makers select in various PSS design contexts. The authors offered a new perspective of Service Modeling and Distributed Simulation Environment based on G-DEVS/HLA to support design validation. Aurich et al. [32] proposed a theoretical framework for PSS configuration, containing all necessary activities to achieve desired benefits for manufacturers and customers. However, ever-increasing complexity of modern capital goods calls for some software to support the configuration. The authors did not address this issue in the proposed framework. Geng et al. [33] proposed a three-domain PSS conceptual design framework based on quality function deployment. The three domains are customer, functional, and product-service domain. There are three steps in the framework: establishing the ANP network model of HOQ (house of quality), computation of the initial importance weights of engineering characteristics (ECs), and determination of the final importance weights of ECs using data envelopment analysis (DEA). They applied fuzzy set theory and group decision-making technique to deal with vagueness and uncertainty in decision-making process. The limitation of their work lies in the complex dependency relationships of ANP. They did not focus on a systematic decision approach for PSS planning to cope with the complexity.

Durugbo [34] developed a co-design approach on the basis of multi-methodology within the scenario of IPS2 to realize collaborative design. To capture implementations of co-design and strategize an IPS2, the author applied a multi-case logic and expert interviews. The most important contribution of this study was that the author focused on how managers can design an IPS2 and leverage the benefits of co-design, with an involvement of joint work and overlapped processes. However, he did not address the key underlying themes to co-design an IPS2, the role of contracts, dialogs, and design transitions and the significance of IPS2 implementations in establishing relationships. Komoto and Tomiyama [35] proposed Integrated Service CAD and Life cycle simulator (ISCL) for product design in PSS. In the proposed methodology, the service CAD helps to generate PSS alternatives on a basis of service modeling, and the life cycle simulator contributes to analysis of their economic and environmental performances. It is also useful to accommodate new functions such as changing computer hardware or just upgrading software in designing a business process model. Yang et al. [36] developed a methodology to realize product-oriented PSS and use-oriented PSS for consumer products by combining product life cycle data, IDU (Intelligent Data Unit) and the service enabler, which can be used to intelligent, sustainable and environmental friendly product design. Typically, there are three stages in the proposed methodology. Firstly, designing IDUs and embedding them into products to obtain life cycle data; secondly, developing a service enabler as a service agent to receive life cycle data; thirdly, transmitting data to service enabler by the Internet.

Chou et al. [37] proposed a framework and innovative tool for service models construction such as "feedback diagram" and "service flow model". The proposed framework for service model generation includes three steps: key factor analysis and sustainability guidance; value validation and service model generation, detailed design and resource distribution. Their study did not focus on the efficiency of service models and sustainable development in order to save time, capital, and resources. Nor did they develop quantitative evaluation method to comprehend the performances in detail. To interpret the relationship between products and services, Geum and Park [38] proposed a product-service blueprint, an innovative way of illustrating how PSS facilitates sustainable production and consumption. At the stage of preparation, the purpose, concepts, and components should be identified and clarified. Then the elements and activities of each area are represented, and relationship can be established from the supporting area, service area, and product area. Limitations of their work lie in the following aspects. First of all, the product area may not be represented as detailed as the service area due to its basis on activity. Secondly, they did not consider different typology and implication for different PSS types. Thirdly, they did not integrate scenario-based representation into PSS blueprint, which may be fruitful for PSS design.

3.1.3. Visualization methods

Within the designing process of a product service system, designers usually do not take the life cycle requirements into consideration, leading to a lack of exact expression of consumers' value. They tend do make design decisions subjectively and implement PSS with more uncertainty. Therefore, it is of great significance to develop visualization methods to aid the design of PSS. Bertoni et al. [39] identified the gap in PSS hardware design, i.e., there was no way to inform designers of value-related information. They proposed a lifecycle value representation method named LiVReA, using color-coded 3D CAD models to visualize the value information of different hard ware. However, they did not investigate the visualization of reliability and the basic principle of value score, nor did they explore the problem of company collaboration capabilities. Durugbo et al. [40] reviewed the development of information flow diagrammatic models including their origin, concept, and applications. Moreover, they discussed an information flow modeling technique related to key features of a PSS. Lim et al. [41] proposed a structural tool named PSS Board, visualizing the PSS process and demonstrating the way that PSS providers and stakeholders help their customers to accomplish their work. The advantages of the proposed PSS Board method lie in the easy visualization of the PSS process and an efficient analysis of the PSS elements. However, they did not develop systematic aids to support the utilization of stakeholders and a user-friendly software system.

