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The Product Service System Lean Design Methodology (PSSLDM): Integrating product and service components along the whole PSS lifecycle

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Integrating product and service components along the whole PSS lifecycle

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Abstract

Purpose – Nowadays manufacturers companies are increasingly compelled to navigate towards servitization. Different methods and approaches were proposed in literature to support them to switch from traditional product-based business model to product service systems (PSSs). However, new knowledge, capabilities and skills were needed to consistently develop PSSs, since they need a joint focus on both customer's perspective and company's internal performance and at the same time a proper support for the integration of product and service design. The purpose of this paper is to propose the Product Service System Lean Design Methodology (PSSLDM), a structured methodology to develop PSSs along their entire lifecycle.
Design/methodology/approach – Retrieving concepts from interpretative, interactive and system development research traditions, and strongly reminding the design research methodology framework, the adopted research methodology is composed of three main phases (observation and conceptualization, theory building and tool development, validation) and involved three heterogeneous companies.

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Findings – This paper provides an overview of the PSSLDM, explaining how the different methods supporting its conduction should contribute to properly design an integrated PSS. Moreover, companies highlighted several benefits in the different stages along the PSS lifecycle deriving by the adoption of the PSSLDM.

Research limitations/implications – The development of a platform based on the PSSLDM methodology raises a discussion on the possible changes needed by current Product Lifecycle Management (PLM) models and systems when they have to do with PSSs.

Originality/value – The PSSLDM enriches the already proposed SErvice Engineering Methodology, introducing new several components 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 supprting the deatil design of both prodcut and service components.

Keywords Product Service System, Service Engineering, Product development, Lean design, Service systems, Knowledge-based systems

Paper type Research paper

1. Introduction

The growing importance of the services in the last decades has pushed manufacturing companies to change their traditional product-oriented business model towards a new one, based on a bundle of products and services, namely Product Service Systems (PSSs) (Beuren *et al.*, 2013; Brax, 2005; Burton *et al.*, 2017; Vandermerwe and Rada, 1988). Nowadays offering products or services alone is not enough: organisations must provide their customers with a satisfactory experience, orchestrating all the clues that people collect and provide (Berry *et al.*, 2002) along the entire solution lifecycle, including use and service delivery phases. Moreover the advent of the so-called 4th industrial revolution, bringing new and advanced technologies (Porter and Heppelmann, 2014), different expectations of customers for always new and more functionalities (Norman, 2010) and the necessity of new solutions enhancing the value of customer's interaction with the artefact along its lifecycle (Tan *et al.*, 2010), placed new demands and challenges. In this evolving scenario, manufacturers are compelled to navigate the so-called servitization phenomenon: during this transition they face different type of challenges (Martinez *et al.*, 2010) and need to be able to systematically build PSS innovation capabilities (Wallin *et al.*, 2015) in order to maintain revenue streams and improve profitability (Baines *et al.*, 2007, 2009). As a result, pushed by the final aim of reaching new market competitive advantages (Porter and Heppelmann, 2014), they risk obtaining less profit than expected (Gebauer *et al.*, 2005). Indeed, they attempt to increase their actual capabilities: to proactively manage lifecycle data (Gandhi *et al.*, 2014), to provide customers with solutions better meeting their needs (Tan *et al.*, 2010) and also to obtain back customer feedback and usage data to effectively (re)design and deliver new solutions on the market (Ponsignon *et al.*, 2015). In this new context, the necessity to integrate and manage multiple sources of knowledge along the PSS design process in a systematic and structured way to allow an innovative design of PSS has been emphasised in the literature (Brissaud and Tichkiewftch, 2003) (Trevisan and Brissaud, 2016).

The lack of methodologies enabling the collaborative design of product and service features in an integrated way (Doultsinou *et al.*, 2009; Vasantha *et al.*, 2012) along its entire lifecycle is acknowledged (Trevisan and Brissaud, 2016) (Rondini *et al.*, 2017). In this perspective, the Product Service System Lean Design Methodology (PSSLDM) has been developed.

In this paper, the new PSSLDM is proposed and described. To develop the methodology, an interactive approach (Ellström, 2007), based on the analysis of both available literature and companies' needs has been performed. The methodology was developed and validated by three manufacturing companies, which have been involved in the concept definition providing useful input and feedback to improve its development. The methodology developed has been used as a basis to develop a collaborative environment for product service design. For this purpose, an engineering environment and a set of software tools have been developed in order to translate theoretical methodology and methods. Therefore, on this basis, formerly in Section 2 the paper introduces the research context, unveiling which are the related gaps and explaining the basic principles used to fill them through such methodology. Then, Section 3 provides the results from business cases and requirements analysis, from concept definition to proof of concept. Therefore, Section 4 provides an overview of the methodology and of the related methods and tools developed to support the definition of a PSS following a lean approach, while in Section 5 an application case is reported. Finally, Section 6 discusses and concludes the paper, evidencing its strengths and weaknesses from managerial and practical perspective, and introduces the future research developments, a new comprehensive engineering environment able to conceptualise, design and monitor PSS along its entire lifecycle.

2. Research context

So far, one of the leading gaps dealing with PSS design can be originated in the lack of methodologies able to support the integration of the product and service components since the early stage of the design phase (Trevisan and Brissaud, 2016). This may be caused by a limited development of supporting tools with a consequent scarce adoption in the manufacturing context (Clayton *et al.*, 2012; Marques *et al.*, 2013; Moser *et al.*, 2015) and by the necessity of integrating actors from both product and service fields of knowledge to consider all the PSS features (Brissaud and Tichkiewftch, 2003).

In this perspective, most of the PSS design and development methodologies existing so far (Alonso-Rasgado *et al.*, 2004; Aurich *et al.*, 2006a, 2009; Garetti *et al.*, 2012; Komoto and Tomiyama, 2008; Maussang *et al.*, 2009; Mitsuishi *et al.*, 2008; Morelli, 2002, 2006; Pezzotta *et al.*, 2014; Sakao *et al.*, 2009; Shimomura *et al.*, 2009), are already theoretically promoting elements such as effective communication, information sharing and continuous improvement inheriting concurrent engineering (CE) and lean product development (LPD) concepts (Baines *et al.*, 2007; Sassanelli Terzi, Pezzotta, and Rossi, 2015; Pezzotta, Rossi, Terzi, and Cavalieri, 2015). From a practical point of view, few attempts were made in the past to create communication interfaces between product and service engineers (Cheng *et al.*, 2001) even if not definitely able to achieve effective knowledge management (KM) (Dalkir, 2013) along the design process.

In such a context, if the PSS engineering models methodologies, the related methods above mentioned and the most recent literature reviews on the PSS research area (Beuren *et al.*, 2013; Mendes *et al.*, 2015; Mourtzis *et al.*, 2016; Qu *et al.*, 2016) are analysed in details, many gaps continue to reside. In the following, the main gaps identified by the analysis of the actual PSS literature are reported:

- Even if they mainly focus on the customer perspective (Arai and Shimomura, 2004; Fritz *et al.*, 2007; Komoto and Tomiyama, 2008; Lindahl *et al.*, 2006; Rexfelt and Hiort af Ornäs, 2009; Sakao *et al.*, 2006; Shimomura and Tomiyama, 2005), there is a frugal orientation on the understanding of the real customer needs by the adoption of a systematic customer analysis and there is a lack of approaches and tools to bridge customer needs into technical constraints, company's internal performance and capabilities are generally not considered (Pezzotta *et al.*, 2014), potentially undermining the company economic sustainability in the long run (Neely, 2008).
- An entire lifecycle perspective along the PSS development is missed, most of the PSS methodologies focus their attention on the PSS conceptual definition (Trevisan and Brissaud, 2016; Pezzotta *et al.*, 2012; Matzen and Mcaloone, 2006; Bertoni *et al.*, 2013; Emili *et al.*, 2016; Luiten *et al.*, 2001; Halen *et al.*, 2005; Vezzoli *et al.*, 2017; Maussang *et al.*, 2009; Welp *et al.*, 2008), lack of dedicated methods to enhance the coordination between the back-end and the front-end capabilities, even if this aspect is considered crucial to deliver and design good PSSs and improve companies internal performance (Dewit, 2016).
- Most of the available methodologies focus on either product design (Aurich *et al.*, 2009, 2006b; Alonso-Rasgado *et al.*, 2004; Tran and Park, 2014) or service design (Aurich *et al.*, 2010; Brezet *et al.*, 2001; Manzini and Vezzoli, 2003) avoiding a

systematic design of product and service features as an integrated system, considering both customers' needs and companies' internal performance.

