Defining lean product service systems features and research trends through a systematic literature review

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Abstract: Through the digitalisation of manufacturing, product-service systems (PSS) and smart connected products are, from the companies' side, driving a market transition from a sale of products towards a sale of use of solutions, and, from the customers' side, reshaping the concept of value. The systematic integration of intangibles services with physical products requires companies' alignment also in terms of practices and tools adopted to develop and design these complex solutions adequately. The extant literature proposes several approaches to develop PSSs: it has been stated that the majority of them embedded in their structure some characteristics that are typical of concurrent engineering and lean product development theories. In the meanwhile, a research stream, named lean PSS, has progressively arisen up in the last few years. However, how so far the extant literature has already contributed to the forthcoming lean PSS domain is not clear. In order to better clarify and address this issue, this article, based on a systematic literature review approach, defines lean PSS, also exploring its main features and application areas and defining the related possible research opportunities.

Keywords: product service system; PSS; lean; lean PSS; design guideline; systematic literature review; research trends; circular economy; knowledge management; product lifecycle management.

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1 Introduction

Nowadays, the manufacturing world runs more and more over the service economy (Fuchs, 1968; Santamaría et al., 2012), compelling companies to radically change their structure (Sassanelli et al., 2018b) to pursue servitisation (Vandermerwe and Rada, 1988). To heed this phenomenon, manufacturers are always using more information and communication technology (ICT) (Balocco et al., 2019; Santamaría et al., 2012) in their systems, as for example internet of things (IoT) technologies, to guide the market shift from selling traditional product towards the delivery of integrated products and services. Extending their market proposition through the incorporation of additional services to traditional products (Baines et al., 2007), manufacturing companies were able to reach new market competitive advantages (Porter and Heppelmann, 2015), prolonging and strengthening their relationship with customers, involving them along the entire lifecycle of the solution proposed and also managing to pursue sustainable up to date trends as circular economy (CE) (The Ellen MacArthur Foundation, 2015). These integrated bundle of products and services, named for the first time by Goedkoop et al. (1999) product-service systems (PSS), have been often enriched through embedded technologies by a smart feature: their introduction triggered a breakthrough in manufacturers’ business models that were pushed from the traditional *sale of products* towards the more

customer-driven *sale of use* (Baines et al., 2007). As a consequence the concept itself of customer value resulted radically reshaped from possession to utilisation, leading consequently to a change of perspective in the way in which the different lifecycle stages of the PSS are managed during their conception, design and engineering. However, even though since the '90s several tools and methodologies for designing PSSs have been proposed, especially in the context of Service Engineering discipline (Aurich et al., 2006), most of these methods are typically a rearrangement of conventional processes and lack a critical and in-depth evaluation of their real performance in practice (Baines et al., 2007; Xin et al., 2017). Moreover, the majority of the methodologies proposed in literature for PSS design and development "have a clear heritage in concurrent engineering and lean product development methodologies: identification of customer value, early involvement of the customer in the system design, effective communication, information sharing, and continuous improvement" (Baines et al., 2007). At the same time, intending to couple the PSS concept with lean thinking, lean product-service system (lean PSS) is rising in literature as a new research topic (Sassanelli et al., 2015a), mainly link to the PSS development and design phases. Lean is an approach strongly focused on the customer value, promising hence to enable a participatory value-driven attitude of the user along the entire lifecycle of the PSS, also through the support of ICT enabling technologies.

With this article, the authors want to highlight the actual application of lean in the PSS context, contributing to the definitive dawn of this research topic that is overcoming but is still implicit and at a latent level (Baines et al., 2007).

Indeed, starting from the extant literature, this paper aims at opening the way to the lean PSS research, defining its real concept, detecting its main features and gaps and proposing a discussion on its future, in terms of the related opportunities and the possible connected research topics. With this objective, the paper is organised as follows:

- Section 2 presents the main elements of PSS, lean thinking (focusing in particular on lean product development (LPD) as a declination of lean in the design process) and of lean thinking applied to PSS. Based on the context described, the research questions are reported.
- Section 3 shows the research methodology adopted to answer the research questions previously defined.
- Then, Section 4 reports the results of the systematic literature review investigating the research areas of lean PSS and grasping their trends.
- Section 5 discusses the results, detecting lean PSS gaps and opportunities.
- Finally, Section 6 concludes the paper and introduces the next research steps.

2 Research context and objectives

The context of this research is composed of two main extensive and complex concepts: PSS (together with PSS design and engineering) and lean thinking (together with LPD).

In this section, after clarifying both of them, the research objective and the related research questions (RQ) have been defined and provided.

2.1 Product service system and PSS design

As reported by Baines et al. (2007), Goedkoop et al. (1999) gave the first formal definition of a PSS, as composed by three constitutional elements:

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

During the years, many other definitions have been introduced in literature, adding some elements to the Goedkoop's one, but keeping it as the core. Based on a four-section basis analysis (*definition*, *focus*, *system components*, *objectives*) (Sassanelli et al., 2015a), PSS could consist either on a system/combination (Brandstotter et al., 2003; Goedkoop et al., 1999; Mont, 2001), to be intended sometime *pre-designed* (Centre for Sustainable Design, 2002), or an *innovation strategy/solution* (Manzini and Vezzoli, 2003; Wong, 2004). When intended as a combination, PSSs are composed of products and services with additional support of networks and infrastructures. When instead the concept of innovation strategy/solution prevails, PSS is intended as merely made of products and services (Sassanelli et al., 2015a).

The literature highlights a lack of knowledge and experience regarding PSS business models (Beuren et al., 2013). In this direction, (Reim et al., 2015) provided five operational-level tactics (contract, marketing, networks, product and service design, sustainability operation practices) to be linked to each of the three main PSS business models (product-, use- and result-oriented) (Tukker, 2004). These five tactics, associated with each of these three business model categories, have been detected to ease, support and foster a proficient generation of value, depending on internal and external organisation conditions. Indeed, several are the variables that could affect companies, both positively or negatively, to switch their approach from a product-centric to a service integrated one: while tools and external practices can foster this transition, market and company constraints can represent hurdles (Sassanelli et al., 2018b) in this tough pursuit (Oliva and Kallenberg, 2003). At this purpose, Pacheco et al. (2019a, 2019b, 2018, 2017) specifically focused on the barriers that could be faced by SMEs when approaching sustainable PSSs.

Wrapping up, generally, PSSs are made to pursue industrial competitiveness, customer satisfaction and also sustainable development (Tukker and Tischner, 2006). Different authors (e.g. (Mont and Lindhqvist, 2003; Tukker and Tischner, 2006)) have highlighted how this win-win scenario can be realised only by a careful design of the PSS, involving all the significant stakeholders since the early phases of the design stage, as reported in the following subsection. A lifecycle perspective should be adopted in the PSS design (Xin et al., 2017): researchers should avoid neglecting either specific phases of the PSS lifecycle (Sassanelli et al., 2016) or parts of the supply chain involved (Ebikake et al., 2018) or components of the entire system analysed (Sassanelli et al., 2017b).

All the definitions reported above underline that all the components characterising the PSS must be designed in order to design a solution able to fulfil customer needs (Boehm and Thomas, 2013). Due to the heterogeneity of PSS components, manufacturers usually

adopt methods based on a traditional engineering perspective to design and develop their solutions: while tangible parts are engineered, the intangible elements are developed through intuitive processes and methods (Cavalieri and Pezzotta, 2012). These gaps claim for additional empirical research.

2.2 Lean thinking and lean product development

The root of lean thinking, residing in "creating more value, defined from the customer's perspective, while consuming fewer resources" (Womack and Jones, 1996), practically finds its natural application in the product development domain. Indeed, product development has the final aim of generating knowledge to be reusable to create profitable value streams into a product (Ward, 2007). Moreover, since customers are no more satisfied with simple products or services, customer value is gradually shifting from a pure product (or service) to an integrated solution, named PSS (either product- or use- and result-oriented). As a result, nowadays, product development cannot be limited anymore only to physical products: it is in charge to lead innovation into the delivery of PSS through a suitable problem-solving process.
Wrapping up, lean product and process development can be categorised into three main components (Rossi et al., 2017):

1 Creating value: value is everything the customer is willing to pay for and, conversely, wastes represent those activity using resources without bringing any value for customers. In product development value streams are generated for all the downstream operations. Indeed, these value streams should assure the manufacturing and delivery of the product (and/or service) for which the customer is willing to pay. To do it effectively and efficiently, usable knowledge is created, becoming itself value for both product development and the entire organisation (Ward, 2007).

