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To cite this version:

Elaheh Maleki, Farouk Belkadi, Alain Bernard. Industrial Product-Service System modelling base on Systems Engineering. 16th IFAC Symposium on Information Control Problems in Manufacturing, INCOM, Jun 2018, Bergamo, Italy. hal-02006164

HAL Id: hal-02006164

https://hal.science/hal-02006164v1

Submitted on 18 Mar 2019

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Industrial Product-Service System modelling base on Systems Engineering: Application of sensor integration to support smart services

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Abstract: Product-Service System (PSS) has been proposed as a promising value-creation strategy to handle the new market's challenges. Despite the numerous proposed methodologies, PSS development is still a perennial topic of debates. To solve this issue, either product or service development processes are adopted. Though, a customised development process according to PSS characteristics seems more efficient. In this context, Systems Engineering (SE) could be advantageous since it supports the integration of the interconnected heterogeneous components of PSS. Moreover, industrial PSS is highly tight with the Cyber-Physical Systems (CPSs). This integration improves the manufacturers' capability in the information capturing and eases the service providing. Consequently, the sensing system, either as a component of service or a service enabler, plays a crucial role in PSS. As a result, managing the interfaces between the sensor, product and service is necessary for PSS integration. This paper aims to explore the idea of using SE recommendation for PSS modelling to integrate different viewpoints in PSS lifecycle. To do so, the deployment of SE to integrate sensing system in PSS has been explored as an industrial use case.

Keywords: Product-Service System (PSS), PSS business process, PSS lifecycle, Semantic model, Sensing System, Systems Engineering (SE)

1. INTRODUCTION

Evolving product-centred business models to Product-Service System (PSS) has been brought into the discussion from 1962 (Boehm & Thomas 2013). Afterwards, considerable efforts have been put forward on research on PSS development and its related issues (Mont 2002). Companies create added value in PSS offer, by providing an integrated system of tangible and intangible components interacting "throughout the lifecycle stages" to meet the customer's need while reducing environmental impacts (Manzini & Vezzoli 2003). PSS has been passed throughout a transition from the primary after-sale services to the current internet based lifecycle solution. As a result, the competitive capability of companies is not anymore on adding offline services to their product but to propose a smart function or solution to fulfil the customer needs like remote monitoring and preventive maintenance.

According to this approach, PSS results from the synergetic integration of various domains (such as mechanical, electrical, software, service engineering) into a system (Cavalieri & Pezzotta 2012; Vezzoli, Kohtala, & Srinivasan, 2014). This integration consists of managing the complexity and heterogeneity caused by inter-connected domains that are collaborating to create the function (Gausemeier et al. 2013). This interdisciplinary nature requires a standards-based "multidisciplinary systematic" foundation to manage various viewpoints and to encompass all heterogeneous components during the development project (Cavalieri & Pezzotta, 2012; Boehm & Thomas, 2013).

In this context, Systems Engineering (SE) recommendations could be advantageous since it provides a guide to integrating the heterogeneous interconnected components of the system (Chenouard et al. 2016). SE enables firms to develop PSS as an interdisciplinary system that consists of diverse and interrelated components (tangible and intangible) to provide the required function (Mamrot et al. 2016). SE approach is vastly applied to develop mechatronic systems (Lefèvre et al. 2014). As a result, its capability for modelling physical component of PSS is promising. However, integrating diverse elements in PSS development is still a big challenge (Mamrot et al. 2016).

Comparing to the product or the service, PSS sub-systems have different modes of value delivering which must be integrated into a unique PSS offer. As a result, PSS lifecycle incorporates with the connection of various interdependent lifecycles of tangible and intangible components. While the PSS definition is well-described in the literature, its development model is still indeterminate. Despite the fact that various systematic approaches are proposed for PSS engineering (Hollauer et al. 2015; Wang et al. 2014; Welp & Sadek 2008), a function-based process model to cover its whole lifecycle in the practical cases seems to be challenging.

Considering all above, the ultimate ambition of this research is to develop a semantic model to support the PSS through-life development. This research tries to propose a framework to ease the PSS development process by synchronising lifecycle and process models of various sub-systems. This

paper aims to explore the perspective and the methodology of research work on representing PSS architecture by integrating different viewpoints in PSS lifecycle and business processes.

To do so, the remainder of this paper is organised as follows. Section 2 gives a brief overview of the theoretical background. Section 3 describes the global framework of the proposed model. Section 4 presents the analysis of the industrial use case. The last section draws the discussion and future work.