To overcome these limitations, Lean Product Development (LPD) theories may be adopted (Sassanelli Terzi, Pezzotta, and Rossi, 2015; Sassanelli Pezzotta, Rossi, Terzi, and Cavalieri, 2015). In particular, LPD promotes strong attention on the way companies manage, use and re-use knowledge (Dalkir, 2013; Stenholm *et al.*, 2015). The use of design rules represents a best practice to support the integrated PSS design process considering both service and product features, enabling the respect of both companies internal constraints and customer needs since the early design phase (Sassanelli *et al.*, 2018): however, so far, none of the methodologies proposed in literature follows this approach. Indeed, a methodological framework and related supporting methods and tools for the systematic development and design of PSSs are needed.

Based on this analysis and on the potential detected in LPD to cover PSS development gaps, among the several methodologies existing in literature (Aurich *et al.*, 2010; Hara *et al.*, 2009; Kett *et al.*, 2008; Marilungo *et al.*, 2015; Medini and Boucher, 2016; Pezzotta *et al.*, 2012; Rapaccini *et al.*, 2013; Shimomura *et al.*, 2009; Cees Van Halen *et al.*, 2005), the SErvice Engineering Methodology (SEEM) (Pezzotta *et al.*, 2014; Pezzotta, Pirola, Rondini, Pinto, and Ouertani, 2016) was selected to be further improved to cover the gaps detected. SEEM only aids PSS designers to comply with both consumers' needs and companies' necessities; however it mainly focusses on the service features avoiding the design of the product. In this sense, it is not able to adequately integrate product and service components in a systematic way and to properly bridge customers' needs feedback into the designed solution.

In order to fill these gaps, some improvements are considered by authors in each of the phases encompassed by SEEM: from customer needs analysis to process prototyping, from process validation to offering identification and analysis. Among them, a particular attention is given to: the definition of guidelines and rules, enabling a better KM and working as a *trait d'union* between product and service design as well between concept and detailed design phases, and the introduction of the lean development concepts by defining lean development process rules, aiming at identifying and reducing wastes along the entire PSS development process.

The result is the here proposed PSSLDM: this methodology includes new innovative aspects, comprising the previously mentioned aspects coming from LPD theories. It will hence guarantee more effective PSS design thanks to a better link with the front-end, the service and the product design, and more efficient PSS design by anticipating reworks and revisions at the early phases of the design process with the ultimate objective of reducing time to market and costs. In this sense, along with the entire PSSLDM, a critical role is played by lean rules coming from lean thinking philosophy. In general, a lean rule is defined as a set of explicit principles, governing the procedure within an enterprise, in order to eliminate waste, amplify profit, reputation and satisfaction and abridge cost, energy and lead time. Lean rules assume a supportive role in the PSS development process, crucial to ensure that customer needs and requirements are respected and embedded in the PSS to be designed and delivered; and the company internal performance is optimised.

3. Research design

All these elements, and others described in the next sections, concur to compose the here presented PSSLDM and the set of methods and tools supposed to be called in its conduction. One of the main scopes of the PSSLDM is to be industrial oriented and able to answer to manufacturing companies' needs facing the servitization transformation. For this reason, the PSSLDM has been developed considering both literature gaps and industrial requirements.

Thus, the research methodology (Nunamaker and Chen, 1990) has been defined and declined according to different traditions or philosophies: it retrieves concepts from interpretative

(Williamson, 2002), interactive (Ellström, 2007) and system development (Nunamaker and Chen, 1990) traditions, resulting thus in being purposive and theoretical (Williamson, 2002).

In particular, the design research methodology (DRM) framework (Blessing and Chakrabarti, 2009) due to its interactive approach has been adopted as a primary reference. In addition, DRM wants to provide understanding and improving design research with the final aim of enhancing the design process, in both theory and practice. Likewise, the here proposed research methodology guided the authors to develop the PSSLDM in order to improve the PSS design and raise designers and engineers' consciousness in designing PSS in a systematic and integrated way.

Wrapping up all the principles and steps belonging to the above-mentioned research traditions, the design of this research follows the schema traced in detail in Figure 1 and can be described as following. The first stage is the observation phase: research object is interpreted, gaps and research questions are detected, and the PSSLDM is conceptualised. The second phase, namely theory building and tool development, was carried out with the aim to progressively improve the methodology through company experts' feedbacks and obtain the final consolidated methodology design. Finally, the third phase is aimed at validating in an industrial environment the PSSLDM integrated with the tools needed for its adoption, with the aim of obtaining the system development full prototype.

To develop the PSSLDM according to the here proposed research methodology, three in-depth business cases and requirements analysis have been carried out. Indeed, during the first phase, these three cases were used to define general requirements upon both the methodology and the related methods and tools to be developed. Additional requirements gathered from other manufacturing companies have been collected, in addition, two ICT vendors have provided insights into the market available solutions, including own products, and into the corresponding state-of-the-art. Furthermore, during the second phase, the overall methodology has been implemented in the three application cases also to understand its completeness, its ability to collect the needed information and its usability in a real context.

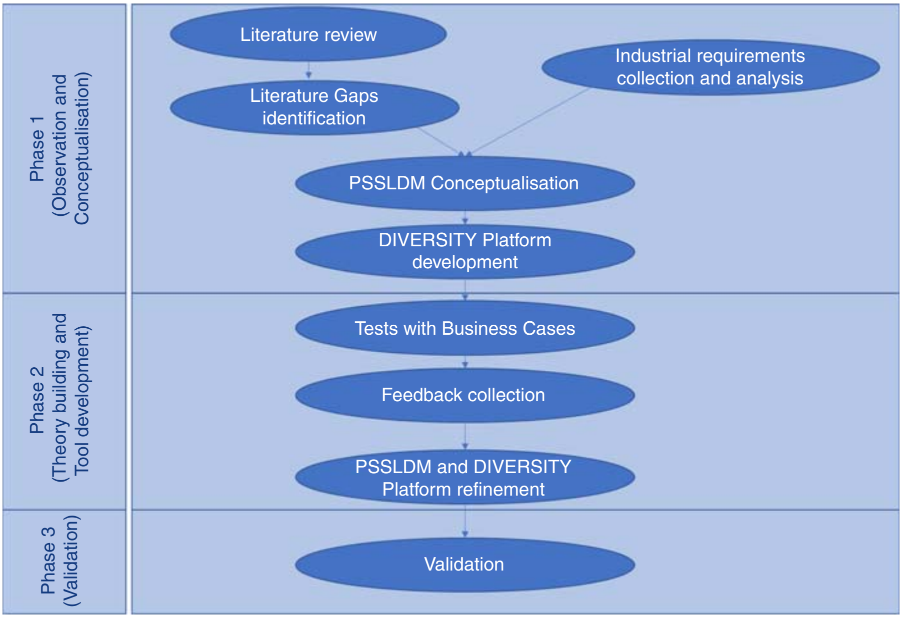


Figure 1. Research methodology to develop PSSLDM and the related diversity platform

