Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 60 (2017) 428 – 433
www.elsevier.com/locate/procedia

27th CIRP Design 2017

# PSS Pattern concept for knowledge representation in design process of industrial product-service systems

Farouk Belkadi[a,]*, Yicha Zhang[a], Luis Usatorre Irazusta[b], Elaheh Maleki[a], Alain Bernard[a], Spyros Koukas[c]

[a] *Ecole Centrale de Nantes – IRCCyN, UMR CNRS 6597, 1 rue de la Noë, Nantes, France*
[b] *Instrumentation & Smart Systems, I&T Division, TECNALIA, Vitoria, Spain*
*c INTRASOFT International S.A, software development Greece, Athens*
* Corresponding author. Tel.: +33-240-396-954; fax: +33-240-396-930. *E-mail address:* firstname.lastname@irccyn.ec-nantes.fr

**Abstract**

To save time and cost in development process of new customized product-service systems, engineers need methodological guidelines and useful knowledge that help constructing specific solutions for new customers' requirements and business opportunities. Despite the specific character of every PSS due to several customization issues, many characteristics are shared between PSS from the same product and/or service family. This paper proposes a knowledge-based methodology to support the PSS design process, extending the concepts of pattern and instance as main knowledge fragments. The main idea is to encapsulate in the pattern a conceptual definition of a collection of potential verified solutions, able to achieve a product-service with certain performance value with regard to a set of working conditions. These solutions are then filtered and refined by means of PSS instance when answering one specific PSS demand.


Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference

*Keywords:* Product-Service, PSS Pattern, PSS design process

## 1. Introduction

Moving from "Product" centered towards "Product-Service" centered business is challenging for companies that want to maintain a distinctive position in competitive markets. With a Product-Service System (PSS) offer, the company will provide an additional value for the customer through a long term relationship covering large part of the PSS lifecycle. The concept of PSS has been discussed on several works [1]. One of the first definitions was given by Goedkoop et al. [2] as "a system of products, services, network partners and supporting infrastructure that is economically feasible, competitive and satisfies customer needs".

PSS is not a simple addition of separate product and service components. It is a complex integration process of mechanical, cyber-physical and IoT components as well as organizational infrastructures, with the involvement of heterogeneous stakeholders along the whole PSS lifecycle.

The adoption of a PSS-centered strategy implies the need of design process evolution [3] that should enable collaboration between various system engineering processes (mechanical, electrical, organizational, etc.). Depending on the type of PSS (for instance: product-oriented, use-oriented and result oriented [4]), the focus and the level of integration of both service and product components could be different.

This research work focuses on the case of machinery providers, as a product-oriented PSS, where the following issues have to be considered:

- The company wants to provide new standard PSS offers to be included in their catalog. Feasibility checking and preliminary cost estimation should be fulfilled for all offers before their proposition to potential customers.
- Despite the generic offer, any client order should be treated as a specific PSS due to customization and target working constraints. In addition, the customer could request several services associated to the same machine.


Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference
doi:10.1016/j.procir.2017.01.001

- Regarding the investment rate, the company prefers a product-oriented PSS type, where additional components could be added to the machine for providing a service, with possible slight adaptations on the machine structure.

Several interactions between engineers from different business domains are achieved to select the optimal solution for PSS implementation regarding its target working environment, as specified by the customer (e.g. temperature and humidity in the shop floor, connection to other machines, waves' disturbances, etc.). Thus, engineers need methods and tools to manage in a consistent way huge quantity of information during the design processes of both standard PSS offers and specific solutions answering customers' demands.

Knowledge-based frameworks give relevant advantages for such a topic. This work is part of the European project "ICP4Life" that aim to develop a collaborative framework supporting the whole development process of industrial PSS. Several software modules will implement the activities of PSS demand analysis, solution design and optimization, and production planning respectively. This paper focuses only on the conceptual framework as a back office of the "Designer" software module. The concepts of "Pattern" and "Instance" are used to support conceptual design of generic PSS offers and detailed design of specific PSS for customer respectively.

After a literature survey in section 2, the concept of PSS pattern is introduced in section 3 as a knowledge fragment to support the conceptual design of standard PSS. A simple industrial case study is presented to illustrate the proposed conceptual approach. The PSS design process based on the PSS pattern concept is described in section 4.

