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PSS Design Evaluation via KPIs and Lean Design assistance supported by Context Sensitivity tools

Dimitris Mourtzis[a,*], Sophia Fotia[a], Ekaterini Vlachou[a]

[a] Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 265 00, Greece

* Corresponding author. Tel.: +30 2610 997262; fax: +30 2610 997744. E-mail *address:* mourtzis@lms.mech.upatras.gr

Abstract

Over the last decade, Product-Service System (PSS) has been established as a prominent business model which promises sustainability for both customers and organizations. A great amount of literature work has been devoted to PSS issues, but there is fairly limited published work on integrated and easily applicable evaluation methodologies for PSS design, as well as lack of Lean PSS approaches. Contributing to these directions, the present work introduces a conceptual methodology for the evaluation and improvement of the PSS design procedure using Key Performance Indicators (KPIs) and Lean rules respectively, applied throughout all stages of PSS design lifecycle. The methodology contains two phases: i) PSS design evaluation, and ii) Lean PSS design assistance. According to the evaluation phase, a certain appropriate set of KPIs is selected and suggested to the PSS designer via a context sensitivity analysis (CSA) tool through a pool of 170 KPIs, which have been identified after intensive literature survey, and systematically classified into four main categories: Design, Manufacturing, Customer, and Environmental. From the collected and classified KPIs, a successive grouping is carried out of those KPIs that contribute to the Sustainability of the designed PSS offering. During the phase of Lean design assistance, Lean Rules are selected using CSA, and suggested to the designer at all design steps to ensure the minimization of wasteful activities. Enabler for the context awareness is the availability of feedback gathered from the manufacturing, shop-floor experts and the different types of Customers (Business or final-product Customers), as well as the PSS lifecycle stages which the designer treats. An ontology knowledge model for KPIs and Lean rules is proposed to support the CSA. The methodology is discussed in a case study of the PSS design from a mould-making industry.

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Keywords: Product-Service System , Key performance indicators , Manufacturing

1 Introduction

To meet requirements of mass customization and personalization, the B2B and B2C companies need competitive business strategies and powerful engineering environments to allow multi-dimensional exchange of knowledge throughout the supply chain. The Product-Service Systems (PSS), which is the hybrid solution [1] of providing services together or instead of the product’s ownership [2], promises competitiveness and sustainability via the identification of customer value [3]. Thus, the servitisation of manufacturing gains ground the last years [4], and the general industry sector shifts to the Industrial product-service systems (IPSS). Having common aspects with the previous [2], Lean Thinking has been, for decades, deeply defined and coded as dynamic and knowledge-driven, continuously striving to eliminate waste with the goal of creating value, and where customer satisfaction should be always be in priority [5]. Key performance indicators (KPIs) can contribute to the evaluation of the PSS, aiming to eliminate waste, better process control

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and data acquisition, and utilise manpower resources [6]. The exponential growth of internet [7], creates new potentials since it allows for easy access to knowledge as well as the opportunity to publish opinions in blogs and social networking sites. This particular information- retrieval and interpretational visualization in order to guide the PSS designers, still remains a challenge [8]. There are limited works concerning performance indicators for PSS [9], as well as integrated methodologies for PSS evaluation [10].

The present work attempts to address the above identified gaps by proposing a conceptual methodology for the evaluation of PSS design via KPIs and lean design assistance by providing lean rules. Taking the advantages of context sensitivity analysis (CSA), the selection of appropriate KPIs and lean rules through a pool for PSS design is carried out. It is beyond the scope of this paper to develop new algorithms for CSA or to provide in detail the structure of them, but it is concentrated on how the CSA successfully could be used in the PSS design knowledge awareness.