All the feedback collected during the implementation have been included in the methodology with the aim to increase the industrial orientation and applicability. It is remarkable that this research methodology also supports the development of the methods and the tools involved in each stage of the methodology. To do this, the PSSLDM has been used as a starting point, resulting in being strategically relevant to define, through brainstorming and workgroups with scientists and managers, the related engineering environment architecture and the tools' features. Indeed, requirements collected in business cases were analysed and detailed and then data model, functional specification, external interfaces, and technical specification were derived (Pezzotta, Sala, Pirola, Campos, Margarito, Correia, and Mourtzis, 2016; Pezzotta, Pirola, Rondini, Pinto and Ouertani, 2016) with the aim of finding the features that could better allow the creation of compelling but intuitive tools for the conceptualization, definition and monitoring of new PSSs. Concerning the sample, the three cases are very heterogeneous, this leads to a methodology able to satisfy different kind of needs. These three Business Cases (BCs) are typical European SMEs Business-to-Business (B2B) manufacturing companies in the addressed sectors: one in machines for consumer goods production, the second in development of control systems for air-conditioning and refrigeration and the third in moulds production. Thus, they are characterised by a different level of technology even if they have both a consolidated design process and product portfolio. Their main business is to design and deliver pure products, but their willing is to move towards servitization in order to improve their portfolio in a service perspective and become more competitive, also discovering new market shares.

In the following section, the PSSLDM is presented, describing in detail the different steps composing it. Furthermore, the final validation of the entire methodology, conducted in one of the three BCs, i.e. the mould shop, is reported to show the applicability and accuracy in supporting manufacturing companies in design PSS in a systematic way, taking into consideration both customers and companies' needs.

4. The PSS lean design methodology

As stated in section 2, one of the main gaps in the PSS design and service engineering (SE) models and methods previously described, is the absence of a methodology which supports manufacturers in focussing on both customer's and company's perspective and that at the same time adequately supports the integration of service and product design. This rather myopic view can lead either to the development of services fulfilling customer's needs entirely, but that can potentially undermine the company's economic sustainability in the long term, or vice versa to an inefficient PSS design since the product and service designers have not appropriately interacted in the early phase of design, implying reworks and revisions later in the design process. For these reasons an industrial-oriented methodology, the PSSLDM is proposed, constructed considering both the theory and the analysis of industrial requirements collected during the application in the three BCs. To support companies in their PSS offering and engineering, it is fundamental to consider both company and customer(s) perspectives: therefore the SEEM (Pezzotta *et al.*, 2014; Pezzotta, Pirola, Rondini, Pinto, and Ouertani, 2016) has been used as the base to develop the PSSLDM, since it is the only one developed with that specific focus. In this perspective, two main areas constitute the core elements of the PSSLDM: customer and company. Moreover, in order to allow a better integration of product and service features since the early phase of development and avoiding reworks, CE (Winner *et al.*, 1988) and LPD (Womack and Jones, 2005) concepts are integrated into the methodology, as shown later on. The PSSLDM encompasses four phases, namely: customer analysis, solution concept design, solution final design, and offering analysis. As shown in Figure 2, the first and the fourth phases belong to the customer area, aiming at collecting and analysing customer needs, while the central phases belong to the company area, aiming at managing the integrated design process in the

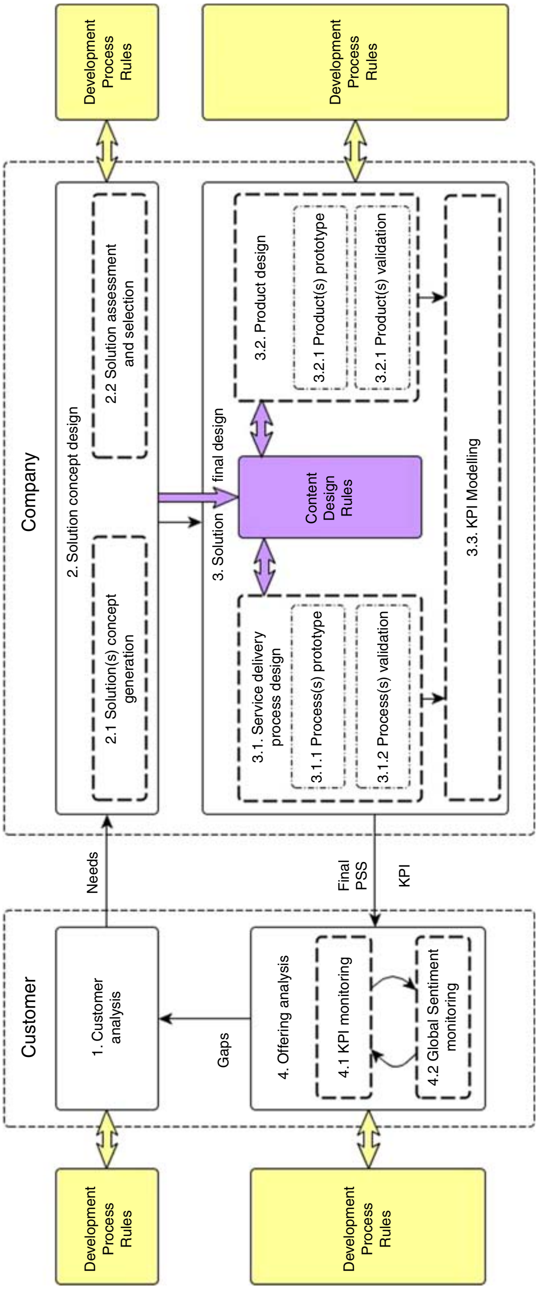


Figure 2.
PSS lean design methodology (PSSLDM)

most efficient and cost-effective ways. In addition, some of these phases are further decomposed into tasks, and for each of them, a specific method has been adopted.

Since the product/service development process is not easy to perform effectively and efficiently, along with the entire PSSLDM, a critical role is played by lean rules, occurring at two different levels: the content design level and the development process level, and referring to product, service, or the design process itself. Both content design and development process rules serve as guidelines to be followed by designers and engineers to guarantee the respect of customer requirements and technical constraints from one side (effective PSS) and waste-free PSS development process from the other side (efficient PSS development). In practice, such rules become precise instructions for engineers, designers and project managers to be followed during their daily activities.

Too often, in fact, product and/or service design takes place through inefficient and under-effective processes that generate a considerable amount of wastes and reworks at any levels and stages of the PSS design process.

In the following, a detailed description of all the steps composing the PSSLDM is reported, specifying the supporting methods and tools needed to perform each of them.

4.1 Customer analysis

The aim of this phase is the analysis of the customers' information with the aim to identify customers' needs. The Customer analysis starts due to:

- the need of a new PSS to be designed, as the result of the company strategy; and
- the need for a PSS re-design due to gaps identified through the analysis of either the global sentiment or the PSS KPI's monitored along the lifecycle.

The first step, towards the identification and the selection of PSS concepts, is the identification of customers' needs and wishes. From a methodological point of view, the customer's needs identification can be done in two different ways according to the company's business/market and considering data availability.

Here is a brief description of the two options (Rondini *et al.*, 2016).

(1) Customer's information available: users posts, collected through social networks (public or internal) or communication channels and related to a specific PSS offer are analysed to obtain feedback that can be used for the definition of the concept. In this way, all the actors involved in the whole lifecycle of PSSs are considered.