## 2. Knowledge reuse in PSS design process: A review

Tran and Park [5] summarize the main characteristics of PSS on the integration of heterogeneous systems for the delivery of a complete solution composed by both material and immaterial offers. This new phenomenon increases the number of disciplines and knowledge involved in the PSS development process [6].

Knowledge sharing between actors is necessary for the success of any collaborative process. The aim is to ensure a common representation of the studied problem through the integration of knowledge fragments created separately by several experts according to their skills and point of view [7]. Knowledge-based design is the process to reuse knowledge capitalized from past experience in new projects [8]. It is also conducted through knowledge sharing between involved stakeholders to ensure common representation of the problem of interest and consistency of the final solution [9].

Although the PSS design process exploits classical CAD tools, the current collaborative tools fail to consider specific integration constraints of the PSS development process [10]. As any collaborative process, consistency of interconnected data and knowledge are critical factors that can improve the efficiency of the PSS design process [11].

Importance of Knowledge management (KM) for product-service design was increased during the last decade [12]. Maintenance is presented in [13] as a promising application field of KM for PSS realization. Another example in aerospace domain discussed by Chirumalla et al. [14] shows the complexity of knowledge sharing network in PSS development project comparing to traditional ones. Four knowledge dimensions are highlighted as necessary to describe the PSS: Product, service, infrastructures and network. Due to long-term relationship within a PSS business model, customer knowledge is also seen as a prerequisite to achieve a shared understanding of customers' needs along the whole PSS lifecycle [15].

Knowledge capture and reuse is primordial but the representation of such knowledge remains a critical issue in PSS modeling. Majority of the authors commonly asserted that identifying and differentiating products and services in modelling is a big challenge. Welp et al. [16] observed that there are no integrated model-based approaches for handling PSS design activities. Methodologies for PSS are too general and formalization effort of such knowledge still missing [17]. Aurich et al. [18] highlighted the insufficient consideration of mutual influences of products and technical services in current PSS models. The importance of knowledge representation in PSS was also stressed by Sakao and Shimomura [19]. They argued that service blueprint lacks representation of design information and has insufficient normative notation. According to a comprehensive literature investigation, Vasantha et al. [20] assume that a good schema for representing PSS concepts with appropriate notation will avoids misinterpretation between engineers and aid to identify influences, compromises and differences between products and services throughout their lifecycle.

However, some existing initiatives to answer knowledge modeling issue in PSS domain are currently developed in the literature [1]. These models focus mainly on the classification of product and service components separately, but less effort is given to the representation of several links between them.

Setting the above target, the purpose of this paper is to present the concept of PSS pattern as a kernel knowledge item to support the semantic linkage between PSS components. The concept of pattern is not new and has been widely used for ontology structuring [22] and for guiding code design in software engineering [23]. According to Rech et al. [24], a pattern is a "general, proven, and beneficial solution to a common, recurring problem in specific domain".

This paper addresses the conceptual foundations for supporting the design process in case of "product-oriented" PSS. However, the scope of this concept is intentionally limited in this paper to the physical dimension of PSS.

## 3. Conceptual representation of PSS design knowledge

Usually, PSS offer is highly customized to meet specific client's requirements. Intuitively, each PSS solution/offer should be designed case by case to cope with exact needs of the target clients/PSS receivers. However, some invariants can be identified on PSS belonging to the same family. Reuse of embedded PSS knowledge can then reduce the cost and time for PSS solution/offer development while at the mean time guarantee consistency of the final outcome.

According to these new needs and the drawbacks of current methods in PSS design, PSS pattern and instance conception is proposed to facilitate both the generic design of potential PSS solutions and to easily reuse this design knowledge to answer specific demand of the client (Figure 1).


Fig. 1. Concepts of PSS Pattern and Instance

The focus of PSS pattern is similar to the definitions. However, the specificity is the inclusion of more than one potential principles of solution. The refinement of the detailed solution is fulfilled case by case at the PSS instance level.