2. THEORETICAL BACKGROUND

To deliver PSS, it is necessary for companies to achieve a set of capabilities. In this context, it is crucial to moving from their core business competence towards the new customised but repeatable smart solutions (Davies & Brady 2000). To create this solution-ready smart service, increasing the capability of monitoring the product during the PSS lifecycle is a prerequisite. As a result, information capturing from the whole system lifecycle became a central process in industrial PSS. Hence, the integration of PSS, internet, software and sensor as the new path in PSS design is inevitable (Boehm & Thomas 2013; Mikusz 2014; Scholze et al. 2016). Consequently, the product is evolved to mechatronic systems (Muller et al. 2007) and the service to the software-based services embedded in the physical product (Davies et al. 2006).

Considering all above, PSS is regarded as an integrated system of interconnected elements to provide an agreed-upon functionality for customers (Cavalieri & Pezzotta 2012; Tukker & Tischner 2004). PSS consists of tangible product modules like mechanical, electrical and cybernetic which are considered as a mechatronic system (Muller et al. 2007), intangible service modules and enabling system characterised by integrated development process and function allocation (Lindström et al. 2015; Mikusz 2014). As a result, PSS can be considered as an integrated system with unique characteristics. First, PSS development process incorporates various sub-lifecycles that are different in characteristics and development activities (Lindström et al. 2015). In addition to the product development, PSS development is associated with intangible service and enabling mechanisms which can be consisted of physical and non-physical components (Xing et al. 2013). Second, PSS development process is associated with a technological transition in the product along with its life cycle (Scholze et al. 2016). So, the tangible sub-system of PSS could be a mechatronic system consists of mechanic, electric and cybernetic components (Muller et al. 2007).

The involved tangible and intangible elements with organisational and technical complexity as well as their different modelling approaches are the challenges of PSS development (Mamrot et al. 2016). Companies, who are evolving to the integrated solution providers, need to adjust their organisational capability by strengthening their customer relationship, flexible production and organisation focusing on the reusable integrated solution. The system must be based on building modular offer to increase the repeatability of the customised integrated offer and reducing risk and cost. It needs to follow modularity in design and integration in function delivering (Davies et al. 2006). “We define service process modularity as the usage of reusable process steps that can be combined (“mixed and matched”) to accomplish flexibility and customisation for different customers or situations in service implementation” (Bask et al. 2010)

In this context, some methods consider PSS development as an innovative process following standard phases to develop an artefact from requirement analysis to the end of life stage (Nguyen et al. 2014). Various approaches have been put forward to solve this issue by adopting either product or service development processes (Tukker & Tischner 2004). Though, several authors have called these methods into question (Tukker 2015) and argued that rather than adopting classical approaches in product or service development it might be more useful to tailor the development process based on PSS characteristics as an integrated system (Beuren et al. 2016; Song & Sakao 2017).

In this matter, some efforts have been made to adopt Systems Engineering (SE) approach in PSS development projects. Service engineering as an essential part of PSS is designed with a systematic approach (Pezzotta et al. 2015). By using the Spiral Model and the V-Model, PSS development process has been modelled with SE approach (Meier et al. 2010; Pezzotta et al. 2012). The Systems Engineering approach in PSS design is based on the descriptive model with “hierarchical structure” to aggregate the heterogeneous tangible and intangible components through systems levels (Joore & Brezet 2015). With the same viewpoint, PSS functional design is proposed based on sharing knowledge from the set of “function, entity, and delivery process” (Shimomura & Akasaka 2013). In a different approach, PSS is designed from four different viewpoints as “flow model, scope model, view model and scenario model”(Sakao & Shimomura 2007).

In this sense, SE approach supports a wide range of activities from “characterising the existing system” to the “concept formulation, design synthesis and integration” of the system (SEBoK 1.7 2016). By providing interdisciplinary models, SE generates a common understanding of the system to support collaborative system development (SEBoK 1.7 2016). The system model which is a “composition of all views” concurrently evolves because of the multiple stakeholders’ collaboration (Herzig & Paredis 2014) during the development process. As a result, it is advantageous for PSS collaborative development to integrate tangible and intangible components.

3. THE PROPOSED CONCEPTUAL MODEL

According to the proposed system architectures and approaches in PSS (Trevisan & Brissaud 2017) and based on Systems Engineering recommendations (Chapurlat & Daclin 2012), the concepts of System of Interest and Enabling Systems are adopted to deal with the specificity of PSS paradigm (BKCASE Editorial Board 2016). (Fig. 1)

The System of Interest (SOI) is the final result of the development process to be consumed by the client. In PSS, it

is defined as the delivered products and services. Enabling Systems (ES) facilitate progression of System of Interest (creation, production, exploitation and dismantling) through its lifecycle stages but does not contribute directly to its function during operation (BKCASE Editorial Board 2016)(Haskins 2010). In PSS it is the collection of any supportive systems (e.g. technology, resources, people, etc.) to deliver the integrated products and services (Trevisan & Brissaud 2017; Chapurlat & Daclin 2012).

