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Procedia CIRP 47 (2016) 138 – 143

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Product-Service Systems across Life Cycle

Supporting context sensitive lean product service engineering

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Abstract

Modern companies face immense market pressure to meet customers' demands while ensuring the sustainability of business. Consumers are now requesting highly customized products and services, i.e. demanding mass customization from manufacturing companies. The complete value chain needs to develop strategies enabling interaction with customers and consumers, supporting customization of features and services, and even co-design. This paper presents the DIVERSITY approach, which consists on a methodology and engineering environment supporting companies in using social media to realize a context sensitive lean design process of product service systems.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle

Keywords: product service system (PSS); context sensititivy; sentiment analysis; mass customisation

1. Introduction

The transition from local economies to the global competitive landscape, the current fluctuating customer demands, socio-political reasons, and the technological advances, led to the evolution of manufacturing systems from craftsmanship to customer-oriented manufacturing paradigms [1]. To this end, modern enterprises, acting at the global market, need powerful engineering environments to allow for multi-directional exchange of knowledge between product design, service design and manufacturing as well as customers, suppliers. The exchange of knowledge has to be assured along the whole life cycle of the product-services. IT attempt to help manufacturers to reduce development time, to eliminate a significant part of the design and build cycles, as well as to address the need for more customized product variants [2] [3].

To support dynamic building of Product Service Systems (PSS), there is a need for collaboration among various actors across the value chain. This in turn requires dynamic feedback loops between the design, manufacturing and product-service use. Cloud technologies offer strong potential for collaborative design through enhanced coordination of design activities performed by users across the globe and integration of multiple CAx tools [4]. Moreover, the monitoring of the PSS performance throughout its lifecycle is required in order to address the requirements related to sustainability. Measuring the performance of the production systems in general, leads to elimination of wastes, better process control, as well as efficient manpower utilization [2]. Following that, measuring the performance of the PSS design, it will have great impact in the final PSS effectiveness. However, only the 5% of the PSS literature work is devoted to the evaluation concepts or methodologies for PSS.

Real time exchange of knowledge between the designers, manufacturers, maintenance experts, as well as product-service users is mandatory in modern PSS design. This includes

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle
doi:10.1016/j.procir.2016.03.103

automatic data gathering and exchange along the value chain, but also tacit knowledge from various actors. It is especially important to exploit the combined feedback from the users of the products-services (both business customers and final consumers) through manufacturing intelligence in building/updating the product-services.

Internet which is assumed as one of the primary enablers of globalisation, allowed online customisation and purchasing, leading to new disruptive purchasing models [5]. Despite the exponential growth of the internet usage the last years, as well as the adequate number of software tools for intelligent searching and feedback analysis, it is observed limited adoption of these potentials form manufacturing industry [6].

Although the PSS concept has its roots on Lean Thinking [7], very little literature work treats the Lean PSS concept [8] [9] [10], while none of them includes a comprehensive methodology or tool for Lean PSS design. Moreover, the classical product engineering and product data management/product lifecycle management (PDM/PLM) systems do not effectively support concurrent PSS and/or Lean PSS design, nor facilitate acquisition and re-use of the tacit knowledge. The industrial companies, on one side, require a structured approach offered by such classical information and communication technologies (ICT) solutions, but, on the other side, they need high flexibility from tools to allow capturing of dynamically changing requirements and experience of various actors. On top of that, they need solutions to support knowledge sharing across the entire lifecycle and among various actors involved in dynamically changing value network, aiming at optimization of the environmental footprint of the PSS (e.g. reduction of energy consumption, material wastes of machines by remote diagnostics/maintenance).

2. DIVERSITY approach

DIVERSITY is a European project that brings together nine institutions, from academia to industry [11]. Trying to address the identified gaps presented in section 1, DIVERSITY proposes a combination of classical product engineering tools, cloud technologies and social software solutions (see Fig. 1) to meet the requirements of distributed manufacturing enterprises to allow for effective product-service systems engineering utilizing manufacturing intelligence and experience of all actors in the value chain, including both business customers and consumers. On top of that, the enormous amount of knowledge to be gathered and shared under dynamically changing conditions, and diffused to a wide spectrum of actors involved, having different expertise and working conditions/cultures, asks for effective context sensitive solutions for knowledge capturing, analysis and diffusion.

The authors have adopted the definition of a product-service system from [12]: “*A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models.*”

The lifecycle of a PSS has several phases from the initial concept to the final disposal, depicted in Fig. 2. as a closed sequence.

Fig. 1. DIVERSITY main approach.