*3.1. Knowledge description with PSS pattern*

In case of product-oriented PSS, when the OEM wants to add new service into existing product, engineers have to know the mutual impact between sensors and product components when they are integrated together. This impact depends on the chosen integration solution as well as compatibility between service and product components features. PSS pattern concept involves the generic description of these knowledge fragments on a consistent way for optimal reuse in future projects.

By using the modular conception on product development, PSS solution/offer is also regarded as a composition of key modular elements. These elements can be used in several PSS offers. The main logic of PSS pattern concept is to allow progressive definition of PSS components, starting from the definition of product and service features, and finishing by the capitalization of the integration solutions able to implement the connection between PSS components.

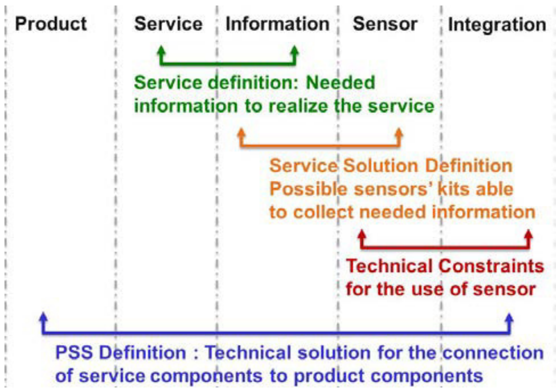


Fig. 2. Main concepts to be managed with the concept of PSS Pattern

A PSS pattern is defined as a combination of only one product and one service with a collection of main possible integration solutions. Focusing on the physical dimension, as shown in Figure 2, the definition of the service is obtained by the clarification of necessary information to be collected or computed to realize the target service. The service solution is obtained through the identification of the resources list (in this case sensors and additional equipment) able to collect or to fulfill the requested information/computing. The whole PSS solution is then obtained as a combination of one product, one service with related list of information, one or several sensor kits and a collection of integration solutions describing at a conceptual level how the selected sensors (and additional equipment) can be connected to the product structure. Each integration solution is colored by a set of performance indicators tailored to nominal working conditions (as specified by components' providers).

*3.2. Integration solution:*

Integration solution concerns the technical implementation of a PSS concept, which also indicates how to connect one service component to another product component by using tangible and virtual links. Deeply, the integration solution includes how to configure resources, e.g. sensors, how to arrange, how to handle identified service information, etc. The following questions are to be answered when defining a potential integration solution:

- What kind of measure technology is possible for the measurement of specific information?
- What kind of sensor is needed to measure information?
- What sensor specification is needed to support measure performance, depending on product working conditions?
- What additional equipment is needed to support the functioning of the selected sensors?
- What are the main potential positions of sensors regarding the product structure for maximum measure performance?
- What is the ideal fixture system for connecting sensors to product components?
- What is the expected performance of the selected sensor following a specific PSS configuration?
- What type of Data processing and analysis methods? ...

The integration solution could also include useful information about the potential manufacturing solutions for the designed PSS. In addition, when the service realization requires measure of needed information with various sensors, a critical question is to identify the best compatible sensors combinations and positions that ensure the final compatibility.

*3.3. Knowledge reuse with PSS instance*

To design a PSS solution tailored for specific client needs, PSS and domain engineers should use the PSS pattern as a template to choose the best components matching with the client's requirements. Thus, the uniquely populated PSS solution for one client is obtained by selecting one and only one set of sensors, additional equipment and a complete integration solution as a smart combination of pre-defined alternatives selected from the related patterns. By adopting the term used in data/information processing technology, this uniquely populated PSS solution derived from the PSS pattern is defined as PSS instance. The population of a PSS instance actually is a process of generating/refinement of PSS solution based on one or more PSS patterns. Hence, to populate a PSS instance, a minimum definition of the related PSS pattern is required in advance to fix the conceptual principle of solution.

In some cases, the client requests more than one service connected to a product. The integration solution of the related instance is obtained from combination of separate solutions coming from various patterns. Compatibility checking became a critical stage to ensure consistency of the whole PSS offer.

Furthermore, as imaged for the real practice, most time, the predefined PSS solutions in the PSS pattern can be directly used to generate an instance. However, in many cases, these predefined solutions cannot be directly used due to high extent of customization characteristics of PSS demand. Hence, for these cases, the predefined solutions could be modified or new solutions should be developed. As a result, the populated modified solutions or newly developed ones can enrich and update the current PSS patterns definition.