2 Value as knowledge and learning: a value creation process, based on knowledge reuse, becomes highly efficient and effective, since it fosters the creation of always more improved and valuable products (and/or services) representing value for the customer. Trade-off curves, limit curves, standards, A3s, checklists, guidelines and others tools avoid mistakes in the late phases of design, postponing decisions at the appropriate time and based on proven knowledge and data (Ward, 2007).

3 System integration (process-people-technology): process is a sequence of tasks required to take a product from concept to launch, aiming at creating value for the customer and avoiding actions that cause waste. People includes both selection and training of engineers and their learning patterns, facilitated by the chief engineer: collaboration and exchange of knowledge foster cross-functional integration and communication of different expertise within the organisation, leading to a concurrent engineering process. Finally, technologies incorporate design and manufacturing supporting tools (computer-aided design systems, machine technology and digital manufacturing), and also soft tools supporting the efforts of people during the development process.

2.3 Lean thinking applied to PSS

Along the years, lean theory contributed with a plethora of methods and tools developed both for product and service design also trying to adapt some of them from a tangible to an intangible dimension and vice versa (Sassanelli et al., 2015b). Based on what stated by Baines et al. (2007), who said that the majority of the PSS development methodologies embed in their structure some characteristics that are typical of concurrent engineering and lean product development theories, Sassanelli et al. (2015a) attempted to verify, not systematically, how lean thinking approaches are popular in the PSS design scientific literature: even if none of the contributions selected cites lean thinking explicitly, they were able to identify the lean methods adopted. Concurrent engineering, effective knowledge management (KM) and waste identification and value focus (expressed on both 5C and standardisation principles) were considered the concepts affecting most the PSS development process. In particular, the analysis underlined that concurrent engineering is the most appropriate approach to manage the PSS design process, supporting the identification and the definition of the most appropriate integration of components and services, aiming at the resolution of the possible design trade-off along the whole development process, stage-by-stage. Effective KM generally impels the adoption of IT solutions, either as a collaborative design platform or as simulation IT-based tool. Waste elimination and value identification are based on the application of methods and tools for eliminating wastes, like the 5C approach (clear out, configure, clean and check, conformity, custom and practice), or for supporting standardisation practices, which foster continuous improvement awareness.

Even though something has already been discussed so far in literature, further investigation is still needed to clarify which of these approaches could be suitable to support the PSS development in a systematic way. Based on Sassanelli et al. (2015b), tools already adopted in the service domain are also functional to the PSS development: value stream mapping and process modelling (allowing visual management and waste elimination), multifunctional teams and ICT, have been considered strategic to understand the real needs better and listen the 'voice' of the customer also in the PSS domain.

2.4 Research questions

The research context clarification phase, illustrated in the previous subsections, supported a better definition of the research objective, i.e., first of all to investigate the current status of research in the lean PSS design and development research context. Linked to this main objective, this paper wants to provide a clear definition of lean PSS and outline the research agenda of this very recent stream.

Based on the objectives reported, the following research question (RQ) has been formulated:

RQ1 What is lean PSS?

In order to be able to answer to this research questions two more punctual research questions have been defined

RQ1.1 Which are the main research categories in the area of lean PSS? How lean PSS design contributes to this research context?

RQ1.2 Which are the opportunities related to this new research topic?

In the next section, the research methodology entitled to answer to the defined RQs is reported.

3 Research methodology

In order to answer to the aforementioned RQs, a research methodology has been adopted. In particular, a systematic literature review (Brereton et al., 2007; Sassanelli et al., 2019; Smart et al., 2017; Software Engineering Group, 2007) has been conducted to analyse the evolution and the trends of this rising research stream, launched in the recent years through two main seminal papers (Baines et al., 2007; Sassanelli et al., 2015a), also analysing its application in the development and design context.

Thus, the keywords, 'lean' and 'product service system' (and its acronym 'PSS') have been used to detect all the documents contributing to the definition of the lean PSS research context. In addition, authors took in account also 'development' and 'design' among the main keywords for this research since the considered seminal articles focused on these two specific phases, indicating the methods and practices related to the beginning of life as the most strategic ones to discover the relationship between lean thinking and PSS (Table 1).

Table 1 Literature review searches by keywords

Search	*Science Direct*	*Scopus*	*Web of Science*
'lean product service system'	14	24	1
'lean PSS'	11	13	6
'lean PSS design'	8	10	5
'lean product service system design'	0	0	0
'lean' AND 'PSS design'	4	65	8
'lean' AND 'product service system design'	24	75	1
'lean product service system' AND 'design'	13	24	1
'lean PSS' AND 'design'	11	12	5
'lean PSS development'	1	0	0
'lean PSS' AND 'development'	12	4	1
'lean product service system' AND 'development'	14	2	1
'lean product service system development'	0	1	0
Total	112	230	29
Total after selection based on the three criteria	24	26	14
Total (avoiding redundancies among DBs)		*31*	

In particular, Figure 1 fully explains the research strategy adopted in the systematic literature review: searches on Science Direct, Scopus and Web of Science databases (using the 11 strings reported in Table 1) led to 371 results. Moreover, 37 documents were detected through cross-referencing processes and 12 through manual search. Finally, seven more serendipity or recommended by experts documents, deriving from

both the contexts of lean thinking and PSS, were added to the list. The total amount of papers found has then been selected based on three main analysis criteria:

1 by redundancies detection and removal (among both searches and databases)

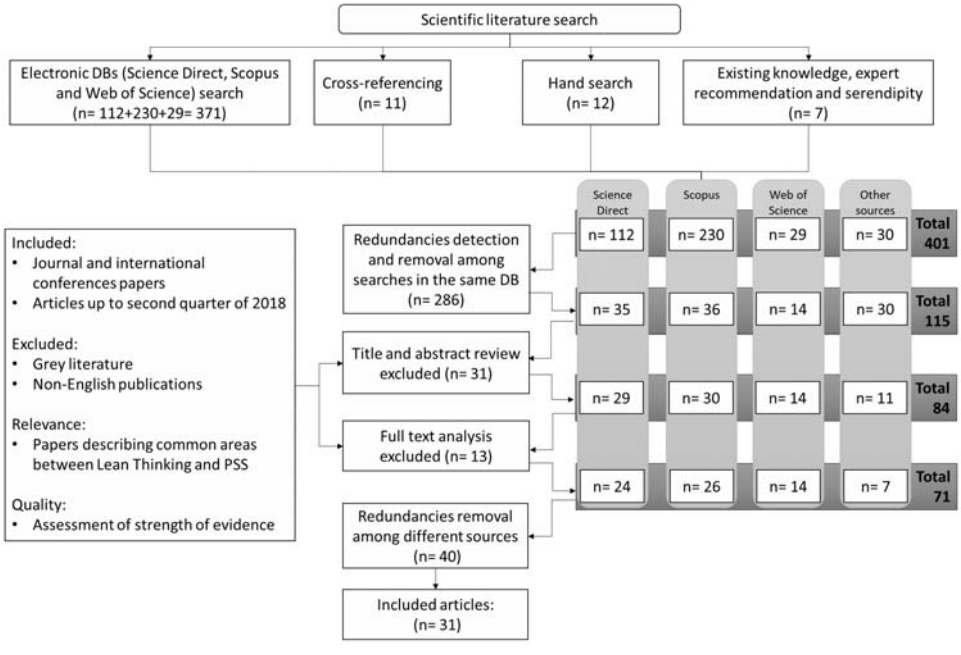
2 by title, abstract and keywords analysis

3 by entire manuscript analysis.

Through the criteria application, the total amount of documents found was reduced to a final set of 31 selected articles that have been deeply analysed by two authors (to avoid bias of interpretation during the review).

Thus, based on the results of the literature analysis performed, gaps and opportunities disclosed by the adoption of lean thinking in the specific context of PSSs have been unveiled, clarified and defined. This opens the room to further researches in the upcoming research context of lean PSS.

