Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 64 (2017) 357 – 362

www.elsevier.com/locate/procedia

The 9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems

From PSS to CPS design: a real industrial use case toward Industry 4.0

Eugenia Marilungo[a]*, Alessandra Papetti[a], Michele Germani[a], Margherita Peruzzini[b]

[a]*Università Politecnica delle Marche, via Brecce Bianche - Monte Dago, Ancona 60131, Italy*
[b]*Università di Modena e Reggio Emilia, via Vivarelli 10, Modena 41125, Italy*

* Corresponding author. Tel.: +39-071-220-4880 ; fax: +39-071-220-4708. *E-mail address:* e.marilungo@staff.univpm.it

Abstract

During the last 10 years, manufacturing companies have faced new challenges for improving their value proposition and being more efficient and effective on the market, satisfying the customer needs. According to this trend, several technologies have been developed and applied in different sectors and with different aims, in order to support such the companies in their reconfiguration. For example, the recent advances in Information and Communications Technologies (ICT) could give also to manufacturing industries the competences required to develop novel sustainable products embedded with a dedicated infrastructure able to provide more service functionalities to customer. In this context, the application of Internet of Things (IoT) have allowed developing the so named Product Service Systems (PSSs). Moreover, the cross-fertilization between such the technologies with the development of other ones have fostered the application of these novel ICT technologies inside the manufacturing companies also at process level. This approach has encouraged the study and development of Cyber-Physical Systems (CPSs). The present paper deals with a real industrial use case, where the application of ICT technologies and specifically the adoption of IoT at a plant of plastic extrusion pipes have allowed optimizing the production process in terms of energy efficiency.

Keywords: "Cyber Physical System design; CPS; ICT; IoT; Industry 4.0"

1. Introduction

Manufacturing companies are changing from being the owners of the only competences and skills to realize more and more products on the market (i.e. mass production), to being a set of human competencies, skills and machine technologies able to realize a complex process. The outputs are products tailored on the customer needs and delivered when these customers require (i.e. production just in time). According to this trend, the rapid technological changes combined with a highly competitive market have fostered the implementation of new approaches for reducing "time to market" [1][2], waste and failures, as well as in order to be both appropriate in terms of quality and cost effective [3] and meet the customers' expectation. Thus, several technologies have been developed and applied in different sectors and with different aims, in order to support such the companies in their reconfiguration. In this way, a new level of human-machine interaction has become possible and more widespread, as well as the opportunity to have more sustainable industrial processes, more efficient factories and more optimized supply chains.

In this scenario, also the company offer is changing according to market demand and customers' needs, fostering the development of Product Service Systems (PSSs) instead traditional products. Indeed, PSS implies the design of a wide set of services that should be delivered by the physical product through the implementation of a dedicated hardware and software infrastructure. This allows delivering to customers new personalized service functionalities able to satisfy their needs and expectations. This approach has been defined in literature as Servitization process [4] and defines the four different integration degrees between tangible (i.e. product) and intangible (i.e. service) assets.

Moreover, in the last years, the PSS spread has been increased by the diffusion of pervasive Information and Communication Technologies (ICT), which strongly reduced the cost for additional sensors and cloud technologies, enabling data monitoring, storage and post-elaboration. The

doi:10.1016/j.procir.2017.03.007

ICT propagation has allowed the creation of higher service layers, which deliver products with new smart behaviors and communicating capabilities (i.e. monitoring the surrounding environment, monitoring the users' habits, interacting with other connected devices, etc.) [5]. In this context, the Internet of Things (IoT) paradigms have become the main tool for connecting the products in order to develop a PSS, and according to this concept, Follett [6] enlists as significant emerging technologies a networked, smart world connected by IoT.

The adoption of these novel technologies in manufacturing companies is the current challenge for Industry, because their application implies a complete reconfiguration of the company, even if they are able to produce benefits, for example in terms of costs reduction, energy efficiency, process performance and product quality. For this reason, the relevance of these technological advances has been implemented in several governmental programmers, like the German "Industry 4.0" paradigm [7] and the United States Smart Manufacturing Leadership Coalition (SMLC) [8] aiming at introducing CPS and PSS into manufacturing [9].

In this context and thanks to the availability of these novel technologies and the national programs, the current concept of Industry 4.0 has been arisen and diffused in the entire Europe. The main scope is reorganize the industrial companies step by step, implementing the IoT and ICT technologies in order to produce some benefits that the companies themselves can use to both: 1) be more and more sustainable in their industrial processes or along their supply chain; 2) to create a new strategic advantage in the market and rather than their main competitors.