Meanwhile, the PSS pattern and instances design evolve constantly with the evolution of markets demands. Through the co-evolution of PSS pattern and PSS instance, important cost and time reductions are expected for the whole PSS development. It can be foreseen that as the accumulating and updating of new PSS solutions, the knowledge base will be more powerful to support PSS design.

### 3.4. Illustrative example

Industrial machineries are a concrete example of products for which service adding takes a great interest. Maintenance is the most known service on this domain. Due to the increasing complexity of industrial machines thanks to recent technological advancements, companies need regular assistance to control different process parameters and to avoid any dysfunctional. Based on their expertise, engineers from the machinery company can provide useful help to their client on the monitoring and the optimal exploitation of the machine capabilities face to new business opportunities.

Considering the case of dust detection service for laser cutting machine, the integration solution intends to identify suitable sensors and search how to connect these sensors to the laser cutting machine for providing the defined service.

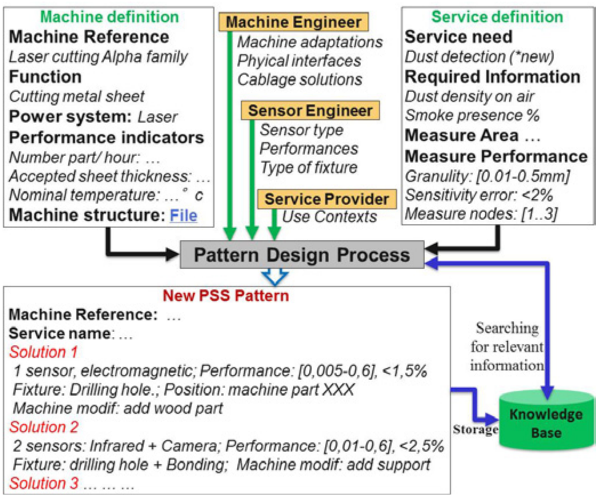


Fig. 3. Example of PSS pattern definition in industrial machinery domain

Hence, as shown in Fig. 3, the PSS pattern for this use case includes the following knowledge:

- Product features definition with PSS integration perspective: In this case, the type of the machine is Laser cutting from Alpha family, which has the function of cutting metal sheet with laser power. The performance of the machine is described by the maximum number of parts per hour, maximum acceptable thickness of the sheet and nominal working temperature at the laser head. These performance indicators will form the working environment of the future sensors to be selected for service information collection. In addition, the structure of the machine and related assembly constraints are connected to the pattern.
- Service definition: includes all information necessary for the realization of the service. In this case "dust detection" in the machine is a new service requiring information about density of dust and presence of smoke on the internal/external environment of the machine. The machine engineers are capable to identify quantity and area of dust can affect the normal working of the machine. Thus, measurement performance indicators are identified like the granularity of dust, the sensitivity or the number of minimum measure nodes to obtain exact evaluation of dust presence in this critical areas of the machine
- Integration solution: based on service requirements and machine features is composed by a set of possible sensor kits able to provide these requirements, respecting the working conditions of the machine. In the illustrative example, matching service requirement and machine features conducts to 3 generic solutions. Each solution is described by the number of sensors (1 in solution 1), their technologic solution (electromagnetic in first solution), the type of fixture, and potential position area in the machine. This area is defined by the concerned machine components in contact with the sensor base (engine area). In addition, fixing of the sensor kit may require in the first solution to add a wood part in order to avoid vibration that can affect the measure performances. Based on this generic description, PSS engineers should achieve an estimation of the related service performance as part of the PSS pattern, taking in consideration the expected working conditions.

In parallel, the PSS instance is colored by two specific constraints: the number of services by the customer for one machine and the real working conditions on the PSS in the manufacturing shop floor. As it is shown in Fig. 4, various information coming from the customer are considered, such as: the expected number of measure nodes, the frequency of measure, the presence of Wi-Fi waves, the temperature and humidity in the shop floor or the risk of disturbance lied to presence of other machines and equipment, etc.