Figure 1 Research strategy adapted by Sassanelli et al. (2019) and Smart et al. (2017)



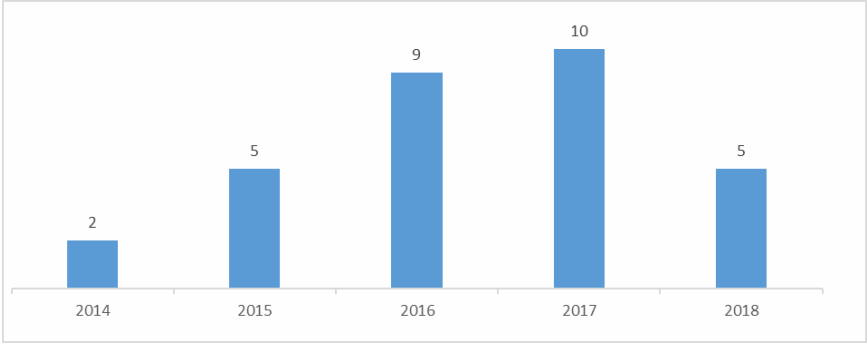
4 Current state of the art: sample description and analysis

In this section, the results of the systematic literature review, aimed at investigating and exploring the concept of lean PSS, are reported.

First of all, current findings say that authors' interest in lean PSS topic had a surge especially during the last years: this can be explained by the fact that manufacturers are always more absorbed by the service economy, often recurring to PSS business models to adjust their structure and shift towards servitisation. Moreover, two seminal papers have been identified (Baines et al., 2007; Sassanelli et al., 2015a). Figure 2 provides the

general publications trend, displaying how the papers considered in the literature review started exactly after the advent of these two main publications and had a continuous increase along the following years.

Figure 2 Historical series of results by year (see online version for colours)



A total of eight articles (25.8%) were published in scientific journals [i.e., CIRP Journal of Manufacturing Science and Technology (2), Journal of Cleaner Production (1), International Journal of Product Lifecycle Management (1), Journal of Manufacturing Systems (1), International Journal of Product Development (1), International Journal of Agile Systems and Management (1), International Journal of Advanced Manufacturing Technology (1)]: it cannot be detected a preferred journal among those involved in this research context. Instead, 23 (74.2%) were published in proceedings of scientific conferences (most of them published in Procedia CIRP of the Conference on Industrial Product-Service Systems): the majority of these works are indeed conceptual papers and further improvements are needed.

Then, considering the nationality of authors, the highest number of contributions comes from European countries (93.5%), followed by Brazil and Mexico. Considering the nationality of the articles' first author, Italy is the major contributor, with 11 documents (35.5%), followed by Greece with six (19.35%), Sweden with four (12.9%) and Portugal and UK, both with three (9.7%).

The analysis of keywords reported in the articles led the authors to the definition of five macro-categories in which the lean PSS research context could be declined, answering to the RQ1.1. In Table 2, starting from the first level keywords linked to each of the five macro-categories, the related characterising second level keywords are grouped to unveil the collateral streams and topics.

This analysis reveals that the majority of the contributions selected in the literature review, 22 of 31, are aimed at improving the development phase of PSSs, also sometime focusing on the concept and detailed design phase. This is in line with what previous authors have mentioned, instead, three of them want to explore the link between lean and production/service operation. A last stream is also focused on the PSS leanness evaluation and the provision of consistent KPIs, most of the time aimed at supporting the development phase of PSSs (Figure 3).

Table 2 Keywords analysis

	Category 1	*Category 2*	*Category 3*	*Category 4*	*Category 5*
1st level keywords	• Conceptual design • Preliminary design	• Lean product service system (LeanPSS) • Design for X • PSS design and engineering • PSS design • Design guideline • Concurrent engineering	• Lean product service system development • Lean implementation • PSS lean design methodology • PSS development • Engineering environment • Integrated design	• Leanness • KPI • Lean rules	• Lean service • Lean production
2nd level keywords	• Value driven design • Value model • Integrated product-service design	• Eco-innovation • Context sensitivity • TRIZ	• Sentiment analysis, • Circular economy, • Value co-creation • Sentiment • Context sensitivity • Customer • Opinion • Feedback data	• Knowledge management • Context sensitivity	• Remanufacturing • Circular economy • Knowledge management
Resulting topic of categories	• PSS concept	• PSS design	• PSS development	• PSS lean evaluation and KPI	• Lean service operation and lean production

Figure 3 Research main topics (see online version for colours)

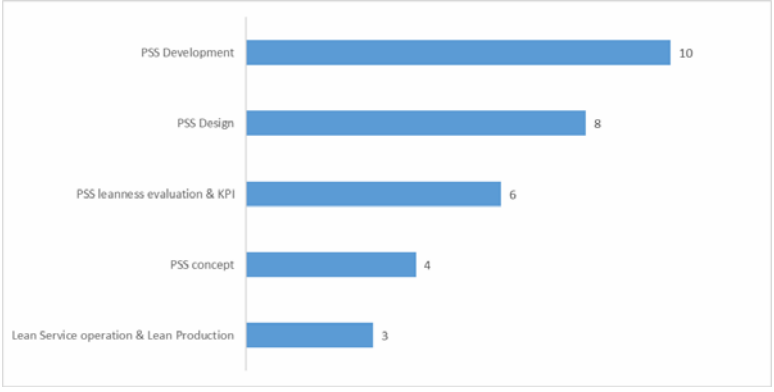


Figure 4 Main typologies of research (see online version for colours)

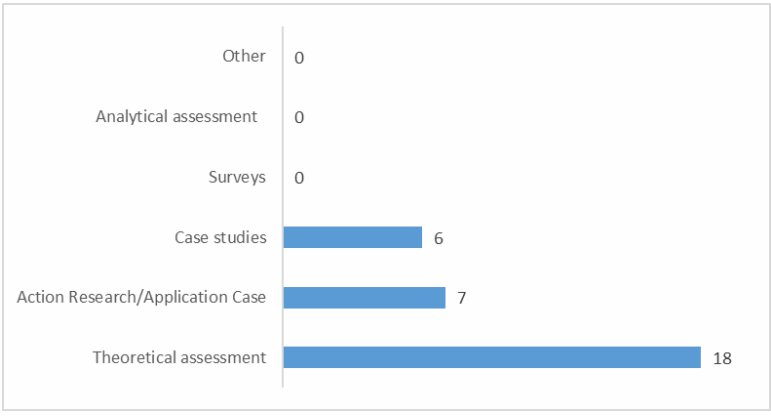


Figure 4 also shows the research approaches adopted in studying lean PSS in its different declinations. It confirms that the majority of the papers proposed an analysis/framework/platform/method, most of the time at a conceptual level and thus still needs further improvements. However, 13 of them (41.9%) also supported their theoretical results with industrial applications: case studies and application cases were indeed used to validate and give practical relevance to the researches.

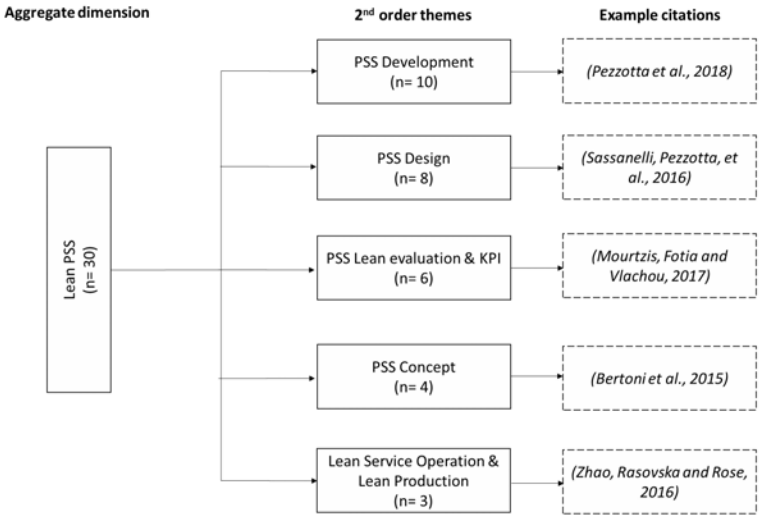
From this, it can be deduced that lean PSS is a recent concept: it represents a niche research context mostly deriving from the application of lean thinking to the design and development of PSSs. Academic interest in exploring this area is continuously rising, sometimes also involving practitioners through application cases and case studies.