2 State of the Art

Recent literature survey shows that there is limited work on PSS evaluation [9],[11] while the existing works are in preliminary stages [10],[11],[12]. Most of the PSS evaluation approaches target to the assessment of PSS sustainability [13]-[15]. In particular, a proposed framework is introduced which controls the sustainability performance based on appropriate defined KPIs, and guides the stakeholders' actions [13]. Lifecycle Assessment for Value Assessment through measures of life cycle performance, life cycle cost, and life cycle environmental impact by a sustainability-oriented value assessment model is proposed [14]. It is observed that most PSS evaluation approaches that address the entire PSS lifecycle are based on KPIs. In a similar direction, an evaluation scheme is proposed, in which all the phases of PSS lifecycle are taken into account, from both customer and company perspectives, by using appropriate PSS lifecycle-dependent performance criteria [15]. Concentrating on the sustainability and quality of PSS offerings of a machine tool manufacturer, a software tool is developed based on a KPIs monitoring framework, which measures PSS quality by defining new quality KPIs, such as Process Stability, On Time Delivery, Mean Down Time [16]. Finally, after gathering and classifying the most appropriate KPIs for PSS (which are monitored in different lifecycle phases, and have been receiving input from many stakeholders such as manufacturing, design, business and final customers), a conceptual framework for an effective PSS design model is proposed [11].

2.1 Lean PSS design

As mentioned before, PSS have their roots in Lean philosophy, as mentioned by Baines et al. [2]. Limited amount of literature work has been devoted to Lean PSS, and most of it is state of the art analysis. Specifically, after an extensive literature review, Sassaneli et al., identified which aspects of Lean Thinking, such as waste identification and value focus, Set-Based Concurrent Engineering, are already applied in PSS Development, and uncover gaps for potential research, such as the definition of what is waste and what is value in a PSS design process [17]. Elnadi et al., bridge the gaps between Lean Thinking and PSS by focusing on the existing challenges, such as the understanding of Lean, waste definition, the nature of Service Process, etc. by taking interviews of Lean implementation experts who work in a PSS company [18]. Also, a framework for Lean Product-Oriented PSS, with description of the fundamental elements which characterize Lean Production and Lean Service operations is proposed by Resta et al. to two best-in-class PSS lean companies, in order to analyze PSS activities under the aspect of Lean Thinking [19]. Finally, a conceptual model is suggested [20], created through interviews with industrial experts and academics, consisting of three basic levels; (i) Enablers, such as "Management Leanness", (ii) Lean Criteria, and (iii) attributes, i.e. "Lean Services driven by the CEO, all these for measuring the degree of PSS Leanness in UK manufacturing industries. In a similar direction, classification and collection of KPIs for PSS design evaluation, related to the leanness among others have been introduced [11].

2.2 Context Sensitivity Analysis

Nowadays, there is a lot of software which supports the social networking and CSA of big volumes of data though internet [21]. However, the adoption of these technologies in the creation of appropriate tools that support the PSS design, are extremely rare [8]. Such solutions could be used by the product-service designer to easily obtain information/knowledge from the customers' opinion on the designed product-services or on relevant ones. With the recent advances on context-aware computing, an increasing need arises for the development of formal context modelling and reasoning techniques. The basis for context-aware applications is a well-designed Context Model (CM). A CM enables applications to understand the user's activities in relation to situational conditions. There are various types of context-aware systems. In general, a context-aware system follows four steps to fully enable context-awareness [22]: (i) acquisition of context information, (ii) storing acquired context information into a repository, and (iii) controlling the abstraction level of context information by interpreting or aggregating context data.

There are no tools for building context-sensitive solutions in the manufacturing industry, especially PSSs in the manufacturing industry. According to relevant research, the context modelling approach seems to be most appropriate for industrial use, and especially for PSS design- is based on ontologies [8]. The present paper does not design a new CSA tool, but will specify the characteristics that need to be fulfilled. The ontology was developed as a conceptual data model for the representation of technical information. An ontology-based approach is presented by Akmal et al., which can determine the similarity among two classes using feature-based similarity measures that replace features with attributes [23]. Also this approach is evaluated against other existing similarities and is illustrated in a case study on Product-Service Systems design problems. Moreover, Annamalai et al., propose an initial structure of PSS ontology by separately identifying the existing taxonomies of product and service ontologies and by identifying the root concepts of a Product-Service System through interviews with experts [24]. Finally, an Industrial Product-Service System business model ontology is presented by Rese et al., which includes the definition, the characteristics and their independencies of an IPS[2] [25]. This model is implemented in a Solution Provider company.