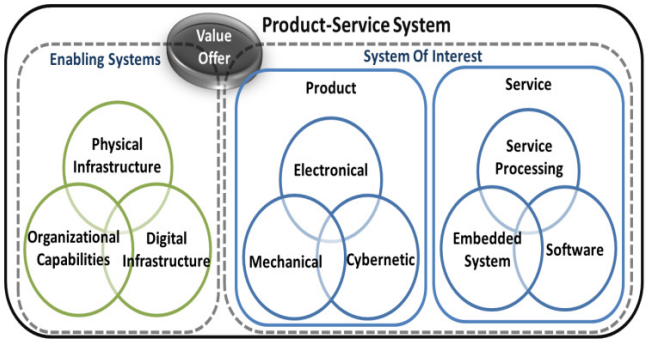

Figure 1. PSS System from an SE perspective.

This paper aims to describe the idea of using SE to propose a PSS development framework. To do so, we adopted an analytical conceptual research method (Cavalieri & Pezzotta 2012). This method is a mixed research method of top-down for an academic point of view and bottom-up from the pragmatic point of view.

Three steps to acquire information from the pragmatic viewpoint are as follows:

1. Observing the development project activities.
2. Comparing the differences and similarities with the literature.
3. Analysing the results from the industrial case by the academic point of view.

In this context, the idea of services per life cycle stage (System life cycle stages and processes) is proposed to fulfil the need of each phase (Andriankaja et al. 2016). System life cycle processes are defined based on ISO/IEC/IEEE 15288 standard (Jarmo Alanen & Salminen 2016) and the System Life Cycle Stages based on the ISO/IEC 2001 (ISO/IEC 2001). PSS Lifecycle is defined by connecting the chain of Life stage-Events-Action-Process. In this point of view, each event during the PSS lifecycle triggers a new stage (Fig. 2). As an example, the service-related data for EOL considers the required actions related to the materials flows which are possible to recover or to reuse in the same PSS or other systems (Corti et al. 2016).

To proceed toward the system lifecycle stages, the business process is performed. In PSS, all business processes are considered as Enabling Systems. Four main categories of processes during PSS lifecycle are as follows: (Fig. 3).

1. The PSS creation process is made up of the all processes (such as design, supply, production and knowledge management) to create a new PSS or its re-usable packages of products and services.
2. The associated process is the prerequisite process (such as lifecycle assessment, financing and resource alignment) to support the PSS operation.
3. The Operation process is the necessary process (such as operational service, system integration and business consultant) to set the PSS in motion.
4. The Operation control process is a collection of processes (such as monitoring and planning) to manage the associated process and PSS operational function and operation process.

In the next section, one scenario about using the sensing system to provide service in PSS is described.