(2) No customer data are available. this option is less structured since no information from the customer is available. The needs and related wishes are identified "manually" through traditional brainstorming or focus group.

4.2 Solution concept design

Starting from the analysed customer's needs, to identify promising PSS concept's solutions and to evaluate them, the Product Service Concept Tree (PSCT) method (Rondini *et al.*, 2016) has been adopted. This method aims at suggesting a possible way to:

(1) identify PSS solutions capable of fulfilling customers' needs;

(2) represent solutions in a structured approach; and

(3) manage the selection of the "best" PSS concept to implement.

It is organised in four main levels according to the elements described hereafter.

The structure of the PSCT is represented in Figure 3:

- needs: elements that customers consider essential or desirable;

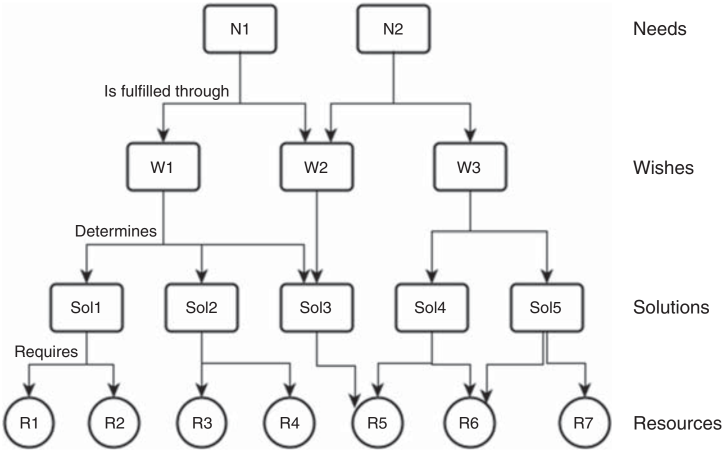


Figure 3.
PSCT structure

- wishes: represents the need of your customer in relation to company business;
- solutions: possible solutions (product, services or a bundle of them) that the company can identify to fulfil customers' wishes and needs; and
- resources: what are the main human/software resources and/or products and related features necessary to implement a solution.

All the levels must be connected to each other according to their relationship. This method and the related tool are going to support the manufacturing companies both in the concept generation and evaluation phases.

4.2.1 Task 1: solution(s) concept generation. Starting from the information collected about the customer, as a first step, the PSCT method supports the concept generation. The aim of this sub-phase is to identify new solutions that can answer to customers' latent or declared needs and wishes and associate the resources required to deliver the product service. The customers' needs (Kano *et al.*, 1984; Pirola *et al.*, 2014) and wishes identified in the first phase (either through social network, surveys to define personas or brainstorming) are used as input. The output of this phase is a high-valuable concept.

The PSCT supports the formalization of the results by graphically connect the needs, considered as inputs, to the solutions identified (output).

To adequately support companies in following the methods and therefore in identifying needs (level 1) and wishes (level 2) driving to the conceptualization of new PSS(s), hints supporting each phase of the tree development by use of a brainstorming process are included in the PSCT tool developed (Rondini *et al.*, 2016).

4.2.2 Task 2: solution(s) concept selection. The solution(s) identified through the PSCT previously developed should be evaluated, and finally the one(s) that is worth to be implemented is(are) selected.

The PSCT concept relies on an easy and intuitive approach. It considers:

(1) the possible impact that the implementation of a solution can have on the company's value; and

(2) the difficulty that the company could encounter during the implementation.

The two factors are evaluated on a Likert scale from 1 to 5.

Concerning the solution's possible impact on the company business, a score of 1 refers to low impact while a score of 5 implies a significant change in the company that can be in terms of market increase (revenues should be improved as well), innovations in the network, and technology that can positively affect buyers' preferences.

Difficulty in the implementation refers to the effort that the company encounters during the implementation of a solution. A score of 1 means that no relevant changes are required to implement the solution while a score of 5 means that the company needs a profound change in the organisation or a high investment in order to implement this change (e.g. a new organisational structure, an entirely new product with unknown technology).

Reasonably, the first one to be implemented should be the one that requires lower effort (limited difficulty) and produces the higher impact. Once the solution is selected, the final design can start.

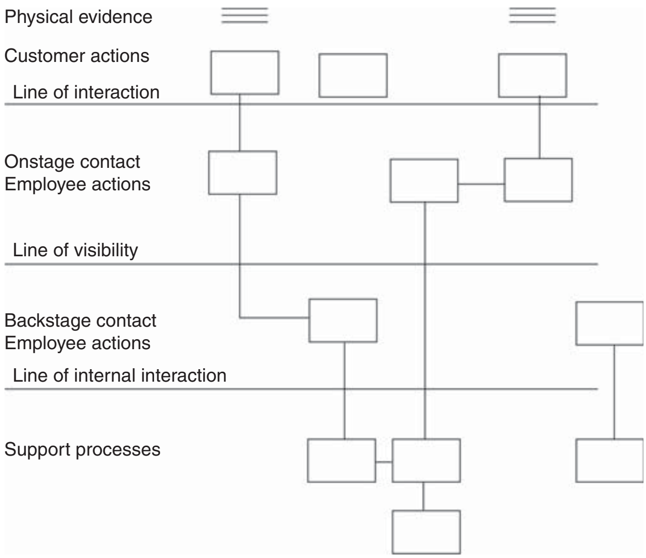
4.3 Solution final design

In the previous phase, the conceptual level of the PSS design has been carried out, in the following phases and related methods for guiding the PSS design from the concept selection to the most detailed levels of the solution definition are provided.

Three areas have been identified to properly design a PSS: a product design, a service design, and an integrated-view. In this last view, lean content design rules are created and used to act as *trait d'union* between service and product design.

4.3.1 Service delivery process design. Task 1: process prototype. This task involves representing the service delivery process(s) for the selected solution. In particular, to facilitate the description of the relationship between the customer/consumer and the organisation, the Service Blueprinting technique has been adopted for simultaneously depicting the customer's journey and the company's processes (Bitner *et al.*, 2008). Since the service blueprinting itself does not provide a taxonomy, the BPMN one has been adopted within the PSSLDM.

Going more into the detail, Service Blueprinting has five components (physical evidence, customer actions, onstage/visible contact employee actions, backstage/invisible contact employee actions, support processes) shown in Figure 4.



Source: Stevenson (2007)

Figure 4.
Service blueprinting structure

The service delivery process is designed considering:

1. the customer's journey;
2. the company's ongoing processes;
3. the product features of a new PSS, identified in the PSCT, and modelled as physical evidence; and
4. the PSS content design rules that help the exchange of knowledge between the product and the service designers and guarantee the balance between the customer and the company value.

In order to allow better integration of the service delivery process and the product either developed by the same provider or by different providers, a predefined service granularity level must be agreed among all the actors involved in the design team. The granularity-level selected must consider the kind of service, the degree of integration needed with the product and the information needed to implement the service later along the lifecycle properly (Rondini *et al.*, 2018). Process description granularity is one of the most sensitive issues in business process modelling (Stecjuka *et al.*, 2008). In general, coarse-grained process description is used to describe the service delivery process model.

Task 2: process validation. The aim is to understand how the designed service works. It is the step in which the customer and consumer can evaluate the designed service. There are many ways to evaluate the service developed depending on the kind and the degree of intimacy with the customer/consumer. Two qualitative methods, not supported by any specific tool, are suggested: Cognitive Walkthrough and Wizard of Oz. Through the adoption of these methods, a qualitative evaluation in terms of possible benefits and unplanned problems is performed. The output of this phase is (are) the service delivery process prototype(s).