3 Conceptual Methodology for PSS Design Evaluation and leanness improvement

The proposed methodology consists of two parts: (i) the PSS design evaluation, and (ii) the Lean PSS design assistance, as illustrated Fig. 1, both supported by CSA. Specifically, according to the evaluation phase, a certain appropriate set of KPIs is selected from a pool of classified KPIs via CSA, and suggested to the PSS designer with respect to the design activity and the available gathered feedback from human, hardware and software sensors. Similarly, in the phase of Lean design, lean rules are suggested to the designer at all design steps to ensure the minimization of wasteful activities. The proposed methodology could be integrated into a PLM system or other engineering environments which support product-service design procedure. Moreover, the integration of tools for visualization, KPIs motoring, and data processing, is required. The present work is reduced to the presentation of the core methodology, while the future work includes the development of the aforementioned engineering environment, supported by open source software and evaluated in the industrial practice.

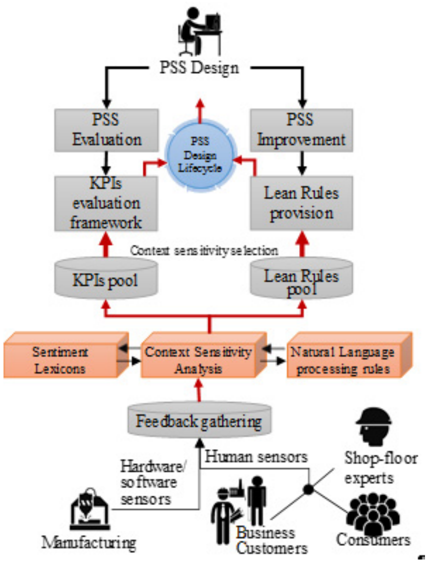

Fig. 1. Conceptual Methodology for PSS design Evaluation and Lean Design assistance using context sensitivity tool.

3.1 KPIs Evaluation Framework for PSS Design

In order to build the KPIs evaluation framework, 170 KPIs are identified for PSS and systematically classified, which is based on the authors' previous study [11]. The main categories of KPIs comprise: Design, Manufacturing, Customer and Environmental, while there are subcategories which include: Cost, time, flexibility, quality, maintenance, etc., as illustrated in Fig. 2. All the categories comprise KPIs which are associated with Environmental, Financial, and Social aspects, the three pillars of Sustainability. Therefore, those KPIs will be used to define the Sustainability category. Similar work [13] combines PSS Lifecycle performance indicators and their respective rating, in order to define the Key Sustainability Indicators (KSI). Every defined KPI contains a Name, a category, a sub-category and a description, aiming to context sensitivity search, as described in detail in section 3.3 in the ontology model (Fig. 3). Since in the present work 170 KPIs have been identified, and the length as well as the scope of the paper do not allow all of them to be shown, representative examples from each of some categories which also contribute to sustainability will be presented along with their short-name. In particular, the unit energy consumption (UEC) during the machining belongs to the category of manufacturing and to the sub-category of cost, while the preventative maintenance hours (PMh) defined as a percentage of the total maintenance hours, belongs to the category of Manufacturing, and the sub-category of Maintenance. The Product Flexibility (PF), which is used to measure if and to what degree IPS2 can fulfil the dynamic customer production requirements in a short term, falls under the category of Design and the sub-category of flexibility. Moreover, in the class of design and in the sub-category of time, the resource utilization is the working time including operating and travel time in relation to the overall availability time of the resources. In the same category, but in the sub-category of the Innovation, PSS innovation (PSSIn) is the KPI which is defined as the number of new or upgraded product features, distinguishable from the previous PSS. Similarly, the idea yield (IY) is defined as the percentage of ideas accepted into concept development. In terms of Quality, the service reliability (SR) measures the relationship of the planned as well as the actual time of a service process.