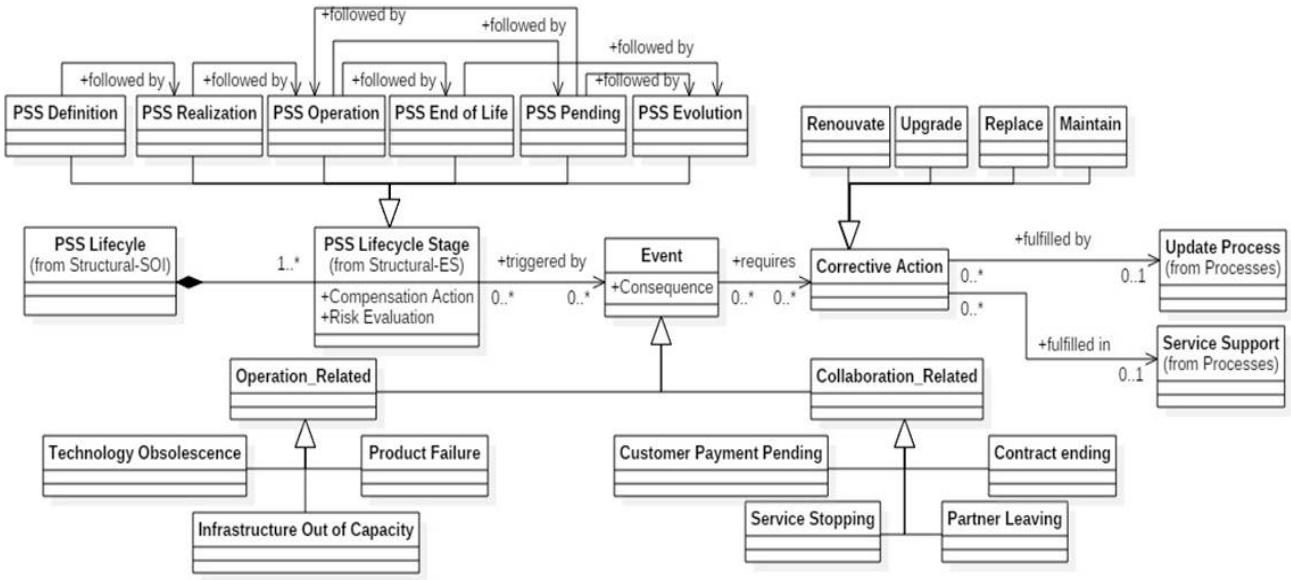

Figure 2. PSS lifecycle schema

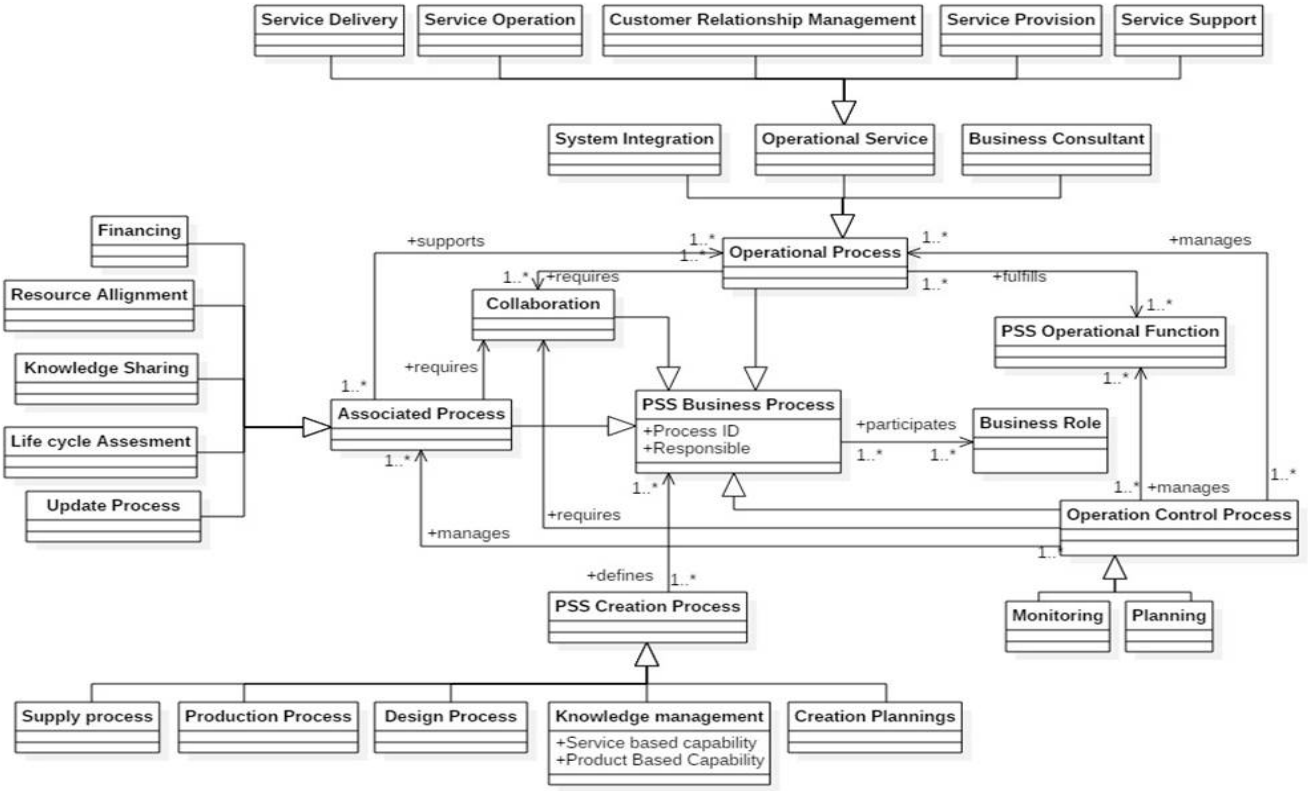

Figure 3. PSS business processes

1. INDUSTRIAL SURVEY ANALYSIS

The industrial case in this project is a manufacturer of industrial machines from the ICP4Life project. "ICP4Life proposes an integrated, collaborative platform for the design, development and support of product-service systems for SMEs, equipment manufacturers and energy suppliers to maximise the impact in the European industry."