3.1.4. Modularity methods

Modularity is an efficient way of reducing operation cost and improving efficiency of PSS. Shikata et al. [42] focused on bettering the performance of a PSS by analyzing product structure. After examining two cases with competitive advantage, they concluded that manufacturers should adopt modularity to extend their services and add value to products. Wang et al. [43] proposed a modular development framework, consisting of three parts: functional, product, and service modularizations. Functional part deals with the planning of products and services and interface design and collaborative dimensions. Product modularization manages the dimensions of product and production. Service modularization realizes the service and process dimensions. Yet they did not investigate the way to improve modular development efficiency with the aid of concurrent engineering. Neither did they enhance the modular development and knowledge reuse in PSS. To realize the product configuration requirements of PSS under mass customization and a prompt configuration of products, Dong and Su [44] developed a modular modeling and configuration approach based upon ontology. They applied reachable matrix to support configuration process and constructed a meta-ontology of product configuration in PSS to share and reuse the model. Li et al. [45] proposed an interactive module design process by analyzing the relationship between products and services. They focused on the module partition principle of integrated service product (ISP), putting forward a three-step module partition processes including service module partition, physical module partition, and module partition methods.

3.1.5. TRIZ

TRIZ is the acronym of Russian phrase "Teorijz Rezhenija Izobretatel' Skitch Zadach", proposed by G. S. Altshuller, an inventor of former Soviet Union, in 1946. The basic idea of TRIZ is the abstraction of a specific problem into a generalized one, trying to solve it according to relative principles. TRIZ has developed into a theoretical and methodological system to solve developing problems of new product invention and is applied extensively in mechanical manufacturing and industrial design. Some scholars are trying to apply TRIZ in PSS. Kim and Yoon [46] suggested an innovative method to develop PSS by applying TRIZ to solve the contradictions between products and services. The suitability of this approach for PSS was evaluated by applying 40 innovative principles in TRIZ method in PSS cases among Fortune Global 500 companies. They adopted quality function deployment (QFD) to determine the key factors of products and services. The limitation of their research lies in the insufficient PSS cases being studied and its descriptive nature. To maintain an optimal balance between tangible products and intangible services, Jiang et al. [47] provided the evolution roads to PSS on the basis of TRIZ final ideal solutions and developed a PSS functional model based on service blueprint and functional system diagraphs. They proposed an innovative PSS method, applying function stimulations including collaboration, supplement, and displacement, which should be improved due to the complexity of computer-aided product innovation process.

3.1.6. System dynamics

J. W. Forrester, a professor from Massachusetts Institute of Technology, proposed the concept of System Dynamics in 1956. System dynamics is a discipline about information feedback system. Lin et al. [48] outlined the concept of system dynamics

(SD) and its role in the simulation process of manufacturing system. They proposed a generic modeling technique with enough details of a SD generic model, providing a means of effective modeling. Bianchi et al. [49] proposed a qualitative system dynamics to improve the product-oriented market mode, including several influencing factors of PSS in a dynamic framework including profits over the whole life-cycle, low environmental impact, and localization of services. Afshar and Wang [50] proposed a SD approach for sustainable product service system to solve the complicated structure in PSS design. It could help to determine the main parts and their interrelationships in PSS, and dynamic behaviors of a system in a broader sense. They conducted a case study of clean transport service to validate their proposed method. Baines and Harrison [51] identified the lack of continuous simulation methods, especially system dynamics, in the computer simulation of manufacturing systems. They explained this phenomenon and reviewed the concept of SD and the modeling technique. As a result, they focused on the application of the SD model and possibilities for future research.

3.2. PSS evaluation methodologies (PSS-EM)

In the transition to PSS, traditional manufactures may suffer from unexpected failure due to lack of relative knowledge about service design. Therefore, it is quite necessary to evaluate the potential PSS alternatives and make an appropriate choice in advance. We conducted the evaluation analysis through three perspectives: customer value, sustainability, and trade-offs between perspectives. Table 6 provides an overview of studies that address PSS-EM.