More in detail, the authors want to remark that the research topic aiming at investigating lean PSSs, with a particular focus on the development and design perspective, was raised by Baines et al. (2007) who stated that the majority of the methodologies proposed in literature for PSS design and development "have a clear heritage in concurrent engineering and lean product development methodologies: identification of customer value, early involvement of the customer in the system design, effective communication, information sharing, and continuous improvement". This statement brought researchers to slowly increase their awareness about the value of lean thinking also in the PSS context and in particular in its development. The first valuable analysis conducted to verify the validity of this important statement, investigating the common points between the two research contexts, was conducted by Sassanelli et al. (2015a): they defined which aspects belonging to lean thinking are already applied in PSS development, also uncovering shortcomings and deficiencies of the methods proposed by the scientific literature so far. In Sassanelli et al. (2015b), it was also defined which lean thinking aspects could positively affect PSSs development and which tools could be more suitable to develop lean PSS, with the final aim to provide companies with best practices improving the PSS development processes performances in a more systematic way.

One year before, Meuris et al. (2014) highlighted the importance of specific IT-based tools as an intrinsic value in the establishment of a lean Industrial PSS design process, with the introduction of metrics and the discovery of hidden information in a local and functional deployed design process. Moreover, Elnadi and Shehab (2015) examined for the first time the factors determining the successful implementation of lean practices in

PSS: the main enablers detected were management status, work process, customers' relationship, employees' status and, finally, suppliers' relationship.

Figure 5 Dimension scheme of lean PSS research context



Source: Smart et al. (2017)

As shown in Figure 5, among the articles selected, lean was introduced to enhance several lifecycle phases (concept, design and development, production and service operation) but also to support their monitoring and evaluation through KPIs definition. In the following, each of these macro topics is described.

4.1 Category 1: PSS concept

Starting from the concept phase, Bertoni et al. (2015) discussed about gaps and opportunities for cross-pollination between value driven design (VDD) and lean product service development (LPSD) to stimulate the use of value-driven method and tools since the concept phase of PSSs. Through the concurrent use of these two approaches, they highlighted the relevance of value innovation methods and tools (as value models, value visualisation and knowledge maturity) as boundary objects for cross-functional discussion and decision making. Their final aim was to raise decision makers' awareness about the 'value' of different design alternatives in the early stage of PSS development when decisions affect the major part of the value created. Belonging to the same research stream, Panarotto et al. (2016) provided the results of experimental activities aiming at investigating the role of 'value models' as 'boundary objects' facilitating cross-functional discussions in the PSS conceptual design phase. They found that, compared to traditional requirement checklists, value models highlight activities related to the clarification of the problem domain and needs and of the lifecycle aspects of a solution concept. They also have the ability to facilitate cross-boundary discussion in the early phases of the PSS design process and to act as boundary objects that provide a common platform for knowledge sharing within the cross-functional team. In another of their works, Bertoni et al. (2016) elaborated the gaps and opportunities for adopting VDD for PSS,

highlighting the opportunity for introducing optimisation models from VDD in the PSS design process, with more qualitative value assessment logic. The conclusion of this research is the proposition of a methodological approach, also applied and verified in aerospace and road construction equipment sector industries.

Haber and Fargnoli (2017) proposed a novel procedure, the functional engineered product-service system (FEPSS), based on morphological thinking to conceptualise PSS offerings, it is effective in merging stakeholders' needs, development activities, as well as products and services elements enclosed in the solution.

4.2 Category 2: PSS design

More are the contributions fostering the adoption of lean practices in PSS design.

Pacheco et al. (2016) proposed a model enabling the use of analytical tools, with impact in eco-innovation based on TRIZ and lean PSS, to identify, eliminate and reduce waste: the TRIZ can give an important contribution in the eco-innovation in a lean PSS design.

Sassanelli et al. (2016) proposed the design for product service supportability (DfPSSu) approach, integrating DfX approaches in the concept of lean design for enhancing the serviceability of the product. Based on a framework proposed in literature by Dombrowski et al. (2014), the aim of this approach is to support the service provision since the PSS design phase. DfX approaches are used under a lean perspective as a connection to derive the required product properties (e.g., user-friendliness, maintainability) from an appropriate set of concrete product characteristics (e.g., dimensions, materials, structure or shape) and inverted. DfPSSu approach requires a synergic use of several criteria that have to be satisfied with a lifecycle perspective to meet the different stakeholders' needs, with the final aim of systematically integrating product and service components, mainly modifying the product and the supporting infrastructure parts more to better support the service during their lifecycle.

Based on this approach, Sassanelli et al. (2017a, 2017b) proposed a methodology generating new design for X (DfX) guidelines to support the early integration of service features already in the product design of PSS. This methodology can raise engineers' consciousness in designing PSSs in a systematic and integrated way and provides insights into the link between the design process of PSS and the design knowledge generation in terms of guidelines and rules. The methodology has been tested in two applications cases belonging to two different industries (machinery for shoes production and mould making). Furthermore, Ebikake et al. (2018) investigated the place of design for supply chain (DfSC) into the DfPSSu concept to explore DfX from a value creation perspective. That is because DfSC encourages innovation in linking product design, process design and SC design together, according to the Concurrent Engineering paradigm. Finally, Sassanelli et al. (2018a), grounded on a combination of lean and DfX-based theories, also aimed at improving the knowledge formalisation and sharing with the support of IT tools. The lean design rules tool (LDRT) is able to manage the PSS design knowledge generated. It was proposed to be integrated into a more holistic engineering environment able to interact with product lifecycle management (PLM) systems.

Also Mourtzis et al. (2016c), with the aim to enhance the knowledge exchange and the collaborative process of PSS design, proposed a conceptual eco-innovative framework for lean PSS design, explaining how enabling technologies such as cloud technology, social media and networking, knowledge management, and context

sensitivity could be combined for the improvements of PSS design and evaluation procedures.

4.3 Category 3: PSS development

As in the design phase, also in the PSS development phase there is room to use lean thinking in a proficient way.

Neves-Silva et al. (2016) proposed the DIVERSITY approach, consisting of a methodology and engineering environment supporting companies in using social media to realise a context-sensitive lean design process of PSSs. It supports the complete value chain to enable interaction with customers and consumers, fostering customisation of features and services, and even co-design. DIVERSITY aims at providing a cloud-based engineering environment and a set of methods/tools to support the collaborative design of PSS based on the knowledge captured and shared across the value-chain actors and the PSS life cycle. It relies on a combination of four main areas of research: lean PSS design; key performance indicator (KPI) assessment; context sensitivity; and sentiment analysis. Pina et al. (2017) focused on the last of these elements, trying to solve the issue to efficiently merging and showing information coming from customers in a meaningful and straightforward way to the designer of new products and systems. By identifying important parameters in posts and opinions, data becomes easier to be categorised and, consequently, comfortably detected by a designer. Campos et al. (2018) presented a software platform that supports companies in developing PSSs using feedback information collected across the value chain.

Sala et al. (2017) proposed the PSS lean design methodology (PSSLDM), considering the entire PSS lifecycle, from its conceptualisation (stating form customers' needs) to the monitoring of its performance (once released on the market), to improve its design and to detect possible future improvements. With the aim of supporting companies in exploiting the PSSLDM, the DIVERSITY platform, an aggregation of tools that cooperate in designing a PSS properly, has been introduced: Sala et al. (2018) presented their application in CAREL SpA, highlighting their benefits. In order to better exploit the power of the PSSLDM and of the connected DIVERSITY platform, Pezzotta et al. (2017), provided an analysis of how customers and other stakeholders can be involved in value co-creation activities in a collaborative PSS development process, and detected which methods should be used to achieve their active participation in value co-creation. Their final aim was to shift the focus of PSS development approaches from a customer-centric perspective to a stakeholder-centric co-creation one.

Romero and Rossi (2017) made a further step introducing the concept of circular lean product-service systems (CLPSSs). They demonstrated the compatibility of circular economy and lean principles in the context of PSSs: their integration foster customer-oriented solutions minimising resources consumption and enhancing the ultimate value-added to the end-user, contributing to both manufacturing and design phase enhancement.

Finally, Pezzotta et al. (2018) introduced the product service lean design methodology (PSSLDM), explaining how the different methods supporting its conduction contribute to design an integrated PSS properly: they are linked by lean rules in each of its phases (starting from customer analysis, going through solution concept and detailed design, until the offering analysis) and better supporting the detail design of both product and service components.