The present paper shows an approach to design a CPS and its implementation in a real industrial use case, where the application of ICT technologies and specifically the adoption of IoT at a plant of plastic extrusion pipes have allowed optimizing the production process in terms of energy efficiency. Such the paper displays also what are the main benefits for the involved company, due to the exploitation of the specific CPS.

Nomenclature

PSS	Product Service System
CPS	Cyber Physical System
IoT	Internet of Things
ICT	Information and Communication Technologies
P-SLM	Product-Service Lifecycle Management

2. State of the art

The literature review proposed in the following aims to give an overview about what is the factories of the future, how ICT and IoT technologies can foster their development, and how PSS and CPS are involved in this context.

2.1. ICT and IoT for the factory of the future

The opportunity to develop PSS in order to move manufacturing companies towards the factories of the future is born with the arising and more diffusion of ICT technologies and IoT approaches. Indeed, the recent advances in Information and Communication Technologies could give also to manufacturing industries the competences required to develop sustainable PSSs and production processes. Moreover, recent studies demonstrated that ICT could validly support sustainable business by the development of smart products that are able to improve the stakeholder's communication, increase the social inclusiveness and the consumer empowerment [10]. However, despite the ICT potentials, little is known about how such the technologies should be integrated into products to create a sustainable PSS and which opportunities can arise.

Instead, at process level, the implementation of ICT foresters the development of CPS, which conduct the current factories toward the so called factories of the future, where any information required has been translated in digital data.

At the same, IoT is considered by the research community the paradigm with the highest economic impact [11] on PSS development, and on connectivity in general. This technology is wide used by several manufacturing companies that approach the transition from product-centered production to the creation of a new value proposition service-oriented. Moreover, the connection of different devices to a same cloud to share information (i.e. connectivity) can be extended also to a set of machineries that belonged to a same plant or facility, in order to have a "digital production". In this way, IoT can support manufacturing companies not only in the PSS design but also in the CPS design and development. Therefore, in order to these manufacturing companies are able to design one of these smart systems (i.e. PSS, CPS) they need to investigate in deep their current processes and the adopted technologies, in order to define a collaborative environment. This aslo implies that companies innovate with external partners by sharing both risks and rewards. According to this new industrial context, the boundaries between a firm and its environment have become more permeable and innovations can easily transfer inward and outward. Thus, also the knowledge management acquires a key role in the design and development of both PSS and CPS.

2.2. Product Service System design

In literature, PSS concept is mainly centered on the integrated bundle of products and services, and concerns directly the customer. Indeed, it is defined by several researchers as a mix of tangible products and intangible services designed and combined to increase the value for customers [12][13]. During the recent years, clear evidence shows that service plays an increasingly important role in many manufacturing industries, especially in those ones produce complex products, which have moved to delivering PSSs. The Servitization process is a fundamental mean for manufacturing companies that would find new business opportunities and involve new customer segments, increasing their market share [14][15]. Their aim is to propose and sell no more a product (based on its ownership), but rather its usage (e.g. renting, pay-x-use, etc.) and performances (e.g. pay-x-performance).

Usually manufacturing companies product-centered have well-defined and structured product development processes, but they lack a sufficiently in defining service development. Therefore, they are poorly equipped with appropriate approaches, methodologies and tools for supporting in efficient way the design and development of a PSS.

In literature, several methodologies have been proposed to support industrial companies to design a PSS along its entire lifecycle [16]; the main ones are:

- *Service Computer-Aided Design (CAD)*, able to support the decision-making evaluation through the concept design, prompting different alternatives scenarios [18];
- *Software simulation tool* for designing service activity and products concurrently and in a collaborative way during the early phase of PSS design [19][20][21];
- *UML (Unified Model Language) 2.0*, which allows conducting concurrently a systematic technical-services design and the corresponding product design process [22];
- *Model-based approach* to allow Industrial PSS design modelling, fostering the functional PSS behavior [23];
- *Service Engineering* based on Structured Analysis and Design Technique representations [24][25][26][27];
- Lifecycle oriented approaches [28][29][30];

Requirement Engineering (RE) is a crucial method within the Service Engineering approach to adopt during the design process of a PSS, in order to identify the main requirements according to the target market. Indeed, offering PSS instead traditional product requires additional competencies to identify the service functionalities to enhance the product, and a better understanding of the customer requirements to reach [31]. This implies a huge quantity of implicit knowledge to elicit and a big variety of actors to involve [32].