3.2.1. Customer value perspective

Customer value is an important criterion that can never be overestimated to evaluate a PSS option since the ultimate goal of providing a PSS is to meet customer requirements and make profit. We identified 10 publications that discuss PSS evaluation through a customer value perspective. Roy et al. [52] proposed a method to estimate customer satisfaction for designers to compare different alternatives at a conceptual stage with limited information. Their research was limited to a single transaction with a customer instead of cumulative satisfaction. Geng and Chu [23] revised importance-performance analysis (IPA) method to identify improvement potentials. They applied Kano's model to deal with the complicated relationships between attributes performance and customer satisfaction and vague set theory to deal with vagueness in the evaluation process. Shimomura et al. [53] proposed an engineering methodology to rank and choose human resources in terms of customer satisfaction. However, they did not take human resource strategies and product attributes into consideration. Geng et al. [54] developed a systematic decision-making approach with consideration of customer requirements to determine the fulfillment levels of engineering characteristics.

Ranaweera and Neely [55] proposed a comprehensive model of customer retention including service quality perceptions, price perceptions, customer indifference and inertia. They argued that service quality perceptions, price perceptions, and customer indifference had a linear relationship with customer retention whereas there was no such relationship between customer inertia and retention. The limitation of their study lies in its basis on cross sectional data. Besides, the authors did not devote enough attention to inertia and indifference. Moreover, they only examined linear relationships between elements, which may not represent the actual case very well. Yoshimitsu et al. [56] proposed the "Satisfaction – Attribute Value Function" model, helping service designers to measure customer satisfaction. Sakao and Lindahl [57] developed an innovative approach to evaluate PSS based on customer value and budget with effective application of design information. However, the

Table 6
Some PSS evaluation methodologies.

Perspective	Author(s)	Contribution to PSS evaluation methodologies
Customer value	K. Kimita et al.	A method to estimate customer satisfaction for designers to compare different alternatives at conceptual stage with limited information.
	X. Geng and X. Chu	Importance-performance analysis (IPA) method to identify improvement potentials.
	T. Sakao and M. Lindahl	An innovative approach to evaluate PSS based on customer value and budget with effective application of design information.
	X. Geng et al.	A systematic decision-making approach with consideration of customer requirements
	M. Rese et al.	A method to identify customer preference drivers and anticipate customer decisions.
	X. Li et al.	A strategic performance measurement system (SPMS) for firms across supply and demand chains (SDC).
	Y. Shimomura et al.	An engineering methodology to rank and choose human resources in terms of customer satisfaction.
	C. Ranaweera and A. Neely	A comprehensive model of customer retention including service quality perceptions, price perceptions, customer indifference and inertia.
	T. Arai and Y. Shimomura	A prototype system of Service CAD called 'Service Explorer'.
	Y. Yoshimitsu et al.	"Satisfaction - Attribute Value Function" model which help service designers to measure customer satisfaction.
Sustainability	S. Lee et al.	Application of system dynamics (SD) and triple bottom line (TBL).
	H.A. Hu et al.	A framework to evaluate PSS with fuzzy Delphi and fuzzy AHP.
	K. Xing et al.	A sustainability-oriented value assessment model.
Trade-offs between perspectives	C. Durugbo and J.C.K.H. Riedel	A framework to assess the readiness of correlated organizations.
	B. Yoon et al.	A new model to evaluate PSS by considering service providers and customers to reduce risk.
	H. Sun et al.	A product-service performance (PSP) model to evaluate a PSS.
	F. Tonelli et al.	Presenting the learning from an action research (AR).
	T. Sakao et al.	A theoretical and generic framework named the PCP (Provider – Customer – Product) triangle with associated information flow and uncertainty.
	M. Bourne et al.	A framework to analyze the implementation of a performance measurement system.
	A. Neely et al.	A framework to identify the expected features of a performance measurement system.
	X. Shi and H. Meier	An approach to evaluate carbon emissions in production systems by applying a hybrid emission analysis model.
	Y. Shimomura et al.	A model to evaluate service solutions with application of Quality Function Deployment (QFD) and mathematical methods.
	K. Watanabe et al.	An integrated service evaluation framework and a service process model for integrated assessment.

proposed method did not incorporate provider's cost assessment and the balance between customer value and provider's cost.