4.3.2 Product design. Task 1: product prototype. This phase refers to the design and/or re-design of new product features or a new product enabling the PSS defined in the PSCT. This is a phase, in fact, in which companies have been already well-defined tools and design methods, such as product lifecycle management (PLM). A PLM is a strategic business approach that supports all the phases of the product lifecycle, from concept to disposal. Integrating people, processes and technologies and assuring information consistency, traceability, and long-term archiving the PLM enables organisations to collaborate within and across the extended enterprise (Corallo *et al.*, 2013).

Lean content design rules intervene in this phase, guiding the design team in solving PSS design issues, consistently integrating the involved service resources (used in the service delivery process) and product components (listed in PDM and PLM tools).

Task 2: product validation. Through this task, the design product is checked and aligned with the PSS feature identified. A check of the lean design content rules linked to the product to enhance the abilities enabling the PSS is performed. Through this validation, it is possible to understand if the designed product has included all the main relevant aspect of supporting the serviceability, manufacturability and the eco-friendliness. If some features have not been included in the product, design changes could be asked in order to create a product, which is aligned with the customer and company requests.

4.3.3 Content design rules. PSS lifecycle is characterised by several phases from the initial concept to the final disposal. However, as for conventional products, the profit generation and the market success of PSSs critically depend on the decisions taken during the initial lifecycle stages, when PSSs are conceptualised, designed, developed and engineered. To adequately support an integrated design of product and service, specific Design for X (DfX) techniques are used within the PSSLDM. The aim is to drive the definition of lean content design rules that guide the product design phase starting from the service, manufacturing and environmental features the company wants to include in the product. In particular, since the PSSLDM wants to take into account the PSS perspective along with all the design process, DfX techniques such as design for serviceability, design for maintainability and design for lifecycle are strongly integrated into the product design process (as already suggested by Sundin *et al.*, 2009 in the limited context of remanufacturing).

In this direction, the authors have been focussing on identifying and formalizing the initial lean content guidelines/rules, based on literature review and industrial practice, proposing a new more suitable approach to their research context, named design for product service supportability (Sassanelli *et al.*, 2016).

These Guidelines/Rules aim to create a lean process guiding managers, workforce, suppliers and customers through KM. Qualitative lean design guidelines help designers to choose the right product design decisions, they do not provide concrete instructions on an adequate level of detail. Therefore, an integration of DfX approaches with the concept of lean design is necessary (Dombrowski and Schmidt, 2013). Indeed, while lean design focusses on an integrated methodology for an optimised product design, DfX approaches deliver specific recommendations for a specific virtue or stage in the product lifecycle. In PSSLDM, the adoption of lean design and DfX approaches is fundamental for the definition of lean guidelines and rules. In order to start identifying and categorising lean guidelines/rules it is essential to define: what a lean design rule is and in which forms can be declined, how the style of formalization will be, and what technique will be used to address the level of importance of each rule.

Lean content design rules are distinguished in guidelines and rules. Guidelines provide a proper basis for considering generic, non-company-specific, lifecycle-oriented information to be followed during the design phases (Hepperle *et al.*, 2011). They are a reliable way to foster effective KM in terms of knowledge formalization, representation, sharing, use and re-use (Dalkir, 2013; Stenholm *et al.*, 2015). Such guidelines can evolve and be applied to specific company issues of either a PSS or a specific component, leading to the creation of the relative rules that become concrete and quantitative instructions for engineers, designer and project managers to be followed during their daily specific design activities. The set of design rules represents hence the knowledge characterizing and belonging to the company.

For the lean content design rules creation and validation the PSS Design GuRu Methodology, composed of one preliminary step plus 5 additional phases, has been created (Sassanelli *et al.*, 2018).

4.3.4 KPI modelling. The PSS design loop is closed with the definition of an appropriate set of KPIs that will be used to monitor the performance of the designed PSS throughout its lifecycle (Mourtzis *et al.*, 2016). The identification of the appropriate set of KPIs follows a precise methodology consisting of three main steps (Mourtzis *et al.*, 2015; Mourtzis, Fotia, and Vlachou, 2017; Mourtzis, Fotia, and Boli, (2017)). Its final aim is to monitor the PSS status during the entire PSS lifecycle stages. In detail, the selected KPIs should be connected with the data repository to be updated at the end of each PSS lifecycle stage.

4.4 Offering analysis

Once the service delivery process and the product have been validated, and the set of KPIs to monitor the PSS has been created, the PSS can be launched in the market.

In this stage, it is essential to monitor the PSS along all its lifecycle. Two main set of data are provided to the decision makers:

- KPI monitoring: to analysis the company performance. The status of the KPI is fundamental to help the company to identify possible gaps in their offering.

- Global sentiment monitoring: to analyse the customer feedback and emotional evaluations. The sentiment analysis aims at summarizing opinions from social networks (public or private) in one single feedback (the expressed opinion from a post and its accompanying comments) and at aggregating those from different authors and sources during a time interval, to provide a global sentiment towards a company product/service. The global sentiment would be the result of a weighted evaluation of different aspects, and it is used both for estimating current sentiment towards an object and for predicting future trends in sentiment. The output of sentiment evaluation can be used to identify potential gaps in the actual company offer and possible improvement actions (Neves-Silva *et al.*, 2016).

4.5 Development process rules

The product service development process is not easy to perform effectively and efficiently. PSS development process improvement is getting more and more attention from scholars and practitioners, with the aim to increase efficiency. Too often, in fact, product and/or service development takes place through inefficient processes that generate a considerable amount of wastes at any levels and stages of the development process.

All the activities that do not add any value to the product/service and generate waste of knowledge, time and resources should be eliminated from the process, which should be able to flow efficiently, step by step. The more standard is the process and the more "instructions" designers, engineers and people involved in the development team have, the higher their ability to learn how to deal with process development and to avoid mistakes and wastes. Basically, if we say that a lean content rule indicates "what to do", a development process rule indicates "how to do it".

Lean development process rules, developed by use of the MyWaste methodology (DIVERSITY Project, 2017; Rossi *et al.*, 2012), are used to guarantee a waste-free PSS development process. They affect all the phases of the PSS development process also leading the designers and engineers through their PSS development activities.

5. Validation: an application case in mould-making industry

As previously explained, a final validation has been conducted through a face-to-face workshop in the industrial context in order to verify the value of the PSSLDM as a whole and to evaluate its consistency with the adopted and developed methods and tools. To do this, Mould-Making Industry, one of the three companies that already contributed to the development of the methodology during the previous "Theory building and tool development" phase, was chosen: the main advantage coming from this choice has been that its employees already knew the different single methods and approaches constituting the methodology. This interactive final test session was led by two academics expert in product development and SE and involved two additional academics with which the company has a long-term relationship: researchers interacted with the production monitoring employee and one product designer.

The company, Mould-Making Industry, is a B2B Greek SME designing and manufacturing moulds. In its product design process, the use of software tools and design methods is consolidated, supported by a reliable and experienced design and engineering division. Indeed, in the company PSS are not offered so far: services are provided in a disjoint way from the products (i.e. the mould) without considering integrated PSSs. However, mould-making industry is willing to go through the servitization process, since its actual intent is to increase competitiveness and income by improving not only customer involvement in the design phase of their offer but also his satisfaction during the following stages: in this way they would also manage to get access to new market sectors.

In order to achieve these goals, factors as environmental impact, wastes in material, energy consumption, design and machining time, time to market and frequency of failure are considered. Thus, the company started to strategically consider new PSS projects as mould delivery time estimation as a service, maintenance history per customer, joint provider-customer proactive production planning for mould modifications or opinion mining offered to customers as a service.