Anyway, some of these methods are very theoretical and hard to implement in practice, others are very specific and have a limited applicability range. For this reason, in the last years, some authors have studied new PSS design approaches, and the most recent and innovative one provides the integration of some existed tools along the P-SLM [17].

2.3. Cyber Physical System in manufacturing

At manufacturing companies, a CPS can be seen as a PSS translated at factory level. Indeed, such as in PSS there are two main components, one tangible that is the product and ICT infrastructure, and another intangible that is the service delivered and the knowledge required, in CPS there are the cyber component and the physical asset [33][34]. In both the systems, the ICT connectivity is the pillar [35] and it allows the connection and the monitoring of the tangible asset in order to address a specific aim. Indeed, CPS is a collaboration system that provides and uses different service functionalities to assess and process data from industrial processes [36]. For example, CPS is able to provide new ways of human-machine interaction using advanced sensors and actuators. They rely on knowledge and engineering principles from computational and engineering disciplines. Moreover, in order to reach the full potentialities of CPS, they can also comprise the logistics and management processes, as well as internet services receiving, processing and analyzing data from the sensors and controlling the actuators, connected by digital networks and multi-model human-machine interfaces.

The relation between the CPS and the PSS concept can be seen as interdependent or symbiotic [37]. When looking from a CPS perspective, the physical and ICT domains are complemented with service engineering for the development of the solution. This increases the number of stakeholders and adds additional domain-specific models, methods and tools to the development process. As a result, complexity rises, because every service element has to be aligned with all physical and ICT elements of the CPS.

Several characteristics can be identified that describe CPS and distinguish them from other complex systems. The eponymous aspect of CPS is merging the physical and virtual world. CPS involve a multitude of parallel and interlinked sensors, computers, and machines, which collect and interpret data to decide on this basis and control real world physical processes. Thus, systems engineering need to integrate industrial processes and control systems with information technology [38]. Secondly, CPS has to be able to actively configure services and networks with other systems or part of systems, which may be unknown in the beginning, and provide new and composite components and services in a controlled way [39]. Furthermore, an important CPS characteristic is their ability to adapt to environmental changes. This requires continuous monitoring and assessment of environmental and application data [40]. Finally, CPS have to interact with humans also on a physical level, which requires multimodal control interfaces, recognition, and interpretation of human behavior and interactive decision making between the system and single persons or groups [41].

3. Cyber Physical System design approach

The paper aim is to support industrial companies in their reconfiguration toward the factories of the future, adopting the CPSs. Thus, they need a structured design approach that they use as a decision-making tool.

Indeed, usually manufacturing companies have acquired CPS stand-alone solutions and have installed them into their industrial context, with the aim to exploit some activities. Instead, currently, they need to put under control the entire industrial plant and digitalize all the information in order to provide several optimizations. According to such the vision, this paper proposes a design approach, which has been inspired by [42] and [43], in which authors define a method for PSS designing. Indeed, the research aims are the same: design a system that involves both tangible and intangible assets, according to the user requirements.

The methodological approach proposed by this paper is composed by five steps that drive industrial companies in the analysis of the current situation, in the modeling and design of the possible CPS, and finally in the definition and implementation of the novel scenario that provides the exploitation of the CPS solution designed.

In the following, the detail of each methodology step:

Step 1. Analysis of the AS-IS scenario: it involves two main actions. The first one is mainly focused on the investigation of the current production process. This activity is supported by a dedicated modelling tool able to describe in detail the involved company processes, identifying all the activities and, for each activity, the related input required and output generated, the needed resources exploited (e.g. human, material or raw material, etc.), the involved competences and skills, and the control unit (e.g. company's departments, process's managers). The second action is focused on the definition of the current business model, according to the canvas model. Both such the actions are necessary to have a clear vision of the current company status and business, in order to understand which the main strategic process's areas to improve are.