3.2.2. Sustainability perspective

Sustainability is one of the most important characteristics of PSS by combining products and services. However, there are rather limited publications as to PSS-EM through a sustainability perspective. Lee et al. [58] pointed out that PSS was a dynamic and complicated system. They applied system dynamics (SD) to deal with the dynamics, and triple bottom line (TBL) to encompass the multidimensionality of PSS sustainability. The limitation of this study was the validation of the proposed method with public bicycle system and it should be applied in a more practical situation. And more indicators for each dimension and linkages among dimensions should be taken into consideration. Hu et al. [59] proposed a framework to evaluate sustainable performance of PSS with fuzzy Delphi method to identify criteria consistency and fuzzy analytic hierarchy process to determine weights of the selected criteria. However, they did not incorporate all representative factors as to special products or services and it was restricted to early stage of PSS development. Therefore, a more detailed evaluation is needed. Xing et al. [60] developed a sustainability-oriented value assessment model on the basis of life cycle thinking, in which the fitness for extended utilization indicators, the net present value (NPV) approach and life cycle assessment (LCA), were applied as the measures for value assessment. It can be improved with more dynamic modeling of effects such as technology improvement, market competition, operating conditions and so on. Performance capability and burden measures can also be considered in future research.

3.2.3. Trade-offs between perspectives

PSS is a comprehensive network involving many kinds of stakeholders, such as manufacturers, service suppliers, customers, and so forth. It is quite necessary to call for efforts of all involved stakeholders to deliver a successful PSS. Durugbo and Riedel [61] presented a framework to assess the readiness of correlated organizations for PSS delivery, with consideration of the impact of admitting or omitting partners on the whole network. They did not provide a comprehensive model to guide data collection and assessment for facing disciplinary, inter-disciplinary, or multi-disciplinary goals during collaboration. And they did not explore the impact of admitting/omitting partners on customers and the environment. Yoon et al. [62] developed a new model to evaluate PSS by considering service providers and customers to reduce risk. A use-oriented PSS of car-sharing system was used to validate the proposed method. However, they used a limited survey sample and the respondents were not typical and representative enough. The proposed methodology cannot address complicated conflicts between different stakeholders. Sun et al. [63] proposed a product-service performance (PSP) model to evaluate a PSS. They defined the inter-relationship between a service provider, receiver and concepts as product-service network (PSN) and product-service chain (PSC) to describe interrelationships of all stakeholders. The limitation of their study was the ignorance of the network's optimizing algorithms and the dynamic evolution property of the network.

Bourne et al. [64] developed a framework to analyze the implementation of a performance measurement system, which can be divided into three steps: designing of the performance measures, implementation of the performance measures, and usage of the performance measures. They concluded that specific processes were required to align the performance measurement system continuously. Shimomura et al. [65] developed a model to evaluate service solutions with application of quality function deployment (QFD) and mathematical methods. They did not examine the positioning of service evaluation tools in detail and the validation of the proposed techniques need to be reinforced in the future. To describe the influence of a service to different stakeholders, Watanabe et al. [66] proposed an integrated service evaluation framework with two features: multiple evaluation standards from different stakeholders' perspectives and a service process model for integrated assessment with elements such as organization, consumer, natural resources, and environment. What's more, a simulation method was developed to realize quantitative evaluation. The restriction of their study lies in the difference of service quality and agents behavior in other cases. Therefore, it is important to describe such difference to simulate more accurately. And they did not mention the evaluation of environmental impact, which remains an important issue to be addressed in the future.

3.3. PSS operation methodologies (PSS-OM)

The success of a PSS not only relies on a good design, but also on its operation and management. We identified 77 publications dealing with PSS-OM and conducted the analysis through five perspectives: knowledge management, barrier analysis & fault monitoring, business model, technology, and policy perspective. Table 7 demonstrates some PSS-OM and their contributions.

3.3.1. Knowledge management

Johansson et al. [67] analyzed the concept of knowledge maturity as a means to provide decision support and increase decision makers' understanding of the knowledge base. They also proposed a model on the basis of seven requirements for knowledge maturity including support for boundary negotiation, tacit knowledge sharing, learning, visualization, traceability, prioritization, and pragmatic decision making. They argued that input, method, and experience/expertise can be used as dimensions to evaluate the maturity of knowledge at a conceptual stage. The proposed method can help decision makers make a right decision with limited knowledge. However, it also had some limitations in that it did not ensure to solve all problems of assumptions, uncertainty, and ambiguity. Moreover, they applied the model mainly in the aerospace industry, which may be quite different from other industries. Baxter et al. [68] developed a method for knowledge reuse in PSS design context, aiming to collect, represent and reuse knowledge to support product development with the following three key factors: a process based design model, manufacturing capability knowledge, and service knowledge. They adopted "activity" and "object" to discuss processes, but they did not consider "time-point" and "activity occurrence" to improve the capability of their proposed framework. Zhang et al. [69] proposed a framework for knowledge management and reuse in construction machinery industry with four layers: application, process-task, representation, and shared layers, and the proposed framework was validated through expert interview and a case study. The limitation of their study is that the proposed framework does not cover entire ontology modeling for PSS, and it does not integrate with other methods such as road mapping, service blueprint and so on. More case studies need to be conducted in the future.