Based on these business expectations, the PSSLDM was applied starting with customer analysis. The first step has been the detection of the customer, i.e. Thrace Plastic, a company working in the plastic industry. From the feedback collected and the brainstorming carried out during the workshop, the team derived two main specific needs of this customer: monitoring and control mould lifecycle; shorter mould downtime. Starting from them, two wishes were detected: increased information availability; collaborative maintenance operations planning.

Using as inputs these needs and wishes, the team, through the creation of the PSCT (Figure 6), brainstormed on several possible products or services implementations that could help in satisfying them. This led to the generation of five possible solutions: analysis of each repair instance; digital history of repairs for the mould; supporting tool to handle maintenance communication/interactions; accurate delivery time estimation; predictive maintenance.

For each of these solutions, several resources were identified and classified into two categories:

- product resources, those related to the product side of the PSS: inspection support using the digital tool, delivery time estimation tool, mould maintenance tool (web portal); maintenance project manager (engineer); and
- service resources, all those resources (physical or not) used by the company to provide the service to the customers: shop floor operator.

Once listed together with all these components, the PSCT has been created by connecting the different levels (Figure 5).

The final task of the customer analysis has been the solution concept selection: the team evaluated the identified solutions under the aspects of impact and difficulty (Table I), choosing the "digital history of repairs of the mould".

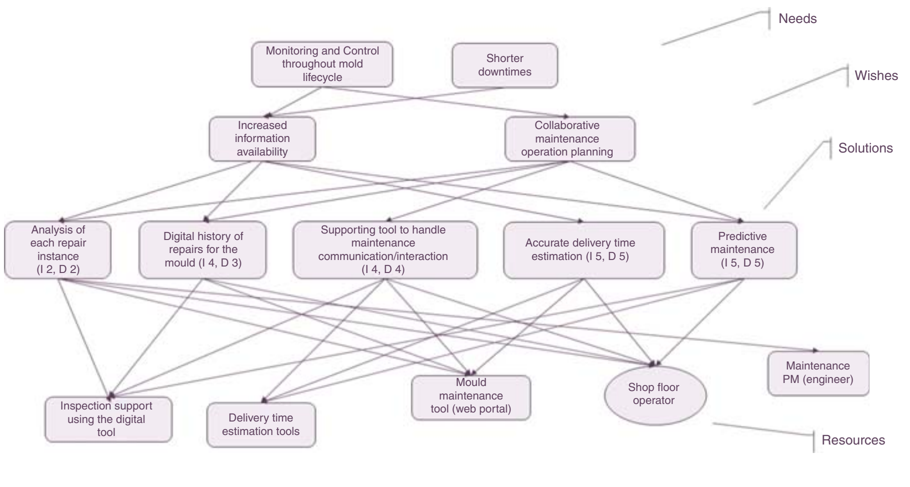


Figure 5.
The PSCT: mould-making industry validation case

With these results, the team moved to the second phase of the PSSLDM, the solution final design. As first, the service delivery process model (Figure 6) was created by use of the Service Blueprinting and the BPMN nomenclature: through it, the company explored and defined how the service resources identified in the PSCT should interact during the delivery process to provide the service to the customers.

Solution	Effort	Impact
Analysis of each repair instance	2	2
Digital history of repairs for the mould	4	3
Supporting tool to handle maintenance communication/interactions	4	4
Accurate delivery time estimation	5	5
Predictive maintenance	5	5

Table I. Solutions evaluation: mould-making industry validation case

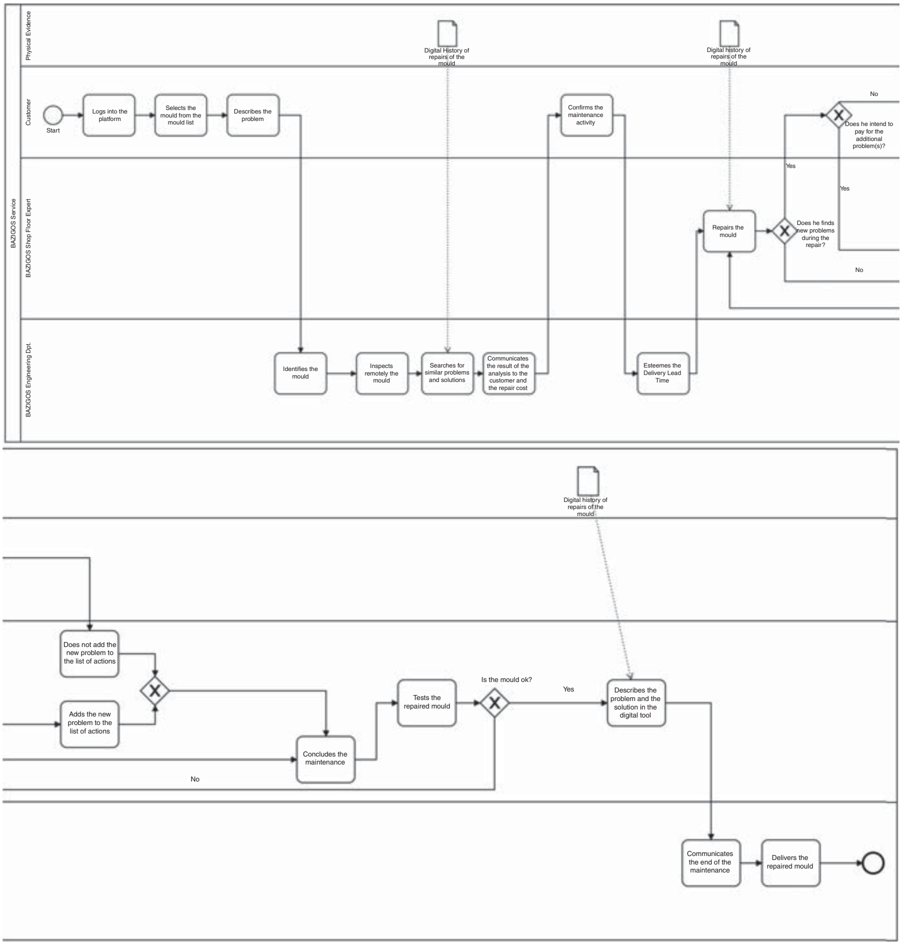


Figure 6. Service delivery process prototype (right and left parts): mould-making industry validation case

Therefore, once defined the PSS concept to be engineered and modelled the service to be delivered with it, the product design phase can begin through the support of the PSS Design GuRu Methodology (Sassanelli *et al.*, 2017). The product chosen to be redesigned, referring to the customer operating in the plastic industry, is the “2 cavity, 1 litre Seal Lid” mould. The product design phase has the aim to make the selected product more suitable to support the service to be added and integrated on it, better addressing, as a result, the PSS digital history of repairs of the mould.

The product is composed of four main components (shown in Figure 7) whose main issues are shown in Table II.