Depending on this customer inputs, the realization of one PSS instance became a collaborative refinement process implying: the selection of related patterns, the selection of optimal sensor kit from each selected pattern and all additional inputs to ensure the co-existence of the selected solutions on the same machine. The final number of sensors and their detailed position as well as fixture and wirings are fixed based on compatibility matrix between sensors' kits.

Hence, in the presented illustrative case, two services are needed. Between all previous solutions, engineers can decide to fix both sensors (for service 1 and 2) on the same machine component or to choose solutions with distinctive positions. Slight adaptations can be achieved on the machine structure to take in consideration these constraints.

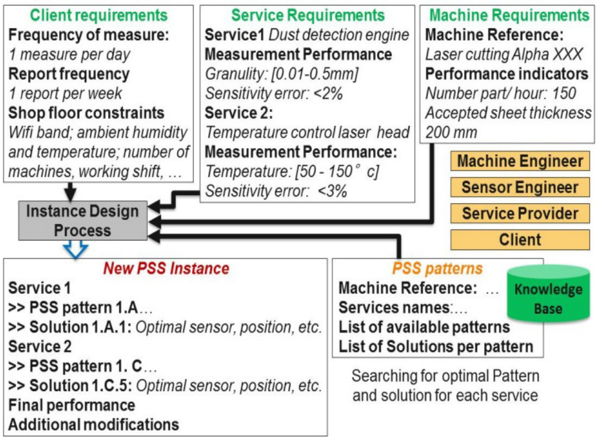


Fig. 4. Example of PSS instance definition based on pattern knowledge

## 4. Pattern design process

Design is a complex iterative process that aims to progressively define a complete, robust, optimal and efficient solution to answer a set of heterogeneous requirements provided by various stakeholders. According to the widely known model of Pahl et Beitz [25], four main stages are to be considered in the design process of manufactured products: (1) Task clarification for the identification of all requirements and its clarification on a technical specifications; (2) the conceptual design stage for the definition of the principle of solution to be respected by the target product; (3) the embodiment design for the description of the principal of solution; (4) and the detailed design stage for the realization of all dimensions and technical documentation.

Considering the physical dimension of the PSS, the design process should respect the main directions of classical product design process by involving at least a conceptual and detailed design stage, in addition to the requirement elicitation stage. Furthermore, respecting the concurrent engineering principles, the development process of a PSS should also integrate generic guidelines about the manufacturing solution.

As shown in Fig. 5, PSS creation process is composed of two stages: PSS conception stage (conceptual design) and PSS alternative implementation solutions development stage (Detailed design). In the first stage, PSS need and requirements as well as constraints are analyzed. The requirements list contains a first description of service details which are necessary to provide. Then PSS conception is constructed. For instance, the PSS conception is to generate a service conception for a product, laser cutting machine in the above example. Tin the operation level, a service is named and attached to the product through a semantic link. After that, the required information to realize the PSS, mainly the named service, should be analyzed and refined if necessary. Then, with the help of domain knowledge, mainly from a data/knowledge repository, potential principal of solutions to realize the service should be configured. This configuration is implemented using anther semantic links in the knowledge repository. It consists of a set of possible resources (i.e. sensors) and their possible fixture positions on the product structure. For instance, in the machinery PSS case, with the help of sensor data base, a couple of potential sensors maybe found to measure the identified service information.

Potential positions and fixture types for sensors and machine components can also be suggested as a first list to avoid time loosing when defining the suitable solutions in the detailed design stage.

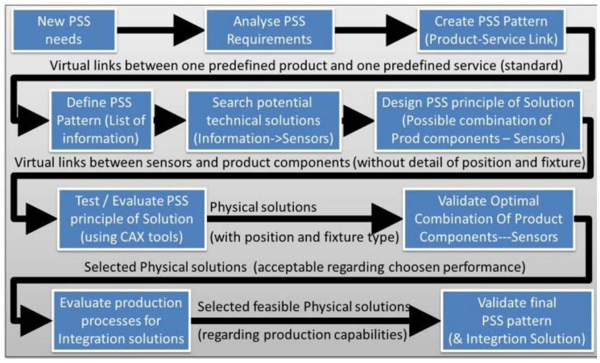


Fig. 5. Nominal scenario of PSS pattern creation process

The work for this stage is mainly managed by PSS engineers and project leader but additional collaboration with business engineers can be required. For the next stage, implementation solution exploration stage, other domain engineers should be involved in order to study more in detail the proposed potential solutions. The aim is to keep only suitable and efficient solutions. Different domain engineers should work collaboratively to testify the pre-generated PSS conception from PSS engineer.