3.3.2. Barrier analysis & fault monitoring

Kuo et al. [70] identified implementation barriers and analyzed the complicated relationships among them. In order to facilitate strategic analysis and provide guidelines for PSS implementation, they applied interpretive structural modeling (ISM) to divide the barriers into a hierarchical system in five steps: analysis of the pair-wise relationship of the barriers, establishment of a binary relationship matrix, computation of the reach-ability matrix, derivation of the structural multilevel hierarchy, and conducting of strategic analysis. However, their research focused on maintenance and remanufacturing activities in PSS, resulting in its

Table 7
Some PSS operation methodologies.

Perspectives	Author(s)	Contribution to PSS operation methodologies
Knowledge managemen perspective	C. Johansson et al.	A model on the basis of seven requirements for knowledge maturity.
	D. Baxter et al.	A method for knowledge reuse in PSS design context.
	D. Zhang et al.	A framework for knowledge management and reuse.
Barrier analysis and Fault monitoring perspective	T.C. Kuo et al.	Identified implementation barriers and analyzed the complicated relationships among them.
	M. Löfstrand et al.	Described an approach of integrating sensor data stream monitoring system into a functional product model.
	E.L.S. Teixeira et al.	A method combining Prognostics and Health Management (PHM) and PSS and an innovative model with the aid of online simulation.
	Z. Zhang and X. Chu	Developed a data exchange mechanism and applied a failure mode and effects analysis (FMEA) tool to discuss failure modes and their effects on products.
PSS business models	D. Kindström and C. Kowalkowski	A business model approach with a comprehensive perspective instead of a detailed discussion.
	N. Li and Z. Jiang	Establishing PSS as a block-structured Markov chain and solved it by Matrix geometric methodology.
	H. Li et al.	A universal Enterprise Manufacturing Service Maturity Model (EMSMM) and a building approach for it.
	J. Lee and M. AbuAli	A methodology for systematic thinking and product-service system design.
	A.P.B. Barquet et al.	A method of applying the concept of business models in PSS development.
	H. Zhu et al.	An MRO (maintenance, repair and overhaul) service model for aerospace industry and an ontology-based knowledge representation model.
	A. Dimache and T. Roche	A decision support method called TraPSS (transition along the PSS continuum).
	Q. Zhu et al.	A PSS for computer numerical control (CNC) machine tool.
Technology perspective	V. Belvedere et al.	The influence of information and communication technologies (ICTs) to PSS.
	R.J. Hernández Pardo et al.	Sustainable ways to develop PSS for small and medium enterprises (SMEs).
	M. Nybacka et al.	A remote technology management (RTM) solution.
	M. Bertoni and A. Larsson	Enabling mechanisms by Web 2.0 technologies for PSS design teams and their applications in product developing process.
	S.A. Schenkl et al.	A technology-centered framework for PSS.
Policy perspective	O. Mont and T. Lindhqvist	Analyzed the essence of policy as a stimulator of environmental improvement and progress in PSS.
	F. Ceschin and C. Vezzoli	Discussed the role of policy in the development of PSS in automobile industry.
	C. Durugbo	Adopted work system theory and four in-depth cases in micro-engineering industry and discussed the importance of relationship and policies in the implementation of PSS.