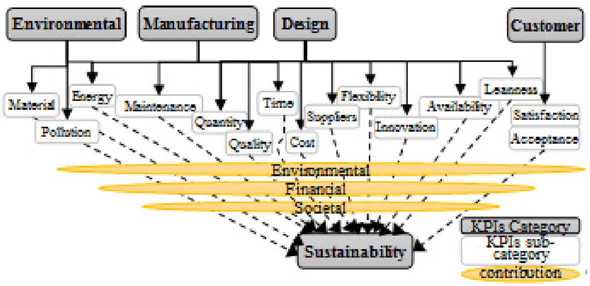

Fig. 2. KPIs collection and multi-level classification for PSS evaluation.

3.2 Lean Design assistance for PSS design

Taiichi Ohno suggests that "muda" - the Japanese word that means waste- accounts for up to 95% of all costs in non-lean manufacturing environments [26]. Lean Rules could be defined, inspired by the lean principles, aiming to give guidelines to the PSS designer in order to minimize the waste ("Muda") throughout an enterprise, while promoting the spirit of continuous improvement among stakeholders. There is no relevant previous work about Lean Rules, so for the purposes of filling this gap, the following definition is introduced:

Definition 1: *Lean Rule* is one of a set of explicit principles, governing procedures within an enterprise, in order to eliminate waste, identify the value, amplify profit, reputation and satisfaction and abridge cost, energy and lead time.

A designer is not obliged to possess deep knowledge of the lean philosophy in order to adapt his design activities to this direction. To this end, the designer needs some auxiliary tools for enhancing his/her lean design practices. From a literature review on lean principles, and from structured questionnaires answered by a mould-making company, several Lean Rules have been extracted regarding Design (D), Manufacturing (M), Environmental (E) and Customer (C). Some of these Lean Rules are presented in Table 1. The ID row denotes in which category this rule belongs to.

Table 1 Lean Rules for PSS design classified into: Design (D), Manufacturing (M), Environmental (E) and Customer (C)

ID	Lean Rules and Impact on Waste
D_1	Designers should also have a deep understanding of the manufacturing processes as well as the equipment and its technical limitations. Aims to reduce: Waiting, Over-processing and Motion
D_2	The designer tends to use/ exploit standardized components as much as possible, even if those components require modifications. *(Both ready-manufactured product and CAD models.* Aims to reduce: Waiting.
D_3	Information/Data through the design/manufacture process should always be stored and be available anytime for similar work/remanufacturing. Aims to reduce: Waiting, Rework
D_4	Tendency to use centralized capabilities for product/service design, particularly taking into account maintenance and repair as well as complementary services co-created with the customer.
M_1	Avoidance of running the machine on (or close to) its maximum RPM, for over 3-4 hours. Aims to reduce: Waiting *(machine tool change or service)*
M_2	The material used in the production process should always be in right quality and meet the same standards set in the design process. Aims to reduce: Over-Processing
M_3	Tendency to use remote access in most of machine processes (*CNC remote control, etc.)* Aims to reduce: Transportation, Waiting
M_4	Dimensional quality control most frequently performed on the CNC machine itself in order to avoid setup times
E_1	Specification of mutually compatible materials and fasteners for recycling
E_2	Minimisation of volume, area and weight of parts and materials to which energy is transferred
E_3	Use of feedback mechanisms to indicate how much energy or water is being consumed
C_1	Tendency to maintain strong interaction with customers through relationships based on product availability and performance. Aims to reduce: Waiting, Over-production, Inventory
C_2	Tendency to proactively contact customers for better scheduling. Aims to reduce: Waiting, Over-production, Inventory
C_3	Every customer/supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses. Aims to reduce: Waiting
C_4	Tendency to be in close contact with customers, who, on their turn, give feedback on quality, cost and delivery performance. Customers must be contacted proactively.