The PSS Design GuRu Methodology procedure has been adopted at this stage: the current design approach of the company was assessed, and the solution was enhanced through the generation of new content design guidelines and rules. Besides the aim of guiding the PSS provider in the creation of a product consistent with the customer’s needs, the design guidelines and rules are useful to limit the reworks, since they are thought to give

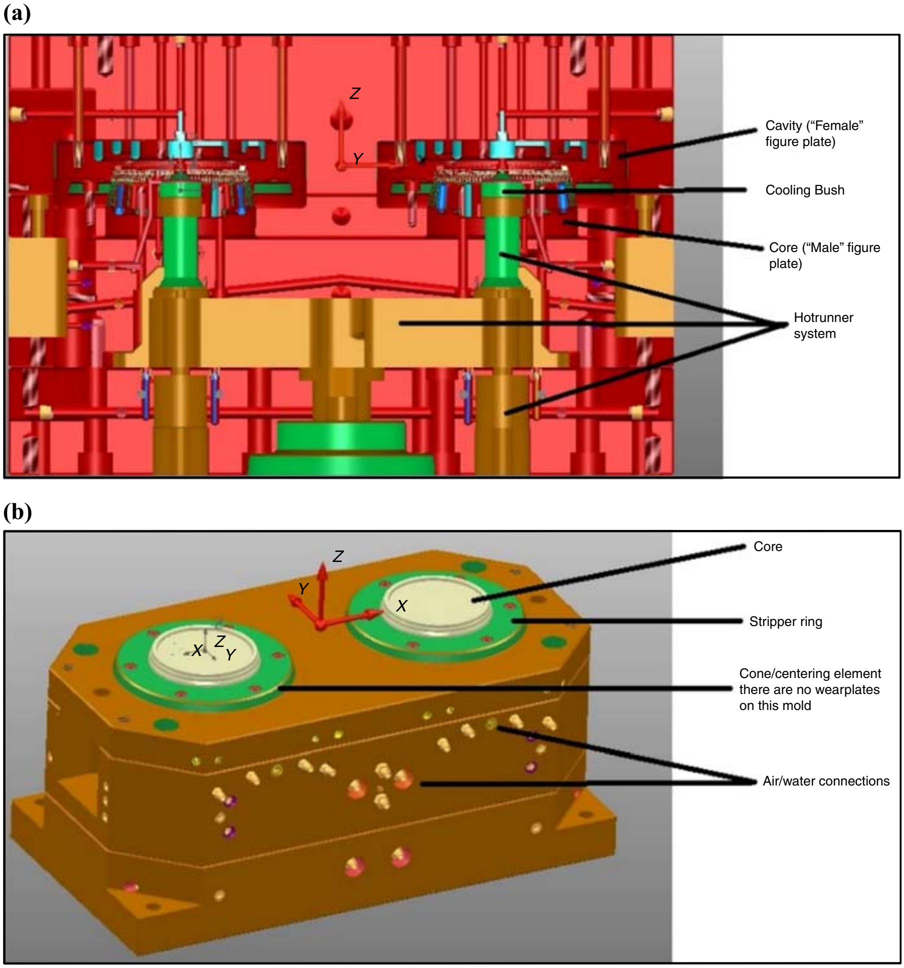


Figure 7. “2 cavity, 1 litre Seal Lid” mould

Notes: (a) General section; (b) fixed side

Table II. "2 cavity, 1 litre Seal Lid" Mould: component and issues description

Component	Description	Issue
1. Core and cavity	The two halves of the mould that create the plastic product geometry	They usually carry the centring elements: these are the two parts that need to be aligned properly
2. Cooling bush	An insert, that carries the injection point (hole) from which the plastic flows, also carries cooling circuit)	The hole is damaged by the material flow. They are designed as inserts for manufacturability reason, and thus they are also replaceable
3. Hotrunner system	Provided by specialised suppliers, distributes the plastic material to multiple cavities	Nozzle tips (and other contact points with accurate fitting are often damaged by the material flow
4. Stripper ring	The component that moves relatively to the core, in order to eject the plastic part from the mould	Accurate fitting is required and, due to natural wear, it needs repair or replacement

precise information on how to design the product. Moreover, they constitute a bridge among the two dimensions of product and service, of engineering and sales divisions: they become the knowledge belonging to the company enabling collaboration between engineering and sales to integrate the product and the service dimensions. content design guidelines and rules are aimed at solving product design issues also with a service perspective, thus fostering and easing the delivery of the PSS, the digital history of repairs, through the integration of the mould with the improved maintenance service along its entire lifecycle. An example of such design knowledge is here provided:

- guideline: "Consider the connectivity of hydraulic and automatic connection to foster Inspectability"; and
- rule: "To improve Inspectability, use water manifold while designing the connectivity of hydraulic and automatic connection".

Therefore, after having designed both the service and the product components constituting the desired PSS and after having generated and followed the new design knowledge needed to integrate them, the design process of the PSS ends with the definition of an appropriate set of KPIs used to monitor its performances throughout its lifecycle. Some examples of the metrics selected by the company are the number of identified customer needs and the on-time maintenance delivery.

Switching to offering analysis phase, the PSS launched on the market is assessed through KPI monitoring (global sentiment analysis is not provided here since no feedback are available on social networks about the product considered in this application case). It is noted that mould-making industry wants to improve the basic maintenance switching towards the PSS maintenance history tracking, addressing the digital solution history of repairs. After putting the new PSS in the market, the actual values of the previously selected KPIs are provided, also giving a comparison between the results concerning the simple service and the PSS launched on the market (Figures 8 and 9) and evidenced improvements in its delivery.

Finally, the entire PSS development process has been guided by a set of development process rules aimed at avoiding wastes and increasing the value brought along it. An example, generated during this validation case, is here reported: "Before starting any PSS development, identify a technical person in charge of the overall PSS development (from concept to launch), who will be your chief engineer".

The PSSLDM should be adopted according to a cyclical process headed to continuous improvement of the PSS: moreover, when available, also sentiment analysis can be strategic in conducting both the offering analysis and customer analysis phases.

6. Discussion and conclusions

This paper detected the leading gaps dealing with PSS design, evidencing the lack of methodologies able to support the integration of the product and service components since the early stage of the design phase. This is also justified by: a limited development of supporting tools able to bridge customer needs into technical constraints, a scarce adoption in the manufacturing context, the necessity of integrating actors from both product and service fields of knowledge to consider all the PSS features, a lack of an entire lifecycle perspective along the PSS development, a lack of dedicated methods able to enhance the coordination between the back-end and the front-end capabilities, the lack of a systematic design of product and service features as an integrated system.

To overcome these limitations, the PSSLDM, a methodological framework and related supporting methods and tools for the systematic development and design of PSSs, has been introduced in this paper. It aims at creating a structured methodology for the design process and at fostering the collaboration between the different actors of the process. Grounded on already existing methodologies, the PSSLDM introduces new innovative aspects, from customer needs analysis to process prototyping, from process validation to offering identification and analysis, contributing to the PSS development context from both a theoretical and a practical perspective. In particular, in order to fill the gaps of the available methodologies, in the definition of the PSSLDM a particular attention has been given to: defining a method enhancing a better KM and supporting a matter integration between

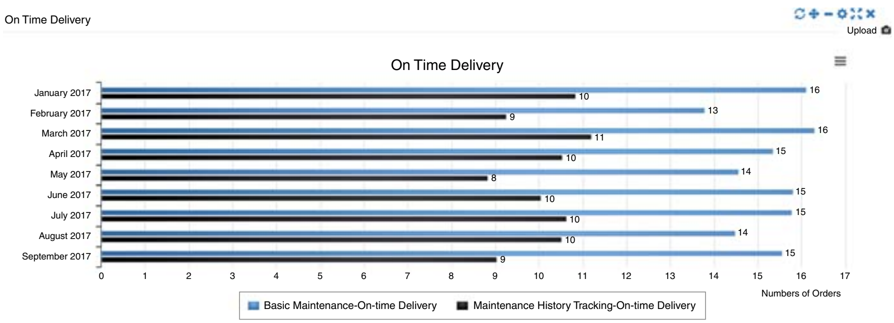


Figure 8.
On-time delivery KPI: comparison of the new PSS with the basic maintenance