feasibility in products with high-value instead of low-value. Besides, barriers may vary from company to company, making the analysis somewhat different. Löfstrand et al. [71] described an approach of integrating sensor data stream monitoring system into a functional product model to predict functional availability and maintenance in response to hardware failure. The proposed model can help to make strategic decisions, develop products through simulation-driven development, and provide support to enable ideal availability. With integration of hardware, support system and monitoring system models, the model is able to incorporate actual operational data. Teixeira et al. [72] discussed a method combining Prognostics and Health Management (PHM) and PSS and proposed an innovative model with the aid of online simulation, which could be used to support short-term operational decisions and help service providers to make decisions. It can be improved by adding some operational adjustments such as anticipating or delaying maintenance inspection, and acquisition of spare parts. They did not pay enough attention to additional investigation into operational service strategies and more sophisticated repair models. Zhang and Chu [73] proposed innovative methods for product and maintenance design, and applied quality function deployment (QFD) to translate users requirements to conceptual ones. They developed a data exchange mechanism to find out the interrelationships of products and maintenance and applied a failure mode and effects analysis (FMEA) tool to discuss failure modes and their effects on products. However, they did not take other services (such as equipment, transport, and training) into consideration and they did not integrate the proposed method with other efficient tools.

3.3.3. Business models

Reim et al. [74] defined business models as "the design or architecture of the value creation, delivery and capture mechanisms." They divided business models into three types: product-oriented, use-oriented, and result-oriented models. Kastalli et al. [75] examined how manufacturers can steer the transition from products to services and identified two dimensions of the market performance of service activities: "service adoption" and "service coverage", which should be supplemented with a "complementarity index". The method can help manufacturing companies to deploy a service-based business model in a sustainable manner. Kindström and Kowalkowski [76] investigated the nature and characteristics of business model elements. They concluded that specific resources and capabilities were required for the proposed business model elements and that companies could conduct service innovation from different starting points and orders. Due to the application of a synthesizing approach, their research was not carried to a detailed level. They presented a business model approach with a comprehensive perspective instead of a detailed discussion. The proposed business models can be applied to visualize changes, increase internal transparency, understanding, and awareness of service opportunities and necessary changes.

Li and Jiang [77] discussed the modeling and optimization of PSS from the view of operation management. They established the product service system as a block-structured Markov chain and solved it by Matrix geometric methodology. Moreover, they studied the system performance sensitivity and the additional service capacity opening threshold by conducting numerical experiments. However, they did not investigate system with non-Poisson arrivals rates or non-exponential production and/or service rates; and they did not share their attention to systems with other customer features either. Li et al. [78] proposed a universal Enterprise Manufacturing Service Maturity Model (EMSMM) to guide assessment of an enterprise's service development. The proposed model could help to increase a firm's profits and was useful to achieve enterprise transformation. But the implementation connotation, framework and methodology were not considered in their work, limiting the contribution to a certain extent.

Lee and AbuAli [79] introduced a series of interrelated tools for systematic innovation, which may help companies to transfer to a PSS. The authors proposed a methodology for systematic thinking and product-service system design depending on the innovation matrix and application space mapping. They did not consider automation of the presented tools and application of space mapping in order to run the tools on all kinds of computer systems. And they did not integrate relevant PLM processes with the proposed service innovation tools to map, model, manage, and evolve the product lifecycle processes. Barquet et al. [80] proposed a method of applying the concept of business models in PSS development, and a framework to instruct companies to analyze their business context, appropriate PSS types and attributes, to provide companies with a useful tool to implement PSS, to investigate different PSS contexts, and to identify the main barriers and challenges. The major limitation of their study lied in a single application of the framework. Zhu et al. [81] proposed an MRO (maintenance, repair and overhaul) service model for aerospace industry and an ontology-based knowledge representation model. Product life cycle management environment and web-based technologies were also developed to provide services in aerospace industry. The authors did not develop a web-based PSS responding to changes in functional requirements and evaluation of the effectiveness. Their model did not cover the effect of changing requirements on MRO services.

Adeogun et al. [82] focused on small point-of-care devices for healthcare contexts to assess the service level of point-of-care testing (POCT) devices as to whether they can form a product-oriented PSS. Besides, they also took into account the type of PSS, its informatics requirements, and the services that such a system could provide. However, they only focused on home-use glucometers and did not consider other POCT devices that were widely used in healthcare center and in remote environments. Dimache and Roche [83] proposed a decision support method called TraPSS (transition along the PSS continuum), aiding decision makers to evaluate PSS business models and make profit. They applied an action research approach to construct, validate, and implement the proposed method, which proved to be useful in helping the transition to an innovative PSS business model. The limitation of their study was that they did not conduct multiple case studies. Zhu et al. [84] developed a PSS for computer numerical control (CNC) machine tool and constructed its configuring and operating framework to enhance the functions of CNC machine tools, and to decrease machining cost. There were three subsystems in the proposed framework: configuration, scheduling and service-supporting. Sundin et al. [85] discussed whether strategic warranty management can be used as a key to efficient transition to PSS and applied multi-case methodology to deal with the relationships between customers and suppliers, showing that advanced warranty management was crucial to efficient PSS. They did not cover success factors and barriers in the proposed method and their study was more descriptive than prescriptive. More importantly, they did not construct quantitative modeling of warranty management and failure probability, which deserved more attention in future study.