3.3 Context extraction Ontology for KPIs and Lean Rules

There are two main sources of feedback, which their knowledge could be advantageous for the PSS design: (i) from hardware and software sensors, and (ii) form human sensors. As Fig. 1 shows, the feedback could be collected by shop-floor experts and Business Customers though intra-organizational digital documents or platforms for communication, consumers providing their opinions regarding the final-product though social software such as Facebook and LinkedIn, and manufacturing/production processes through hardware and software sensors. The latest may not need CSA in case of quantitative measurements. Automated sentiment analysis of digital texts can be performed combining elements from machine learning, such as support vector machines, and semantic orientation using ontology [8]. The CSA tools contain manually crafted Sentiment lexicons and basic NLP Rules *(Nature Language Processing Rule*s), which could analyze each to-be created PSS feature and sentiment by the keywords used in digital documents, determine its value and propose a set of KPIs and lean rules extracted from a database. Sentiment lexicon is a fundamental component for sentiment analysis, aiming to identify and classify the value of keywords [27], while the NLP Rules involve the "understanding" of human language by the computer in order to respond with various ways back to the user [28].

Fig. 3. KPI and lean rules Ontology model.

Based on the previous, and regarding the proposed methodology, an ontology has been introduced (Fig. 3) as a conceptual data model for the representation the PSS evaluation and improvement, which the CSA tool will implement for searching and selecting of appropriate KPIs and lean rules. Each one KPI (e.g KPI_1) and lean rule (e.g LeanRule_1) stored to the database, has subclasses (Environment, Manufacturing, Design, Customer), and has attributes such as Name, Formula and Description.

4 Case Study of a mould-making Industry

A mould-making industry is visited in order to be discussed how this methodology could improve the PSS offering. After the interviewing of engineers and shop-floor experts, the lifecycle of the maintenance design is demonstrated, and it is discussed how the proposed framework could improve the executive time and the efficiency of the maintenance design. The studied company is B2B which is concentrated on the design and manufacturing of injection moulds intended for the mass production of plastic or metallic parts. Three types of PSS offerings are identified in this type of company. The first and most important is the maintenance of the mould, which is a representative example of product-oriented PSS. The second is the renting of a mould for a certain period of time, which is representative of use-oriented PSS since the ownership of the mould remains to the mould-maker and not in the business customer. Finally, the third PSS offering is the design of a mould according to the customer requirements, which is closer to result-oriented PSS [2] since it is paid per design item. The contribution of the methodology for all the aforementioned PSS offerings is illustrated in Fig. 4, and is described in detail in the following paragraph, taking as an example the Maintenance case of a PSS.

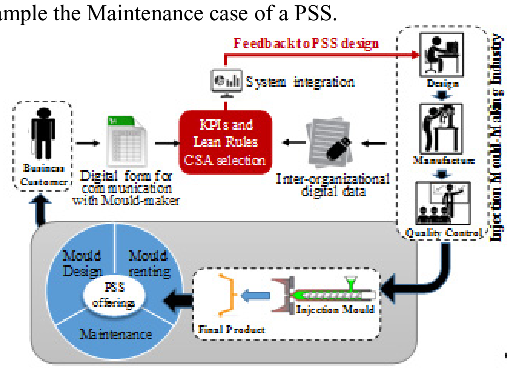

Fig. 4. Case study of an injection mould making-industry.

A mould maintenance procedure is a typical and the most important PSS offering of a mould-making industry, since the wear and the life extension of a mould is directly related to its use-cycle. This fact means that it would need very frequent repair, as mentioned by experts, and that a great part of the mould's lifecycle depends on maintenance. For instance, for many types of moulds their usage in three shifts means 1/3 of use-time returning to manufacturer for repair.

Business customers and mould maker communicate via a digital inspection document. Fig. 5 illustrates a real-life inspection document regarding a mould maintenance request, slightly modified to hide the actual monetary amount and time. As shown in Fig. 5, the top document contains the title of the request which, in the present case, is the mould repair. Using the CSA this is translated into maintenance. The words *maintenance* and *repair*, hold a high-percentage of correlation-based similarity. Similar words which hint maintenance could be; *remove*, *change*, etc. These words that imply a maintenance procedure could be also searched in the body of the digital inspection paper in order to strength the percentage of matching. Accordingly, in the light red column of the document (Fig. 5), the observations of the customer are noted. These observations are replied to by the mould-maker as repair actions accompanied by the approximated cost and total time. The mould needed repair has already shipped to the mould maker, who usually detects some extra failures which were not perceived by the Business Customer. Specifically, in the present document, two new failures have been identified, which will be charged to the customer X5 and X6€. Finally, according to the customer's comment on the second negotiation on 01/10/1015, he postpones those of X6€ and he accepts only those of X5€, also demanding reduction of delivery time from Y1 to Y2. All the previous results show issues in cost and time, which will be the keywords/key-points in CSA which will be used by the sentiment lexicons. In conclusion, the CSA tool will return to the designer KPIs and lean rules associated to: 1) Maintenance, 2) Cost, and 3) Delivery time. It is beyond the scope of this paper to provide in detail the structure of the algorithm, and the length of paper does not allow it, as well.