Step 2. Mapping of the tangible and intangible (T/I) assets: it is focused on the mapping of all the involved company assets, both tangible (e.g. machineries, raw materials, any devices, sensors, etc.) and intangible (e.g. competences, skills, knowledge, relations among tangible components needed to realize another product functionality). Moreover, during this step, also the ecosystem analysis is conducted, through the adoption of interviews and ad-hoc questionnaires to company's employee (Marketing, Sales and R&D departments), which investigate different aspects of the value creation process. Indeed, each question has been defined starting by the analysis of the current company business model, and the survey's results are assessed and elaborated through Datamining technics. The tools used to reach this scope were diagrams and manual aggregations of responses to individual questions.

Step 3. ICT infrastructure modelling: it aims to model the ICT infrastructure that make an industrial process a CPS. During this step, the main sensors and devices are identified according to the company needs, the database to collect the digital data is defined, and finally, the technology required to elaborate such the data and give benefits along the process is recognized.

Step 4. Definition of the new process: according to the infrastructure needed to realize the CPS, the Business Use Case (BUC) techniques have be used [44][45] both to model the novel process that involves the exploitation of CPS, and to identify its main functionalities. At this stage, the company business model can be updated according to the improvement at process level, which can involve the company key resources and key activities, the value proposition and the company relationships with customers.

Step 5. Analysis of the main CPS benefits: at this stage the company is ready to implement and exploit the new CPS solution into its factory. Actually, a preliminary phase where the new process is tested and that allows monitoring the main solution benefits is needed. The quality and benefits of the CPS solutions implemented can be verified in different ways (e.g. lifecycle approaches, performance indicators measurement, customer satisfaction, etc.). This paper is focus on the benefits directly into the production, thus they will be measured in terms of energy efficiency.

4. Industrial use case and result discussion

The use case has been conducted on an Italian plastic pipe manufacturing company which has three plants, one for each different product family (i.e. PE pipes, PVC pipes, corrugate pipes), where the plastic extrusion process was performed. More in detail, the plant involved in this study is affected by the production of polyethylene (PE) pipes, because it has the younger production lines and the whole plant is now changing.

The PE plant involves different macro areas. The main ones are four: 1) the raw materials storehouse, 2) the production area where there are the eight different extrusion lines, many of which are of the latest generation and have a PLC on board, 3) the refrigeration unit, and finally 4) the finished product storage area, which involves the machineries, devices and sensors that allow storing the finished products.

The company involved in this study needs to design a CPS on the entire production plant, in order to monitor its production process for optimizing and making it more efficient, delivering more sustainable products.

In the following, the detail of each methodological step described in Chapter 3.

4.1. Analysis of the AS-IS scenario

The first action is to model the current company's industrial processes. This has been done through the implementation of the IDEF-0 model, after to have analyzed in deep the processes map and its value stream model. The result has been the plastic extrusion process modelled in terms of input needed, output resulted, resources required to exploit the process itself, and finally the constrains and tools involved along the process. About the inputs, the main one is the raw material that is convoyed by the raw material storage area to the extrusion feeder at the beginning of the production line. Indeed, the extrusion line is composed by several machineries: the feeder (AL), the extruder (E1), the extruder head (TE), the co-extruder (CO), the vacuum tank (VV), the cooling tanks (VR1, VR2, VR3), the seal press (M), the drag system (TR), and finally the cutting system (TA).

Fig. 1 shows the scheme of the so composed extrusion line.

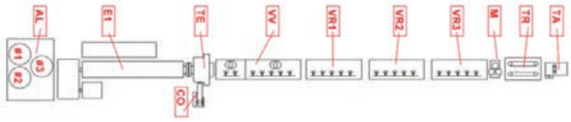

Fig. 1. Extrusion production line scheme

About the output, the production process results are the plastic pipes, while the resources exploited are the electric energy, to start the engine and activate the extrusion, and the water, to cooling the pipe extruded inside the cooling tanks. In this context, the main constrains are linked to the process parameters (e.g. extruder head temperature, extruder speed, drag system speed, etc.) that are needed to be under control.

4.2. Mapping of the tangible and intangible (T/I) assets

During this second step, all the processes involved into the factory plant (i.e. the raw materials storehouse, the production lines, the refrigeration unit, the finished product storage area) have been investigated in terms of T/I assets. Currently these industrial processes are traditional processes; this means that they are mainly composed by tangible assets, as shown in Table 1.