3.3.4. Technology

Belvedere et al. [86] analyzed the influence of information and communication technologies (ICTs) to product service systems. In their points of view, ICTs could create value for PSS and brought about an extraordinary operation of PSS in a more efficient and responsive way. They believed that investment in ICTs would result in efficiency and responsive capacity. Nevertheless, they did not verify the influence of cooperation level among branches on the outcomes of a service strategy and they did not study how firms dealt with the communication and pricing problems. Hernández Pardo et al. [87] proposed sustainable ways to develop PSS for small and medium enterprises (SMEs) to comprehend integrated design of products and services and a firm belief that ICTs can facilitate the development of PSS for SMEs. They developed a reference model to explore relevant factors of their research. However, they did not develop a linking structure of the elements in the reference model to make it applicable to different industries and they did not propose a general framework for other situations. Nybacka et al. [88] presented a remote technology management (RTM) solution and discussed possible activities that may be adopted in service innovation with an intention to visualize the process of service providing. Bertoni and Larsson [89] introduced the enabling mechanisms by Web 2.0 technologies for PSS design teams and their applications in product developing process. Their study revealed the importance of bottom-up and lightweight technologies in enabling PSS implementation. They also identified relevant issues that may hinder the implementation of Web 2.0 technologies in a product development process. Schenkl et al. [90] proposed a technology-centered framework for PSS, delivering an abstract description of PSS on three levels: goal, solution, and technology. The layers were connected by means-end relations to highlight the correlations between goals, PSS elements and technology.

3.3.5. Policy

Mont and Lindhqvist [91] analyzed the essence of policy as a stimulator of environmental improvement and progress in PSS. In their points of view, policies aiming to establish the framework for environmental improvement were superior to detailed legislation in that the former tended to support PSS with a better environmental performance. They also identified a need for more specifically targeted policy measures in the PSS area. The authors discussed possible natures of governmental policies for PSS progress and suggested that informative policy measures be used by authorities. As one of the earliest published papers, the study was significant in pointing out the importance of policy in PSS implementation. Ceschin and Vezzoli [92] discussed the role of policy in the development of PSS in automobile industry with a series of policy measures to illustrate the effect of policies to manufacturers and environment. They argued that general policy measures such as internalization of external costs and extended producer responsibility programs should be integrated with PSS-targeted ones including Green Public Procurement and so forth. Moreover, the authors pointed out that academia such as universities and research centers should be involved in the process of PSS development. Durugbo [93] adopted work system theory and four in-depth cases in micro-engineering industry and discussed the importance of relationship and policies in the implementation of PSS. First of all, the author made an assessment of sustainability, technical and marketability research themes in the field of PSS research. Secondly, he analyzed work systems to deliver PSSs and revealed different application of roles. Thirdly, the study offered insights into how work systems could be applied in practices to provide PSS. The study was limited by its application in a single sector. The author did not consider the role of service contracts and their relationship with decision orientation.

4. Discussion

We conducted a systematic review of PSS literature and introduced PSS publications in Scopus database, with an emphasis on design, evaluation, and operation methods in product service systems. To ensure an objective and comprehensive assessment of the bottleneck of PSS-DEOM, we searched the Scopus database with the term "product service system" and refined the search results to "review" and "English". In all, we identified 26 PSS

Table 8
Comparison of previous literature reviews of PSS.