Certainly, the PSS engineer will also engage in these procedures to act as a coordinate. Intensive technical experiments, tests and communications as well as domain hardware and software tools, e.g. legacy CAX tools, would be required to conduct the technical study. After verification, technical data, e.g. parameters, performance, cost, time, will be documented and attached to fill in the PSS conceptual solutions. Once the resource configuration and technical integration solution, usually mean a couple of alternatives, are verified at the technical level, there is another step to validate the feasibility of PSS implementation alternatives as bill of processes, manufacturing resources, best suppliers, etc. This is similar to “manufacturability analysis” as done in product development process.

As an illustration of the first steps of the design process, Fig. 6 shows an example of graphical user interface that can be used by the PSS engineers to identify the main possible solutions. In the right side, list of all sensors identified as suitable to collect the measures requested by the service. On the left side is described the product structure (BoM). Based on his experience and in collaboration with other experts, the PSS engineer can identify the potential product components, where sensor connection seems possible.

The semantic links between component and sensor are collected on the middle section of the GUI. These potential links are submitted to other engineers for test and refinement before their consideration as a validated integration solution of the targeted PSS pattern.

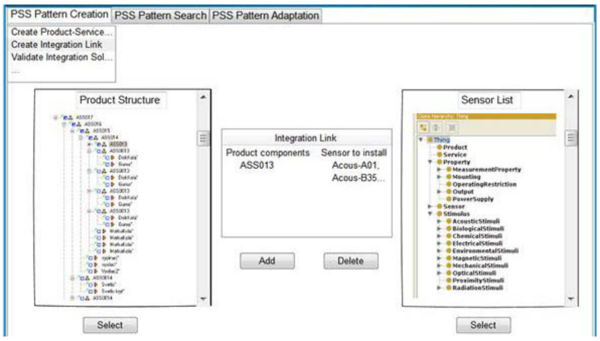


Fig. 6. Illustrative GUI for first steps of PSS pattern definition

## 5. Conclusion

Considering the complexity and multi-disciplinary nature of PSS design process, using knowledge management facilities is critical to ensure efficient communication between engineers from several domains and to save cost and time when dealing with specific customers' needs. In this context, providing a common method to manage the definition of the PSS along its lifecycle and to provide interfaces between various actors is the most interesting primary step.

This paper proposes a new vision of PSS design process based on the concept of pattern, allowing engineers to work collectively on the progressive definition of generic PSS, able to be proposed as standard offer or to be customized for specific customer needs.

This proposition represents the methodological foundation supporting the specifications step of the future "Designer" architecture, component of the ICP4Life framework. The proposed Pattern-based methodological framework is adopted by the consortium. Based on it, various functionalities and software modules implementing searching, optimization and decision-making algorithms are under development. The "Designer" component is connected to the whole ICP4Life framework and tested in real industrial cases.

## Acknowledgements

The presented results were conducted within the project "ICP4Life" entitled "An Integrated Collaborative Platform for Managing the Product-Service Engineering Lifecycle". This project has received funding from the European Union's Horizon 2020 research and innovation program. The authors would like to thank the academic and industrial partners involved in this research.

## References

[1] Lindahl M, Sakao T. Introduction to Product/Service-System Design. Springer-Verlag London Limited 2009. 279P.

[2] Goedkoop M.J, van Halen J.G, Riele H.T, Rommens P.JM. Product service systems, ecological and economic basics, Hague, The Netherlands, 1999.

[3] Reim W, Parida V, Örtqvist D. Product-Service Systems (PSS) business models and tactics - A systematic literature review. Journal of Cleaner Production 2015; 97(15): 61-75.

[4] Tukker A. Eight types of product-service system: eight ways to sustainability? Experience from Suspronet. Business Strategy and the Environment 2004;. 13: 246–260.