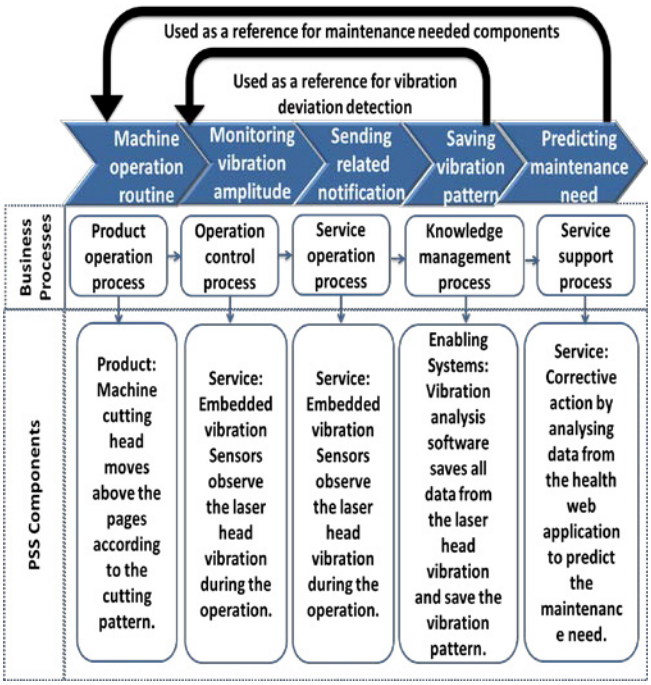

Figure 3 Description of the use case

The scenario to provide the PSS is as follows. The machine health monitoring service is the basis of predictive maintenance and highly relies on vibration monitoring. Involving the sensors in the PSS lifecycle eases the monitoring and predicting services like maintenance. To fulfil this service, vibration sensors are integrated with the machine to monitor its vibration during operation. To do so, the part of the machine which should be observed will be chosen to add the sensor. The health monitoring application will analyse data from this sensor. When the vibration amplitude shows deviation from acceptable acceleration and frequency during its normal operation, an alarm notification will be sent to the equipment user. The vibration pattern (the machine behaviour) is saved and used as a reference for vibration deviation detection. Based on this, the maintenance need is Predicted. The necessary process for each step of the scenario is then defined. As an example, 'predicting maintenance need' is fulfilled by the 'service support process'. Accordingly, the components involved in each process is determined (Fig. 4).

The development process to provide the final PSS follows the through lifecycle engineering. The first challenge during the PSS development is to distinguish the elements that are part of the system of interest (such as software) from others considered as the enabling system to make the job done (such as digital infrastructure). In this case, PSS consists of software to monitor the machine, embedded software in the machine to get the job done and software as the collaborative platform. According to the required function, each PSS component (e.g. software) can be identified as a part of the product, the service or the enabling system (digital infrastructure). PSS elements, in this case, are categorised

according to the proposed model in figure 1. The product is the customizable machine which is associated with some intelligent health monitoring services. The components of service are various from hardware to service processing and software. The collaborative platform supports the knowledge sharing through lifecycle development process. The architecture of the proposed supportive platform is based on a central knowledge repository through which different business applications are interconnected to provide technical assistance to users during PSS collaborative development. Other infrastructures and organisational aspects are also identified to enable the PSS development. (Table 1)

Table 1 PSS components

	PSS Components	Industrial case (Machine health monitoring)
System of Interest	**Product**	**The Machine**
	Mechanic	Machine Bogie
	Electric	Sensors
	Cybernetic	Control system
	Service	**Machine vibration analysis**
	Service Processing	Vibration measure and analysis
	Software	Installed software to automatically perform frequency and temperature analysis
	Embedded Systems	Sensors, Wifi equipment
Enabling	Physical Infrastructure	Monitoring data centre, maintenance equipment
	Digital Infrastructure	Collaborative platform
	Organizational Capability	Resources and Processes for maintenance network (techniciens, control center, etc.), Processes of maintenance, hazard alarming.

2. DISCUSSION AND FUTURE WORK

While in theory, classifying and modelling PSS and its sub-systems and components is possible, function-based modelling in the practical situation seems to be challenging. Considering the PSS characteristics, to correctly represent its architecture, we propose to use through life cycle modelling approach to support the integrative PSS architecture. Building the globally integrated model of PSS and its different subsystems are the final output of the project. Such architecture will let us adopt required modules to use/reuse in special PSS development projects which will be beneficial in the matter of PSS cost and time to market.

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.

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