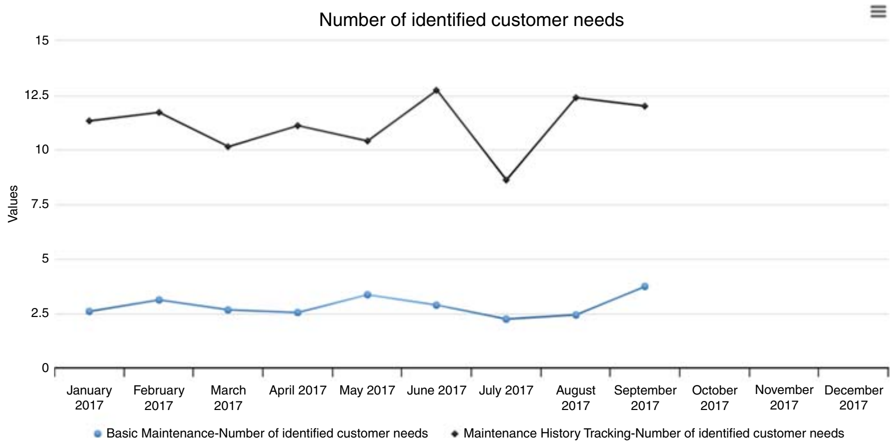


Figure 9.
Number of identified customer needs KPI: comparison of the new PSS with the basic maintenance

product and service design as well between concept and detailed design phases, and the introduction of the lean development concepts aiming at identifying and reducing wastes along the entire PSS development process.

Indeed, it promotes LPD theories to manage, use and re-use knowledge: design rules are proposed as best practice to solve the issue of integrating both service and product features in the PSS design process, enabling the respect of both companies internal constraints and customer needs since the early design phase. This leads to a strong integration of the design process of the product and service features through the lean content design rules. Moreover, through the lean development process rules, it fosters a PSS design process focussed on waste reduction. It will hence guarantee, from the practical point of view, more effective PSS design thanks to a better link with the front-end, the service and the product design, and more efficient PSS design by anticipating reworks and revisions at the early phases of the design process with the ultimate objective of reducing time to market and costs.

Furthermore, from a practical point of view, this paper has provided an overview of the PSSLDM, explaining through the description of a validation case, how the different methods supporting its conduction should contribute to the methodology in order to properly design an integrated PSS. Indeed, the methodology has been validated through three application cases and related to manufacturing company's needs. Therefore, it is very likely that the methodology with related methods and tools, developed satisfying needs in these business cases, will be applicable to wide scope of industrial companies in various sectors. Furthermore, as shown in Table III, companies highlighted several managerial implications along the PSS lifecycle deriving from the systematic adoption of the PSSLDM.

The practical transliteration of this methodology is the set of tools to be developed in a platform. Connected to this, the necessity to raise the awareness and to start a discussion on the possible changes needed by current PLM models (Sassanelli *et al.*, 2018) when they have to do with PSSs, supported by DfX approaches adoption, was also recently highlighted by (Wuest and Wellsandt, 2016). (Burton *et al.*, 2017), strengthening this research stream, argued about the importance of adopting a platform approach to foster the servitization process of manufacturing companies, aided by the surge of digitalization. In fact, using the platform deriving by the PSSLDM in Figure 10, some managerial implications can be detected: first, companies should be able to identify and monitor easily the customer needs. At the same time, they should be able to create PSSs that are customer driven and at the same time economically sustainable in the long term (this also by avoiding valueless reworks and activities). The final

PSS lifecycle phase	Managerial implications
Concept	Systematic support in the detection of needs from customer inputs
	Generation of new product-service ideas and selection of the best one
	Support to achieve new market sectors, improving competitiveness and customer satisfaction
Design	Definition and improvement of the product/service features needed to create the new PSS
	Reduction of time to market to update the product thanks to a better knowledge of the customer needs and improved use of knowledge
	Reduction of environmental impact, wastes in material, energy consumption and frequency of failure
	Involvement of all the stakeholders in the PSS design thanks to effective knowledge management
	Reduction of design time thanks to effective design knowledge sharing
Use and service delivery	Monitor the PSS feature thanks to a systematic collection of KPIs
End of life	Support of reconfiguration and re-design of the product, based on customer feedback and KPIs

Table III. Managerial implications

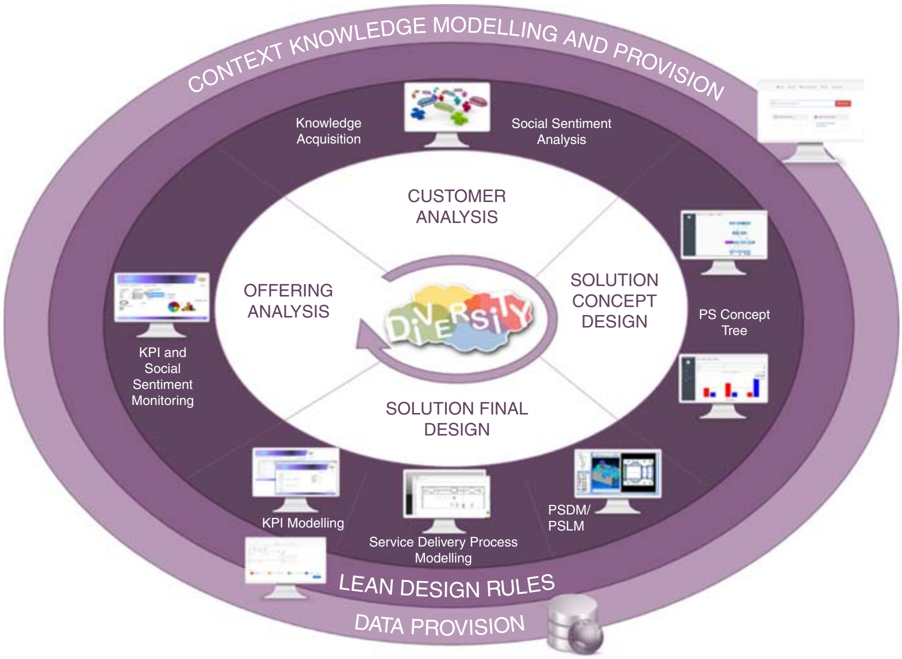


Figure 10.
From methodology to platform

output is an improvement of the company performance both internally (e.g. on the operational side) and externally (e.g. gaining a certain competitive advantage over the competitors). On the short term, companies will be provided with an innovative engineering environment and a set of methods/tools to support the concurrent collaborative design of PSSs based on the knowledge captured and shared across the value chain actors and the PSS lifecycle. On the long-term, the functionalities of the tools will be applicable to build different product service solutions and collaborations within extended enterprise, opening new business opportunities and making manufacturing industry less prone to failure.

For this reason, it is important to stress that the adoption of the PSSLDM and therefore of the platform foresees many challenges since the manufacturing transition "from products to services" entails a significant change in the company business models and organisations. In particular, in relation to the design phase of a PSS, the definition of a proper alignment of the product and the service design processes and responsibilities is one the main challenge to create a coherent offer and therefore effectively respond to customer needs. This represents the main risk against a proper adoption of the methodology and of the related design support tools. To reach such an alignment, cultural change in the company and in the design department is needed, even if this requires a new service culture quite distant from the ones of traditional manufacturing companies. In particular, product designers, generally focussed on the creation of high technology products, have to change their focus from the pure-product performance to the solution ones. Internal processes and capabilities must also be revised to align the company design procedures to the ones suggested by the methodology and to allow a fruitful relationship between the product and the service company functions. The KM features of the methodology aim to support cooperation inside the companies and make everyone aware of the main feature/s needed to answer to customer needs. In this sense, new service-oriented skills along all the company functions are needed and must be involved along with all the design phases.

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