Table 1. Tangible and intangible assets recognition

Company's processes	TANGIBLE ASSETS	INTANGIBLE ASSETS
Extrusion lines	Machineries, raw material, final product, refrigeration water, electric infrastructure	People competences and skills
Refrigeration unit	Machineries, refrigeration water, electric infrastructure	-
Raw materials storehouse	Machineries, raw material, electric infrastructure, storage infrastructure	Management software
Finished product storage	Machineries, final product, electric infrastructure, storage infrastructure	Management software

For each asset identified, the related owner and supplier have been identified through the investigation inside the Marketing, Sales and R&D company's departments. The company has decided to focalize any effort only in the production area where the production lines work, because this is the area that exploit most of the resources.

4.3. ICT infrastructure modelling

During this step, the ICT infrastructure that will be involved in the development of the new CPS has been modelled. According to the results of the previous step, it has been designed to digitalize the production process, in order to monitor and control the production lines, for optimizing the main resources' consumption and the resources exploitation. Fig. 2 shows such the infrastructure model.

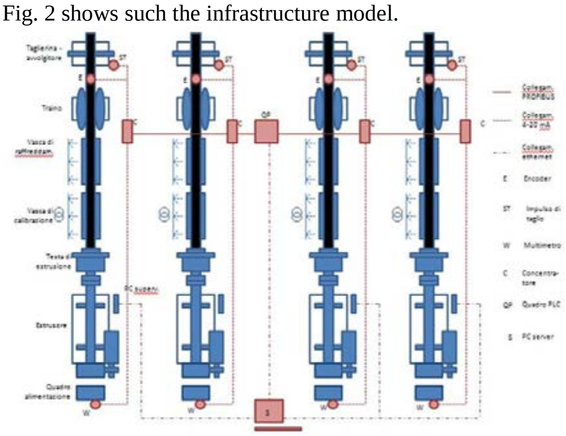

Fig. 2. ICT infrastructure along the production lines

The sensors' network allows properly monitoring the energy and the other resources consumption along the production line. Data measured have been stored into a dedicated database to be used by the production plant manager through a tailored software application, which allows monitoring the technical parameters of the production plant and the energy performances of each production line.

4.4. Definition of the new process

According to the process digitalization and the company need of managing the production data in order to schedule the production size for reducing the energy exploited and used along the production process, the BUC has been modelled. It has highlighted the key resources and key activities needed to implement the proposed CPS with the design ICT infrastructure. The main object derived was the optimization of the energy exploited along the production line. According to this result, also the company business model needs to change, above all in the areas that involve the resources, activities and costs.

4.5. Analysis of the main CPS benefits

This new extrusion process is able to monitor several process parameters (i.e. energy used, power consumption, head extrusion temperature, spindle push, extrusion flow, production speed, weight per each meter of extruded product) in order to calculate the production line efficiency and the energy consumption. All these values have been stored into a dedicated database, and through a tailored algorithm, data elaboration has been possible. Fig. 3 shows the efficiency of each extrusion line, according to the elaboration of data collected by the ICT infrastructure.

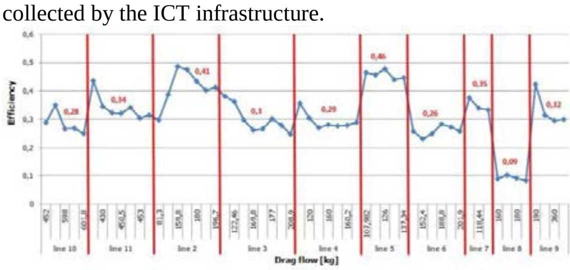

Fig. 3. Extrusion lines efficiency

Data collected and elaborated have allowed optimizing the production plant, scheduling the production according to the lines' efficiency. In this way, the entire energy plant spent for the production process has been reduced a lot. The energy efficiency assessed at the end of the first month, in which such the CPS has been implemented into the production plant, was about a 5%. This was a very great result for the company, considering that this process is high energy consuming.

This implies that for manufacturing companies that are energy consuming, the adoption of a CPS can generate positive results in terms of resource efficiency and sustainability.

5. Conclusions

The case study investigated a methodological approach to design a CPS into an industrial factory. Such the CPS aims to investigate the energetic performances for an extrusion process, analysing the AS-IS scenario, its main T/I assets, and defining the ICT infrastructure according to the product and process parameters measured in the most critical area of the plant involved. Such the case study have demonstrated that following the proposed methodology it is possible to design and implement a successful CPS, with great results for the company itself in terms of energy efficiency. Anyway some improvements are required because the methodology proposed has been applied only in this specific case study and thus needs to be tested more in order to define a general model that can be adopted in any industrial sector.