4.4 Category 4: PSS lean evaluation and KPI

As evident from the results of this literature review, PSS lean evaluation and KPI has been considered a relevant area for lean PSS design and development.

Elnadi and Shehab (2014) proposed a conceptual model to measure the degree of PSS leanness based on five lean enablers (supplier relationship, management leanness, workforce leanness, process excellence, and customer relationship), declined in 21 criteria and 73 attributes. Based on this model, they proposed an index to measure the degree of PSS leanness in manufacturing companies quantitatively.

Mourtzis et al. (2016a) created a comprehensive and applicable library of lean rules to formalise, identify and classify lean rules. Through lean rules, the designer wants to show how a company can apply lean to all its organisational levels.

Connected to this, Mourtzis et al. (2018) introduced a framework for the evaluation and improvement of the lean PSS design using key performance indicators (KPIs), lean rules, and sentiment analysis, aiming to feed all the stages of PSS development lifecycle. Via a context-sensitivity analysis (CSA) tool, an appropriate set of KPIs is chosen and proposed to the PSS designer. In Mourtzis et al. (2016a), an ontology knowledge model for KPIs and lean rules is proposed to support the CSA. Then, through sentiment analysis the polarity of the customer opinions regarding the PSS offerings is defined. Therefore, lean rules are provided to the designer to guarantee the minimisation of wasteful activities, thanks to the availability of feedback coming from the manufacturing, shop-floor experts and the different typologies of customers.

Mourtzis et al. (2017b) proposed a methodology for improving the leanness of PSS design, through the combination of real-time KPI monitoring with lean principles and practices: the total leanness index (TLI) of the procedures is obtained through a correlation of typical wastes with the metrics used in the calculation of KPIs. The proposed lean rules extraction methodology (LeanREM) automatically provides lean rules to improve the performance of PSS lifecycle phases, based on the assessment of TLI. Moreover, Mourtzis et al. (2017a) proposed a methodology estimating the maintenance time: it is based on KPI monitoring collected in a knowledge repository and processed using a case-based reasoning (CBR) technique. A significant reduction in the number of iterations between customers and the engineering department, improved accuracy of maintenance time estimation and thus an increased customer satisfaction were noticed.

4.5 Category 5: lean service operation and lean production

Regarding lean service operation and lean production, Zhao et al. (2016) proposed a model allowing to link service *muda* (previously detected by Bicheno and Holweg (2016) similar to production *muda* but more related to human factors) with lean tools and KM levels.

Kurilova-Palisaitiene et al. (2018) studied how lean production could be used to tackle remanufacturing process challenges and contribute to shorter lead times in PSS lifecycle. As a result, they detected seven lean-based improvements:

1 standard operations, instructions or/and checklists

2 continuous flow

3 kanban

4 teamwork

5 factory layout for continuous flow

6 employee cross-training and learning through problem solving

7 supplier partnership.

Resta et al. (2015) proposed a theoretical framework for the planning and management of lean PSS operations of product-oriented PSSs. Its aim is to support the delivering of value through a PSS solution, also addressing the evolution of PSS providers' organisation and operations both internally and externally to the company and aiding service activities (streamlining the analysis and reengineering of the PSS business model through lean). The proposed framework divides the characteristics of lean product-centric PSS operations in: process and technology, capacity, facilities, supply chain positioning, planning and control, human resources, quality control, product/service range, new product/service introduction, performance measurement, supplier relations, customer relations. However, the authors highlighted that supporting the application of lean methods and approaches to improve PSS operations could not be enough. Indeed, the success in approaching PSS is strictly dependent on the organisation structure and processes of both the company and the value network involved in its delivery. In this context, lean could actively support and affect the change of mindset needed to operate on these elements.

Therefore, the next subsection wants to grasp the opportunities coming from each of the lean PSS categories presented above, also providing an overall interpretation of what is lean PSS, answering to RQ1.2.

5 Discussing lean PSS gaps and opportunities

Starting from the keywords analysis' results reported in Table 2, this section is aimed to define lean PSS and the main streams and opportunities per each lean PSS category detected (*PSS concept*, *PSS design*, *PSS development*, *PSS lean evaluation and KPI*, *lean service operation* and *lean production*).

Based on the literature analysis performed, lean PSS is defined as a value-driven approach pursuing continuous improvement along the entire lifecycle of the integrated PSS provided. Both product and service components, as well the supporting infrastructure and network, benefit from this approach. Its aim is to create value and eliminate wastes occurring along the different phases of the PSS lifecycle, from the design and manufacturing of the product through the provision of the related services up to the disposal. In this context, knowledge, managed through supporting infrastructure (often represented by digital technologies) and networks, represents a key driver to pursue the continuous improvement of the PSS along a long-lasting customer-driven lifecycle. In particular, design knowledge (as DfX guidelines) has been considered a reliable mean to make the product more suitable to support service features according to both customer needs and providers constraints.

In detail, a focus on each category detected is provided to explain this uprising research topic better.

PSS concept focuses on the detection of the value for all the downstream operations to enable the delivery to the customer of an integrated solution composed of product and services. In the following phase, the PSS design, problem-solving methods are used to properly address the value previously defined through the support of reusable knowledge: Design for X (DfX) and TRIZ are the means suggested to conduct the solution embodiment, with particular heed to eco-innovation aspects. Moreover, a key role is played by context sensitivity. New enabling technologies (Cattaneo et al., 2017) allow the gathering and analysis of big volumes of data from distributed heterogeneous IT systems and, at the same time, allow PSS design improvements by processing the experiences of the business customers, consumers, designers, shop-floor, and by providing feedback to the design phase.

Indeed, PSS development, which by definition encapsulates concept and detailed design phases, enlightens the importance of the adoption of supporting technologies, under the shape of an engineering environment, to enable a profitable use of the data flows occurring along the PSS lifecycle. In this way, thanks also to more efficient customer involvement and interaction (Kimita et al., 2016), the obtained knowledge (often under the shape of guidelines and rules) is used by designers and engineers to improve, along its entire lifecycle, the PSS to be delivered. In this sense, an additional aim seems to be also the transformation of the PSS lifecycle from a linear configuration to a closed loop, according to the circular economy (CE) paradigm (The Ellen MacArthur Foundation, 2015), avoiding to neglect during the PSS development not only the use and service delivery phases but also disposal.

Indeed, under a lean perspective, also service operation and production remark KM relevance with the final aim of addressing CE, mostly through the concept of remanufacturing.

Finally, in line with all the others categories, PSS lean evaluation and KPI category is oriented at continuously monitoring, through the use of lean rules and KPIs, the entire PSS lifecycle that is fed in each of its stages by the significant amount of feedback and opinions coming not only by business customers and consumers but also by designers and shop-floor.

6 Conclusions, research agenda and further researches

In this article, a systematic literature review regarding the application of lean thinking in the PSS context has been conducted. After defining the characteristics of lean thinking (focusing more in detail on LPD theory) and contextualising them in the PSS domain, the results of the review have been reported: lean PSS has been defined (answering to RQ1) and its main characteristics provided and detailed (replying to RQ1.1).

As first result, it has been found that lean PSS is an already existing area of research, raised in 2007 (Baines et al., 2007) and formally arisen in 2015 (Sassanelli et al., 2015a), but still embryonic and under-investigated, as confirmed by the low number of articles selected in this literature review. The analysis of these articles contributed to the definition of lean PSS as a research topic composed of five main areas: PSS concept, PSS design, PSS development, PSS lean evaluation and KPI, lean service operation abd lean production.