[5] Tran T.A, Park J.Y. Development of integrated design methodology for various types of product – service systems. Journal of Computational Design and Engineering 2014; 01(01): 37-47.

[6] Trevisan L, Brissaud D. Engineering models to support product–service system integrated design, CIRP Journal of Manufacturing Science and Technology 2016; 15: 03–18.

[7] Kleiner S, Anderl R., Gräb R. Collaborative design system for product data integration. Journal of Engineering Design 2003; 14(4), 421-428.

[8] Monticolo D, Badin J, Gomes S, Bonjour E, Chamoret D. A meta-model for knowledge configuration management to support collaborative engineering. Computers in Industry 2015; 66(03): 11–20.

[9] Belkadi F, Dremont N, Notin A, Troussier N, Messaadia M. A meta-modelling framework for knowledge consistency in collaborative design. Annual Reviews in Control 2012; 36(02): 346-358.

[10] Cavalieri S. Product–Service Systems Engineering: State of the art and research challenges. Computers in Industry 2012; 63(04): 278–288.

[11] Kvan T, Candy L. Designing collaborative environments for strategic knowledge in design. Knowledge-Based Systems 2000; 13(06): 429-438.

[12] Wenngren J, Thor P, Ericson S, Larsson T. PSS innovation - Discussing knowledge based tools. Proceedings of 2nd CIRP IPS2 Conference on Industrial product-service systems -IPS², Linköping, Sweden, April 14-15, 2010, 423-430.

[13] Wan S, Gao J, Li D.B, Evans R. Knowledge management for maintenance, repair and service of manufacturing system. 12th International Conference on Manufacturing Research (ICMR2014). Southampton, England, the United Kingdom: September, 2014, 65–70.

[14] Chirumalla K, Bertoni A, Ericson Å, Isaksson O. Knowledge-Sharing Network for Product-Service System Development: Is it atypical? 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo, Japan, November 8th–9th, 2012, 109-114.

[15] Bagheri, S.; Kusters, R.J.; Trienekens, J.J.M. The customer knowledge management lifecycle in PSS value networks : towards process characterization. ECKM 2015,16th European Conference on Knowledge Management, 3-4 September 2015, Udine, Italy. Pp. 66-77.

[16] Welp E.G, Meier H, Sadek T, Sadek, K. Modelling Approach for the Integrated Development of Industrial Product-Service Systems. *In* Manufacturing Systems and Technologies for the New Frontier, Springer London 2008, pp. 525-530.

[17] Komoto T, Tomiyama Design of Competitive Maintenance Service for Durable and Capital Goods using Life Cycle Simulation. International Journal of Automation Technology 2009; 03(01): 63-70.

[18] Aurich J, Fuchs C, Wagenknecht C. Life cycle oriented design of technical Product-Service Systems. Journal of Cleaner Production 2006; 14(17): 1480-1494.

[19] Sakao T, Shimomura Y. Service Engineering: a Novel Engineering Discipline for Producers to Increase Value Combining Service and Product. Journal of Cleaner Production 2007; 15(06): 590-604.

[20] Vasantha G.V.A, Roy R, Lelah A, Brissaud D. A review of product–service systems design methodologies. Journal of Engineering Design 2012; 23(09): 635-659.

[21] Annamalai G, Hussain R, Cakkol M, Roy R, Evans S, Tiwari A. An ontology for product-service systems. Decision Engineering Report Series. Cranfield University, July 2011. 62 P.

[22] Clark P, Thompson J, Porter B. Knowledge Patterns. *Book chapter 10 in* Staab S. & Studer R. (Eds.) Handbook on Ontologies, Springer, Berlin Heidelberg 2004, pp. 191-207.

[23] Pree W. Design Patterns for Object-Oriented Software Development. Addison-Wesley Publishing New York, USA 1994, 288P.

[24] Rech J, Feldmann R.L, Ras E. Knowledge Patterns. *Book Chapter 2.12 in* Organizational Learning and Knowledge: Concepts, Methodologies, Tools and Applications. Information Resources Management Association 2011, pp. 578-586.

[25] Pahl G, Beitz W. Engineering Design: A Systematic Approach. second ed., Springer-Verlag, London, 1996.