Another investigation area that is under analysis in the same company, and that represents a future work, is about the delivering of service functionalities together with the product (i.e. PSS) through the adoption of the defined CPS.

References

[1] Chang W, Yan W, Chen CH. Customer Requirements Elicitation and Management for Product Conceptualization. In: Stjepandić J, Rock G, Bil C, editors. Concurrent Engineering Approaches for Sustainable Product Development in a Multi-Disciplinary Environment, Springer London. London; 2013:957-968.

[2] Lee S, Park G, Yoon B, Park J. Open innovation in SMEs - An intermediated network model. Research Policy 2010; 39:290-300.

[3] Kossiakoff A. Systems engineering principles and practice. 2nd ed. Oxford: Wiley; 2011.

[4] Thoben KD, Jagdev H, Eschenbaecher J. Extended Products: Evolving Traditional Product Concepts. Prodiceeding of 7th International Conference on Concurrent Enterprising, Bremen; 2001.

[5] Yang X, Moore P, Pu JS, Wong CB. A proactical methodology for realizing product service systms for customer products. Comp & Ind Eng 2009; 56:224-235.

[6] Follett J. Designing for Emerging Technologies. O'Reilly Media; 2014.

[7] Kagermann H, Helbig J, Hellinger A, Wahlster W. Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0: Deutschlands Zukunft als Produktionsstandort sichern; Abschlussbericht des Arbeitskreises Industrie 4.0, Forschungsunion; Geschäftsstelle der Plattform Industrie 4.0, Berlin, Frankfurt/Main; 2013.

[8] Smart Manufacturing Leadership Coalition, Implementing 21st Century Smart Manufacturing: Workshop Summary Report, Washington DC; 2011.

[9] Baheti R, Gill H. Cyber-physical system. The impact of control technology 2011; 161–166.

[10] Hernández Pardo RJ, Bhamra T, Bhamra R. Sustainable Product Service Systems in Small and Medium Enterprises (SMEs): Opportunities in the Leather Manufacturing Industry. Sustainability 2012; 4(2):175-192.

[11] McKinsey Global Institute. Disruptive technologies: advances that will transform life, business, and the global economy; 2013.

[12] Furrer O. Le rôle stratégique des services autour des produits. Revue Française de Gestion 2007 ; 113 :98-108.

[13] Vandermerwe S, Rada J. Servitization of business: Adding value by adding services. European Management Journal 1988; 6(4):314-324.

[14] Wiesner S, Guglielmina C, Gusmeroli S, Dougmeingts G. Manufacturing Service Ecosystem. Mainz Verlag: Aachen; 2014.

[15] Spohrer J, Maglio P. Toward a Science of Service Systems. Handbook of service science. Springer: New York; 2010:157-194.

[16] Garetti M, Rosa P, Terzi S. Life Cycle Simulation for the design of Product-Service Systems. Comp in Ind 2012; 63:361-369.

[17] Marilungo E, Peruzzini M, Germani M. An integrated method to support PSS design within the Virtual Enterprise. Procedia CIRP 2015; 30:54-59.

[18] Komoto H, Tomiyama T. Integration of a service CAD and a life cycle simulator. CIRP Annals - Manufacturing Technology 2008; 57(1):9-12.

[19] Shimomura Y, Hara T, Arai T. A unified representation scheme for effective PSS development. CIRP Annals - Manufacturing Technology 2009:379-382.

[20] Marilungo E, Coscia E, Quaglia A, Peruzzini M, Germani M. Open Innovation for ideating and designing new Product Service Systems. Procedia CIRP, Product-Service Systems across Life Cycle 2016; 47:305-310. doi: http://dx.doi.org/10.1016/j.procir.2016.03.214.

[21] Sakao T, Shimomura Y, Sundin E, Comstock M. Modeling design objects in CAD system for Service/Product Engineering. Computer-Aided Design 2009; 41(41):197-213.

[22] Aurich JC, Fuchs C, Wagenknecht C. Life cycle oriented design of technical Product-Service Systems. J of Clean Prod 2006; 14(17):1480-1494. doi: 10.1016/j.jclepro.2006.01.019

[23] Welp EG, Meier H, Sadek T, Sadek K. Modelling Approach for the Integrated Development of Industrial Product-Service Systems. Proceeding of 41st CIRP Conference on Manufacturing Systems; 2008.