Request Title: Mould Repair
Mould ID: C9617

	Customer Name: Plastics Producer	Mould Maker			
	Observations	Actions	Est. Cost (€)	Est. Time (days)	Observations
18/09/2015	1. General check 2. Improvement of injection point 3. Distorted produced plastic 4. Intensive beating in the core side 5. Tapping in the cavity side	1. Hard metal & Mfg on the existing cooling brush	X1	Y1	1. Identified problem on air valves No 2 and 4 2. Air valves replacement (cost X5 €) 3. Hard metal & Mfg new cooling brush (cost X6 €)
		2. New core	X2		
		3. Manufacturing pre-possessing for removing the old core side	X3		
		4. Welding and machining of the beating points	X4		
Total estimated cost (C1): X1+X2+X4					
01/10/2015	1. We do not prefer hard metal & fg on new cooling brush at the moment 2. We agree with the air valve changing 3. We prefer the earlier delivery time of the repaired mould	1. All the maintenance actions written on 18/09/2015	C1	Y2	1. The earlier possible delivery time includes Y2 days
		2. Air valves replacement	X5		
Total estimated cost (C2): C1+X5					

Fig. 5. An instance for a digital inspection document for communication.

Following the CSA the ontology model presented on Fig. 3, the lean rules which resulted from the previous digital conversation could be, according to Table 1, D1 to D3, M2, C1 to C3, and the proposed KPIs that should be measured are those of Table 2 through the KPIs pool (Fig. 2).

Up until now, in the mould-making industry, the evaluation of the maintenance design had been carried out empirically, without a structured way. The proposed framework aims to easily and accurately evaluate the design process of PSS, taking into consideration information included in the digital inspection documents. The larger the database of the KPIs, the better the designer's results on the evaluation. The existing database, which includes globally-applied KPIs in manufacturing, could be extended to include specific purpose KPIs, such as some about air valves features.

Table 2. Indicative set of KPIs for maintenance.

KPIs for Maintenance
Remaining operating time of machining
Amount of corrective or preventive maintenance activities
Actual maintenance time
Maintenance Effectiveness
Ratio of Preventive Man-hours to Breakdown Man-hours
Preventative Maintenance Hours as a percentage of Total Maintenance Hours
Corrective and preventive Maintenance Cost
Percentage of Maintenance Rework
Cost for manufacturing a component vs. cost of buying a new component

5 Conclusions

The exploitation of available knowledge reported in digital documents, or as comments in social media, is still in primary stages for the PSS design. Several gaps related to the PSS design have been identified after the intensive literature review on KPIs, Lean design and context-sensitivity analysis. The main gaps are: (i) limited work has been done on PSS evaluation, while the existing works are in preliminary stages, (ii) limited amount of literature work has been devoted to Lean PSS, while most of it is focused on a state of the art analysis, and (iii) although the exponential growth of internet usage and context sensitivity analysis tools, the adoption of these technologies to support the manufacturing industry and specifically the PSS design, has not been adequately examined yet. Moreover, the issues of how to extract context and manipulate the available information in order to meet the requirements for knowledge enrichment during the design, remain to be solved. The present work attempts to contribute in this direction by introducing a conceptual methodology for PSS evaluation and PSS Lean design assistance via context sensitivity for the selection of appropriate set of KPIs and lean rules to the PSS design. The presented work is reduced to the presentation of the core methodology, while the future work will include the development of the engineering environment supported by open source software and its evaluation in the industrial practice.

Acknowledgements

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