Among these, just counting the related papers, the most contributing area is PSS development. Thus, lean PSS represents a niche research context mainly deriving by the

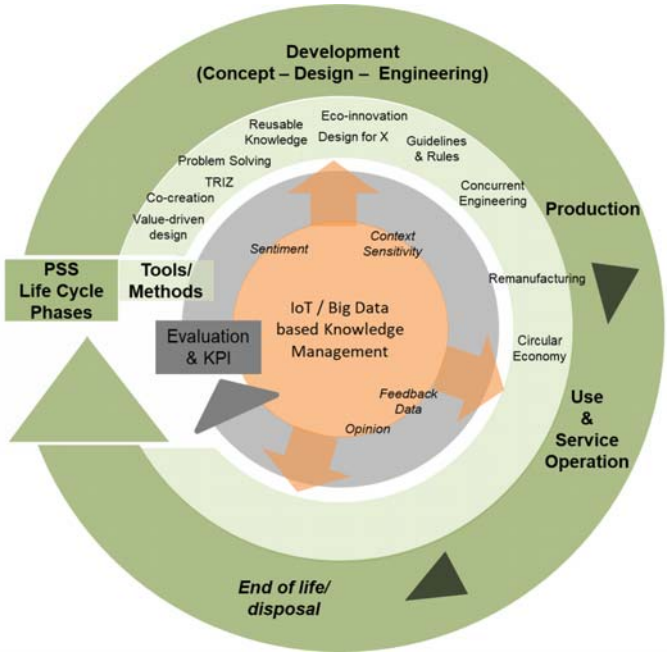
application of lean thinking to the development of PSSs. Dealing with this particular area, Baines et al. (2007) stated that the majority of the methodologies proposed in literature for PSS design and development "have a clear heritage in concurrent engineering and lean product development methodologies: identification of customer value, early involvement of the customer in the system design, effective communication, information sharing, and continuous improvement". This statement fully reflects the findings obtained with the analysis proposed in this article: coupling the PSS concept with lean thinking, an approach strongly focused on the customer value, fosters a participatory value-driven attitude of the user along the entire PSS lifecycle through the support of enabling digital technologies, gathered and coordinated by an engineering environment. As suggested in Romero and Rossi (2017), lean PSS lifecycle has to be considered circular in order to adequately accomplish customer value: in this closed loop, wastes should be streamlined according to a continuous improvement approach and customers involved (Kimita et al., 2016) according to a sustainable cyclical pattern. Indeed, PSS business model has recently been detected in literature as the most suitable one to pursue CE objectives (Rosa et al., 2019a, 2019b). Therefore, the lifecycle of the lean PSS needs to be considered circular (Figure 6): it is fed from the beginning by the customer value, driving the integration of product and services already in the concept phase. This integration is supported during the design stage by problem-solving methods as DfX and TRIZ, fostering the concurrent engineering of the PSS and enabling engineers to consider different aspects under an innovative direction. Moreover, the lean PSS lifecycle is divided into different stages: development (composed of concept, design and engineering), production, use and service operation phase, and end of life/disposal. Along all these phases, a continuous exchange of information takes place, giving birth to knowledge under the shape of both Design Guidelines and KPIs. In this context, digital technologies represent, of course, the driver enabling the pursuit of knowledge along the PSS lifecycle.

Under this perspective, it has to be highlighted the importance of development and design practices to adequately close the PSS loop towards CE. They can ease and support the conception and design of integrated solutions to address both PSS provider's constraints and customer's needs along the entire lifecycle in a systematic way.

However, further investigations are needed in this direction, replying to RQ1.2. From one side a literature review is needed to analyse the extant PSS design and development methodologies deeply and to verify their actual orientation towards LPD and CE theories. From the other, an in-depth analysis of the knowledge-based design methods (e.g., DfX approaches) suitable to support CE along the PSS development would be needed: they would constitute a valuable starting point for practitioners (designers and engineers of manufacturing companies) approaching PSS design according to lean and CE paradigms.

Moreover, an analysis of the digital technologies, referring to the Industry 4.0 context, that could foster an integrated management of the circular lifecycle of the lean PSS (thus, from conception up to disposal) would be helpful. It would support manufacturers willing to deliver lean circular PSSs to understand how to practically manage data and information available both inside and outside to the company boundaries and to grasp valuable knowledge to continuously improve the circular lifecycle.

Figure 6 Overview of lean PSS: circular lifecycle perspective (see online version for colours)



Finally, this research context is also characterised by a main limitation. The majority of the contributions analysed derive from a unique European project, DIVERSITY (GA 636692): thus, they report a limited perspective, even if applied on a cross-sectoral sample of cases, since deriving by research activities of a unique consortium. Indeed, the context analysed represents a multi-faceted research connecting different topics through several methods and tools, mainly focused on supporting the beginning of life of PSS (when it is conceived, designed and developed). For this reason, further contributions to strengthen and practically validate the connection between lean thinking and PSS along the whole PSS lifecycle are needed.

References

Aurich, J.C., Fuchs, C. and Wagenknecht, C. (2006) 'Life cycle oriented design of technical product-service systems', *J. Clean. Prod.*, Vol. 14, pp.1480–1494 [online] https://doi.org/10.1016/j.jclepro.2006.01.019.

Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M. and Wilson, H. (2007) 'State-of-the-art in product-service systems', *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, Vol. 221, pp.1543–1552 [online] https://doi.org/10.1243/09544054JEM858.

Balocco, R., Cavallo, A., Ghezzi, A. and Berbegal-Mirabent, J. (2019) 'Lean business models change process in digital entrepreneurship', *Bus. Process Manag. J.* [online] https://doi.org/10.1108/BPMJ-07-2018-0194.

Bertoni, A., Bertoni, M., Panarotto, M., Johansson, C. and Larsson, T. (2015) 'Expanding value driven design to meet lean product service development', *Procedia CIRP*, Vol. 30, pp.197–202 [online] https://doi.org/10.1016/j.procir.2015.02.153.

Bertoni, A., Bertoni, M., Panarotto, M., Johansson, C. and Larsson, T.C. (2016) 'Value-driven product service systems development: methods and industrial applications', *CIRP J. Manuf. Sci. Technol.*, Vol. 15, pp.42–55 [online] https://doi.org/10.1016/j.cirpj.2016.04.008.

Beuren, F.H., Ferreira, M.G.G. and Miguel, P.A.G. (2013) 'Product-service systems: a literature review on integrated products and services', *J. Clean. Prod.*, Vol. 47, pp.222–231 [online] https://doi.org/10.1016/j.jclepro.2012.12.028.

Bicheno, J. and Holweg, M. (2016) *The Lean Toolbox – A Handbook for Lean Transformation*, 5th ed., Picsie Books, Buckingham.

Boehm, M. and Thomas, O. (2013) 'Looking beyond the rim of one's teacup: a multidisciplinary literature review of product-service systems in information systems, business management, and engineering design', *J. Clean. Prod.*, Vol. 51, pp.245–260 [online] https://doi.org/10.1016/j.jclepro.2013.01.019.

Brandstotter, M., Haberl, M., Knoth, R., Kopacek, B. and Kopacek, P. (2003) 'IT on demand – towards an environmental conscious service system for Vienna (AT)', *Third International Symposium on Environmentally Conscious Design and Inverse Manufacturing – EcoDesign'03*, IEEE Cat. No. 03EX895, pp.799–802.

Brereton, P., Kitchenham, B.A., Budgen, D., Turner, M. and Khalil, M. (2007) 'Lessons from applying the systematic literature review process within the software engineering domain', *J. Syst. Softw.*, Vol. 80, pp.571–583 [online] https://doi.org/10.1016/j.jss.2006.07.009.

Campos, A.R., Correia, A.T., Mourtzis, D., Margarito, A. and Ntalaperas, D. (2018) 'Engineering environment to support product-service design using value chain data', *2017 Int. Conf. Eng. Technol. Innov. Eng. Technol. Innov. Manag. Beyond 2020 New Challenges, New Approaches, ICE/ITMC 2017 – Proc.*, January, pp.1465–1471 [online] https://doi.org/10.1109/ICE.2017.8280055.

Cattaneo, L., Rossi, M., Negri, E., Powell, D. and Terzi, S. (2017) 'Lean thinking in the digital era', in Ríos, J., Bernard, A., Bouras, A. and Foufou, S. (Eds.): *Product Lifecycle Management and the Industry of the Future. PLM 2017. IFIP Advances in Information and Communication Technology*, Vol. 517, pp.1–12.

Cavalieri, S. and Pezzotta, G. (2012) 'Product-service systems engineering: state of the art and research challenges', *Comput. Ind.*, Vol. 63, pp.278–288 [online] https://doi.org/10.1016/j.compind.2012.02.006.

Centre for Sustainable Design (2002) 'Sustainable service systems, (3S)', *Transition towards Sustainability: Sixth International Conference*.

Dombrowski, U., Schmidt, S. and Schmidtchen, K. (2014) 'Analysis and integration of design for X approaches in lean design as basis for a lifecycle optimized product design', *Procedia CIRP*, Vol. 15, pp.385–390 [online] https://doi.org/10.1016/j.procir.2014.06.023.