No. in reference list	Method	Time range	Articles
[94]	Structured key words search	2006–2010	149
[5]	Database search and internet search; systematic review	2000–2013	278
[3]	Database search; systematic review	1995–2006	40
[4]	Database search and internet search; systematic review	1973–2012	265
[95]	Systematic review	–	–
[74]	Database search; systematic review	1988–2012	67
[96]	Database search; Web investigation	2001–2011	79
[97]	–	2001–2010	8
This article	Database search and internet search; systematic review	2000–2015	258

review papers. By checking the titles and abstracts manually, full texts of 8 PSS review papers were downloaded. Then we made a comparison about their research methods, time ranges and numbers of articles being analyzed. Boehm and Thomas [4] integrated the results from three disciplines, information system (IS), business management (BM), and engineering & design (ED) to achieve a unified definition of PSS and notions of the concept within the three disciplines. They conducted the analyses with different views or perspectives, i.e.: strategic, organizational, marketing, design, innovation, business level, sustainability, macroeconomic, and meta-level. Tukker [5] focused his attention mainly on engineering and design field and addressed the following issues: PSS concept, PSS design methodologies, business and environmental advantages or disadvantages of PSS. His intention was to identify the contribution of PSS to resource-efficiency and circularity. Reim et al. [74] conducted a study to find out the way that companies adopt and implement PSS. They categorized the operation-level tactics into contracts, marketing, network, product and service design, and sustainability practices.

Different from the above-mentioned studies, we carried out a comprehensive and systematic literature review to understand current status of PSS design, evaluation, and operation methodologies through different perspectives. Table 8 shows the comparison of previous literature reviews of PSS and this article. It is obvious that this study has a rather recent and long time-range over the past 15 years. Moreover, number of articles being analyzed in our study is among the top three. Therefore, it is safe to arrive at the conclusion that our study can reveal the newest achievements in PSS-DM, PSS-EM, and PSS-OM with a considerable depth. The analyses of PSS-DM were divided into six perspectives, i.e., customer perspective, modeling techniques, visualization methods, modularity, TRIZ, and system dynamics. The majority of PSS-DM were conducted from customer perspective and modeling techniques. By contrast, research in the other four perspectives seemed rather limited. We conducted the analysis of PSS-EM through three perspectives: customer value, sustainability, and trade-offs between perspectives. It is noteworthy that an overwhelming percentage of PSS-EM literature is evaluating a PSS from customer value and comprehensive perspectives. And PSS-OM was discussed through five different perspectives: knowledge management, barrier analysis & fault monitoring, business model, technology, and policy. Most of the studies focused on PSS business models, demonstrating the interest of the actual application of the proposed methodologies.

On the basis of the above analyses of design, evaluation and operation methods in product service systems, future research trends can be proposed as follows:

(1) As to PSS-DM, more attention should be directed to visualization methods, modularity, and system dynamics. Besides, methodologies from other disciplines may be adapted to fit for PSS design, especially those of engineering, environmental, and business management.
(2) Future study of PSS evaluation should care more about sustainability. Although PSS is advocated because of its advantages in environmental protection, rather limited researches focused on sustainability. Besides, current researches pay little attention to producer and cost perspectives, which are also crucial in the process of PSS evaluation and operation. And more criteria should be identified to evaluate the efficiency of a PSS.
(3) More studies should be carried out in the field of PSS operation with diversified views of point. Our study identified the following five perspectives: knowledge management, barrier analysis & fault monitoring, business models, technology, and policy. However, this may not represent the actual case comprehensively.
(4) More quantitative researches need to be conducted in future research. Compared with qualitative studies, quantitative ones are more objective and persuasive to demonstrate the influence of PSS on economy, society, and environment. Researchers should conduct more quantitative studies in future works.

5. Conclusions

To conclude, we find that research in PSS-DEOM is developing and progressing quite well. The years of 2009–2012 witnessed a peak of number of publications related to PSS-DEOM. PSS-DM are always dominant in the number, usually several times the number of PSS-EM and PSS-OM, especially between the year of 2005 and 2012, showing that researchers are more interested in the design of PSS than its evaluation and operation. Moreover, many proposed methodologies were evaluated in the same paper they were proposed, reducing the number of PSS-EM to a certain extent. We identified the following limitations of our study: First of all, although we applied different search terms while selecting references, the searching was carried out only within Scopus database, which may not include all PSS publications. Secondly, we took only English journal articles into consideration, excluding conference papers, books, and those published in other languages. However, those excluded publications may also contain important information. Thirdly, we classified the selected publications into three categories: design, evaluation, and operation. That is to say, one paper can only belong to a specific category, which is sometimes not the actual case. Finally, for each of the three categories, we classified articles into different perspectives according to number of publications. This categorization method may not represent the current status of PSS-DEOM objectively and comprehensively. We would like to address these issues in future research. Despite all of these limitations, our study has contributed to comprehending the state-of-the-art of PSS design, evaluation, and operation methodologies.

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