[24] Tomiyama A. A design methodology of services. In: Samuel A, Lewis W, editors. Proceedings of the 15th International Conference on Engineering Design (ICED), Melbourn: Barton 2005;1970-2014.

[25] Komoto H, Tomiyama T. Systematic Generation of PSS Concepts Using a Service CAD Tool. In: Sakao T, Lindahl M, editors. Introduction to Product/Service-System Design. London: Springer Verlag 2009;71-92.

[26] Sakao T, Shimomura Y. Service Engineering: a novel engineering discipline for producers to increase value combining service and product. In: Huisingh D et al. editors. J of Clean Prod 2006; 15(6):590–604.

[27] Sakao T, Shimomura Y, Sundin E, Comstock M. Modeling design objects in CAD system for Service/Product Engineering. Computer-Aided Design 2009; 41(41):197-213.

[28] Matzen D, Tan A, Andreasen MM. Product/service-systems: Proposal for models and terminology. In: Meerkamm H editor. Design for X: Beiträge zum 16. Erlangen: Lehrstuhl für Konstruktionstechnik 2005;27-38.

[29] Tan A. Service-oriented product development strategies. Stokkemarke: Scandinavian Digital Printing A/S; 2010.

[30] Peruzzini M, Marilungo E, Germani M. A QFD-based methodology to support Product-Service design in manufacturing industry. Proceedings of International Conference on Engineering, Technology and Innovation: Engineering Responsible Innovation in Products and Services ICE 2014, Bergamo, Italy;1-7. doi: 10.1109/ICE.2014.6871572.

[31] Miller D, Hope Q, Eisenstat R, Foote N, Galbraith J. The problem of solutions: balancing clients and capabilities. Business Horizon 2002;45(2):3-12.

[32] Wiesner S, Peruzzini M, Doumeingts G, Thoben KD. Requirements Engineering for Servitization in Manufacturing Service Ecosystems (MSEE). In: 4th CIRP IPS2 Conference, Japan; 2012.

[33] Poudel S., Ni Z., Malla N. Real-time cyber physical system testbed for power system security and control. International Journal of Electrical Power & Energy Systems (2017), vol. 90, pp. 124-133.

[34] Bernieri G., Miciolino E.E., Pascucci F., Setola R. Monitoring system reaction in cyber-physical testbed under cyber-attacks. Computers & Electrical Engineering, in press

[35] Stefanov A. and Liu C.C. Cyber-Physical System Security and Impact Analysis. Proceedings of the 19th World Congress The International Federation of Automatic Control Cape Town, South Africa. August 24-29; 2014.

[36] Monostori L. Cyber-physical production systems: Roots, expectations and R&D challenges. Procedia CIRP 17 (2014) 9 – 13.

[37] Wiesner S.A., Marilungo E., Thoben K.D. Cyber-Physical Product-Service Systems – Challenges for Requirements Engineering. International Journal of Automation Technology 2017; 11(1):17-28

[38] R. Rajkumar, I. Lee, L. Sha, J. Stankovic, Cyber-physical systems, in: the 47th Design Automation Conference, Anaheim, California, p. 731.

[39] A.W. Colombo, S. Karnouskos, T. Bangemann, A system of systems view on collaborative industrial automation, IEEE International Conference on Industrial Technology (ICIT 2013), Cape Town, 2013, pp. 1968–1975.

[40] K. Wan, V. Alagar, Context-Aware Security Solutions for Cyber-Physical Systems, Mobile Netw Appl 19 (2014) 212–226.

[41] G. Schirner, D. Erdogmus, K. Chowdhury, T. Padir, The Future of Human-in-the-Loop Cyber-Physical Systems, Computer 46 (2013) 36–45.

[42] Peruzzini M, Marilungo E, Germani M. Product-service lifecycle management in manufacturing: an industrial case study. Proceeding of Product Lifecycle Management (PLM) conference; 2014.

[43] Peruzzini M, Marilungo E, Germani M. Addressing product-service manufacturing in globalised markets: an industrial case study. Proceeding of Concurrent Engineering (CE) conference; 2014.

[44] Miller D., Hope Q., Eisenstat R., Foote N., Galbraith, J. (2002) The problem of solutions: balancing clients and capabilities', Business Horizon, Vol. 45, No. 2, pp.3–12.

[45] Cockburn A. Structuring Use Cases with Goals, Journal of Object-Oriented Programming (1997).