Ebikake, O.E., Sassanelli, C. and Terzi, S. (2018) 'PSS design through design for supply China: state of the art review', *Procedia CIRP*, pp.198–203, Elsevier B.V. [online] https://doi.org/10.1016/j.procir.2018.03.279

ELIMA (2005) *Environmental Life Cycle Information Management and Acquisition for Consumer Products*.

Elnadi, M. and Shehab, E. (2015) 'Main enablers and factors for successful implementation of lean product-service systems', *Int. J. Agil. Syst. Manag.*, Vol. 8, Nos. 3/4, pp.332–354.

Elnadi, M. and Shehab, E. (2014) 'A conceptual model for evaluating product-service systems leanness in UK manufacturing companies', *Procedia CIRP*, Vol. 22, pp.281–286 [online] https://doi.org/10.1016/j.procir.2014.07.132.

Fuchs, V.R. (1968) *The Service Economy*, National Bureau of Economic Research.

Goedkoop, M.J., Van Halen, C.J.G., te Riele, H.R.M. and Rommens, P.J.M. (1999) *Product Service Systems, Ecological and Economic Basics*, Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), Vol. 36, pp.1–122.

Haber, N. and Fargnoli, M. (2017) 'Design for product-service systems: a procedure to enhance functional integration of product-service offerings', *Int. J. Prod. Dev.*, Vol. 22, p.13 [online] https://doi.org/10.1504/IJPD.2017.10007553.

Kimita, K., Sugino, R., Rossi, M. and Shimomura, Y. (2016) 'Framework for analyzing customer involvement in product-service systems', *Procedia CIRP*, Vol. 47, pp.54–59 [online] https://doi.org/10.1016/j.procir.2016.03.232.

Kurilova-Palisaitiene, J., Sundin, E. and Poksinska, B. (2018) 'Remanufacturing challenges and possible lean improvements', *J. Clean. Prod.*, Vol. 172, pp.3225–3236 [online] https://doi.org/10.1016/j.jclepro.2017.11.023.

Manzini, E. and Vezzoli, C. (2003) 'A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize', *J. Clean. Prod.*, Vol. 11, pp.851–857 [online] https://doi.org/10.1016/S0959-6526(02)00153-1.

Meuris, D., Herzog, M., Bender, B. and Sadek, T. (2014) 'IT support in the fuzzy front end of industrial product service design', *Procedia CIRP*, Vol. 16, pp.379–384 [online] https://doi.org/10.1016/j.procir.2014.01.033.

Mont, O. (2001) *Introducing and Developing a Product-Service System (PSS) Concept in Sweden*, IIIEE Reports 2001:6, Lund University, Lund.

Mont, O. and Lindhqvist, T. (2003) 'The role of public policy in advancement of product service systems', *J. Clean. Prod.*, Vol. 11, pp.905–914 [online] https://doi.org/10.1016/S0959-6526(02)00152-X.

Mourtzis, D., Boli, N. and Fotia, S. (2017a) 'Knowledge-based estimation of maintenance time for complex engineered-to-order products based on KPIs monitoring: a PSS approach', *Procedia CIRP*, Vol. 63, pp.236–241 [online] https://doi.org/10.1016/j.procir.2017.03.317.

Mourtzis, D., Fotia, S. and Vlachou, E. (2017b) 'Lean rules extraction methodology for lean PSS design via key performance indicators monitoring', *J. Manuf. Syst.*, Vol. 42, pp.233–243 [online] https://doi.org/10.1016/j.jmsy.2016.12.014.

Mourtzis, D., Fotia, S. and Vlachou, E. (2016a) 'PSS design evaluation via KPIs and lean design assistance supported by context sensitivity tools', *Procedia CIRP*, Vol. 56, pp.496–501 [online] https://doi.org/10.1016/j.procir.2016.10.097.

Mourtzis, D., Fotia, S., Vlachou, E. and Koutoupes, A. (2018) 'A lean PSS design and evaluation framework supported by KPI monitoring and context sensitivity tools', *Int. J. Adv. Manuf. Technol.*, Vol. 94, pp.1623–1637 [online] https://doi.org/10.1007/s00170-017-0132-5.

Mourtzis, D., Papathanasiou, P. and Fotia, S. (2016b) 'Lean rules identification and classification for manufacturing industry', *Procedia CIRP*, Vol. 50, pp.198–203 [online] https://doi.org/10.1016/j.procir.2016.04.097.

Mourtzis, D., Fotia, S., Gamito, M., Neves-Silva, R., Correia, A.T., Spindler, P., Rossi, M., Pezzotta, G. and Rossi, M. (2016c) 'PSS design considering feedback from the entire product-service lifecycle and social media', *Procedia CIRP*, Elsevier B.V, pp.156–161 [online] https://doi.org/10.1016/j.procir.2016.03.092.

Neves-Silva, R., Pina, P., Spindler, P., Pezzotta, G., Mourtzis, D., Lazoi, M., Ntalaperas, D. and Campos, A.R. (2016) 'Supporting context sensitive lean product service engineering', *Procedia CIRP*, pp.138–143 [online] https://doi.org/10.1016/j.procir.2016.03.103.

Oliva, R. and Kallenberg, R. (2003) 'Managing the transition from products to services', *Int. J. Serv. Ind. Manag.*, Vol. 14, pp.160–172 [online] https://doi.org/10.1108/09564230310474138.

Pacheco, D.A.D.J., ten Caten, C.S., Jung, C.F., Sassanelli, C. and Terzi, S. (2019a) 'Overcoming barriers towards sustainable product-service systems in small and medium-sized enterprises: state of the art and a novel decision matrix', *J. Clean. Prod.*, Vol. 222, pp.903–921 [online] https://doi.org/10.1016/J.JCLEPRO.2019.01.152.

Pacheco, D.A.D.J., ten Caten, C.S., Jung, C.F., Navas, H.V.G., Cruz-Machado, V.A., Tonetto, L.M. (2019b) 'State of the art on the role of the theory of inventive problem solving in sustainable product-service systems: past, present, and future', *J. Clean. Prod.*, Vol. 212, pp.489–504 [online] https://doi.org/10.1016/j.jclepro.2018.11.289.

Pacheco, D.A.D.J., ten Caten, C.S., Navas, H.V.G., Jung, C.F., Cruz-Machado, V. and Lopes, G.H.N. (2016) 'Systematic eco-innovation in lean PSS environment: an integrated model', *Procedia CIRP*, Vol. 47, pp.466–471 [online] https://doi.org/10.1016/j.procir. 2016.03.211.

Pacheco, D.A.J., ten Caten, C.S., Jung, C.F., Ribeiro, J.L.D., Navas, H.V.G., Cruz-Machado, V.A. (2018) 'Eco-innovation determinants in manufacturing SMEs from emerging markets: systematic literature review and challenges', *J. Eng. Technol. Manage.*, Vol. 48, pp.44–63 [online] https://doi.org/10.1016/j.jengtecman.2018.04.002.

Pacheco, D.A.J., ten Caten, C.S., Jung, C.F., Ribeiro, J.L.D., Navas, H.V.G., Cruz-Machado, V.A. (2017) 'Eco-innovation determinants in manufacturing SMEs: systematic review and research directions', *J. Clean. Prod.*, Vol. 142, pp.2277–2287 [online] https://doi.org/10.1016/j.jclepro. 2016.11.049.

Panarotto, M., Bertoni, M. and Bertoni, A. (2016) 'Experimenting the use of value models as boundary objects in conceptual PSS design', *Procedia CIRP*, Vol. 47, pp.370–375 [online] https://doi.org/10.1016/j.procir.2016.03.235.

Pezzotta, G., Romero, D., Pezzotta, G., Cavalieri, S. and Romero, D. (2017) 'Collaborative product-service systems engineering: towards an active role of customers and stakeholders in value co-creation', *International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, pp.1247–1254.

Pezzotta, G., Sassanelli, C., Pirola, F., Sala, R., Rossi, M., Fotia, S., Koutoupes, A., Terzi, S. and Mourtzis, D. (2018) 'The product service system lean design methodology (PSSLDM): integrating product and service components along the whole PSS lifecycle', *J. Manuf. Technol. Manag.* [online] https://doi.org/https://doi.org/10.1108/ JMTM-06-2017-0132.

Pina, P., Góis, G. and Mano, F. (2017) 'A sentiment analysis solution for the re-design of product-service systems', *23rd ICE/IEEE Int. Technol. Manag. Conf.*, pp.1342–1347 [online] https://doi.org/10.1109/ICE.2017.8280030.

Porter, M.E. and Heppelmann, J.E. (2015) 'How smart, connected products are transforming competition', *Harv. Bus. Rev.* [online] https://doi.org/10.1017/CBO9781107415324.004.

Reim, W., Parida, V. and Örtqvist, D. (2015) 'Product-service systems (PSS) business models and tactics – a systematic literature review', *J. Clean. Prod.*, Vol. 97, pp.61–75 [online] https://doi.org/10.1016/j.jclepro.2014.07.003

Resta, B., Powell, D., Gaiardelli, P. and Dotti, S. (2015) 'Towards a framework for lean operations in product-oriented product service systems', *CIRP J. Manuf. Sci. Technol.* [online] https://doi.org/10.1016/j.cirpj.2015.01.008.

Romero, D. and Rossi, M. (2017) 'Towards circular lean product-service systems', *Procedia CIRP*, pp.13–18 [online] https://doi.org/10.1016/j.procir.2017.03.133.

Rosa, P., Sassanelli, C. and Terzi, S. (2019a) 'Circular Business models versus circular benefits: an assessment in the waste from electrical and electronic equipments sector', *Journal of Cleaner Production*, Vol. 231, pp.940–952 [online] doi: https://doi.org/10.1016/j.jclepro.2019.05.310.

Rosa, P., Sassanelli, C. and Terzi, S. (2019b) 'Towards circular business models: a systematic literature review on classification frameworks and archetypes', *Journal of Cleaner Production*, Vol. 236, , Elsevier Ltd, doi: 10.1016/j.jclepro.2019.117696.

Rossi, M., Morgan, J. and Shook, J. (2017) 'Lean product and process development', in Netland, T. and Powell, D. (Eds.): *The Routledge Companion to Lean Management*, pp.1–26, New York, NY; Abingdon, Oxon, UK.

Sala, R., Pezzotta, G., Sassanelli, C., Pirola, F., Bertelè, C., Neves-Silva, R., Campos, A.R. and Terzi, S. (2018) 'The integrated design of product-service systems: an application case', *INCOM 2018*.

Sala, R., Sassanelli, C., Pezzotta, G. and Terzi, S. (2017) 'A comprehensive engineering environment to conceptualize, design and monitor product service systems (PSS): an application case', *XXII Summer School Francesco Turco*.

Santamaría, L., Nieto, M.J. and Miles, I. (2012) 'Service innovation in manufacturing firms: evidence from Spain', *Technovation*, Vol. 32, pp.144–155.

Sassanelli, C., Pezzotta, G., Pirola, F., Sala, R., Margarito, A., Lazoi, M., Corallo, A., Rossi, M. and Terzi, S. (2018a) 'Using design rules to guide the PSS design in an engineering platform based on the product service lifecycle management (PSLM) paradigms', *Int. J. Prod. Lifecycle Manag.*, Vol. 11, pp.91–115 [online] https://doi.org/10.1504/IJPLM.2018.092826.

Sassanelli, C., Pezzotta, G., Pirola, F. and Terzi, S. (2018b) 'What affect manufacturers approaching servitization: a case study in HVAC industry', *PLM 2018 IFIP*.

Sassanelli, C., Pezzotta, G., Pirola, F., Terzi, S. and Rossi, M. (2016) 'Design for product service supportability (DfPSS) approach: a state of the art to foster product service system (PSS) design', *Procedia CIRP*, Vol. 47, pp.192–197 [online] https://doi.org/10.1016/j.procir.2016.03.233.

Sassanelli, C., Pezzotta, G., Rossi, M., Terzi, S. and Cavalieri, S. (2015a) 'Towards a lean product service systems (PSS) design: state of the art, opportunities and challenges', *Procedia CIRP*, Vol. 30, pp.191–196 [online] https://doi.org/10.1016/j.procir.2015.02.123.

Sassanelli, C., Pezzotta, G., Sala, R., Correia, A. and Terzi, S. (2017a) 'Testing the methodology to generate design for product service supportability (DfPSS) guidelines and rules: an application case', *Procedia CIRP*, Vol. 64, pp.265–270 [online] https://doi.org/10.1016/j.procir.2017.03.121.

Sassanelli, C., Pezzotta, G., Sala, R., Koutoupes, A. and Terzi, S. (2017b) 'The design for product service supportability (DfPSSu) methodology: generating sector-specific guidelines and rules to improve product service systems (PSSs)', in Ríos, J., Bernard, A., Bouras, A. and Foufou, S. (Eds.): *Product Lifecycle Management and the Industry of the Future. PLM 2017. IFIP Advances in Information and Communication Technology*, Vol. 517, pp.679–689, Springer, Cham [online] https://doi.org/https://doi.org/10.1007/978-3-319-72905-3_60.

Sassanelli, C., Rosa, P., Rocca, R. and Terzi, S. (2019) 'Circular economy performance assessment methods: a systematic literature review', *J. Clean. Prod.*, Vol. 229, pp.440–453 [online] https://doi.org/10.1016/j.jclepro.2019.05.019

Sassanelli, C., Terzi, S., Pezzotta, G. and Rossi, M. (2015b) 'How lean thinking affects product service systems development process', *XX Summer School Francesco Turco 2015 – Operational Excellence Experiences*, Naples, pp.97–104.

Smart, P., Hemel, S., Lettice, F., Adams, R. and Evans, S. (2017) 'Pre-paradigmatic status of industrial sustainability: a systematic review', *Int. J. Oper. Prod. Manag.*, Vol. 37, pp.1425–1450.

Software Engineering Group (2007) *Guidelines for Performing Systematic Literature Reviews in Software Engineering*.

The Ellen MacArthur Foundation (2015) *Towards a Circular Economy: Business Rationale for an Accelerated Transition* [online] https://doi.org/2012-04-03.

Tukker, A. (2004) 'Eight types of product-service system: eight ways to sustainability? Experiences from suspronet', *Bus. Strateg. Environ.*, Vol. 13, pp.246–260 [online] https://doi.org/10.1002/bse.414.

Tukker, A. and Tischner, U. (2006) 'Product-services as a research field: past, present and future. Reflections from a decade of research', *J. Clean. Prod.*, Vol. 14, pp.1552–1556 [online] https://doi.org/10.1016/j.jclepro.2006.01.022.

Vandermerwe, S. and Rada, J. (1988) 'Servitization of business: adding value by adding services', *Eur. Manag. J.*, Vol. 6, pp.314–324 [online] https://doi.org/10.1016/0263-2373(88)90033-3.

Ward, A.C. (2007) *Lean Product and Process Development*, Lean Enterprise Institute Inc., Cambridge, MA.

Womack, J.P. and Jones, D.T. (1996) 'Lean thinking', *Business Week* [online] https://doi.org/10.1086/601582.

Wong, M. (2004) *Implementation of Innovative Product Service-Systems in the Consumer Goods* Industry, PhD Thesis, University of Cambridge.

Xin, Y., Ojanen, V. and Huiskonen, J. (2017) 'Empirical studies on product-service systems – a review, in: Procedia CIRP, Vol. 64, pp.399–404.

Zhao, P., Rasovska, I. and Rose, B. (2016) 'Integrating lean perspectives and knowledge management in services: application to the service department of a CNC manufacturer', *IFAC-PapersOnLine*, Vol. 49, pp.77–82 [online] https://doi.org/10.1016/j.ifacol.2016.07.553.

Acronyms

CBR	Case-based reasoning
CLPSS	Circular lean product-service systems
CSA	Context-sensitivity analysis
CE	Circular economy
DB	Database
DfPSSu	Design for product service supportability
DfSC	Design for supply chain
DfX	Design for X
FEPSS	Functional engineered product-service system
IoT	Internet of things
ICT	Information and communication technology
IT	Information technology
LDRT	Lean design rules tool
LPD	Lean product development
LPSD	Lean product service development
LeanREM	Lean rules extraction methodology
KM	Knowledge management
KPI	Key performance indicator
PLM	Product lifecycle management
PSS	Product-service system
PSSLDM	PSS lean design methodology
RQ	Research question
SME	Small and medium enterprise
TLI	Total leanness index
VDD	Value driven design