These phases are:

- **concept** – the conceptualization of the PSS comprises the set of objectives to be attained and the added value to the target customer.
- **solution design** – the design of the PSS is an iterative process itself including the configuration of the several involved aspects.
- **service implementation** – the PSS, being a combination of service and product, requires a phase dedicated to the implementation of the service in action.
- **product manufacturing** – in parallel to the implementation of the service, the product is manufactured according with the designed solution.
- **integration** – as DIVERSITY targets an open approach to the design of PSS, i.e. where different market players can provide the services and the products, an integration phase might be needed to ensure compatibility between both components.
- **distribution and sales** – this is the phase when the PSS is taken to the market and specific customer relationships are established and maintained.
- **use and disposal** – in close connection with the previous phase, the use of the PSS (until and including its disposal) is the longest of the lifecycle and the most beneficial on knowledge provision to be used in re-conceptualisation and re-design of the PSS.

The project includes three business cases, with three industrial companies who are equipment providers to large manufacturing companies:

- The first business case involves a German company that delivers worldwide technology for industrial shoe producers. This company is the leading machinery and moulds supplier for direct soling and unit sole processes. The company wants to analyze consumer feedback on products and respond to mass customization without extra costs.
- The second business case comprises an Italian company who is one of the world leaders in control solutions for air-conditioning, refrigeration, and heating, and systems for humidification and evaporative cooling. This company wants to enhance its value proposition, enriching products with new services, opening new business opportunities and supporting direct contact between the company and consumers.

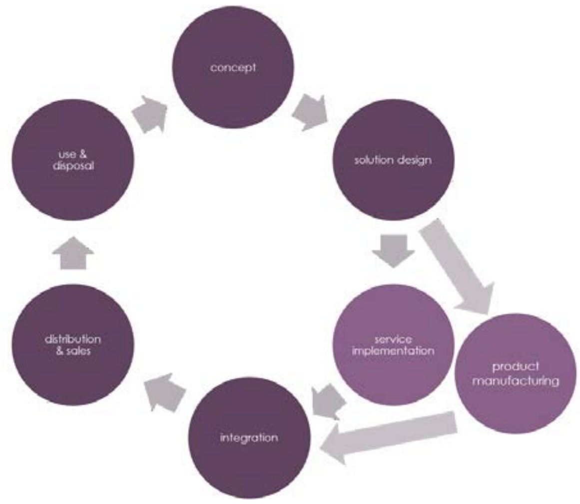

Fig. 2: Product-service system life cycle.

- The third business case includes a Greek company who is one of the biggest mould shops in Europe, combining know-how and high technology. The company wants to develop methods and tools that allow the mould-maker to offer complementary services to its business partners.

These companies have defined requirements on what they need and expect from a comprehensive solution to support lean deign of product-service systems.

A comprehensive and lean design process requires a significant amount of knowledge, in order to be efficient. Therefore, we define a knowledge-based design activity, as the sequence of steps necessary to realize the several stages of the design cycle.

The DIVERSITY project is developing specific results to adequately support a holistic design of PSS, namely:

- **New methodology for concurrent collaborative product-service design** based on the knowledge shared across the value chain and the PSS life cycle. The methodology combines lean-based product design and concurrent engineering principle, aiming to react to changing customer needs (mass customisation).
- **Service-oriented engineering environment** for multidisciplinary PSS design based on real time sharing of knowledge among product design, service design and manufacturing within distributed enterprises.

3. General scenarios

The authors have defined three general scenarios, based on an abstraction of the business cases' needs. Two scenarios describe situations leading to the need of (re-)designing a PSS, and the third represents the design process.

3.1. Detecting a design opportunity

The first general scenario deals with the detection of an opportunity or market need for creating or updating a PSS (see Fig. 3). DIVERSITY is continuously monitoring, or listening, the feedback provided by the business customers and final consumers.

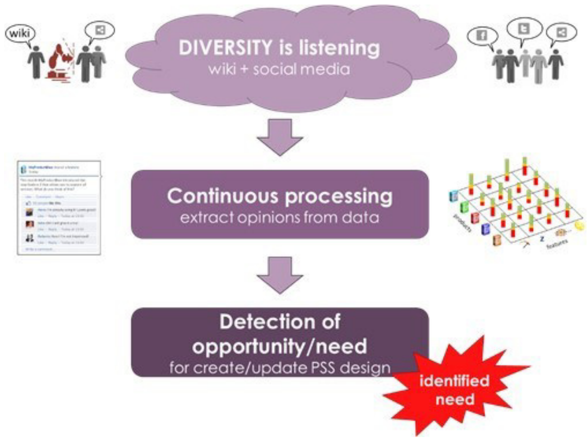

Fig. 3. General scenario of detecting a design opportunity.

The general scenario includes three stages. The first stage is gathering stakeholder's feedback in the form of structured comments inputted on a wiki system, for business customers, and less structured opinions posted on social networks, for final products consumers. This is expected to produce large volumes of raw textual data containing valuable information about the success indicators of the PSS systems being delivered to the market.

The second stage has the ambitious task of extracting the opinions from the raw data. Here, the consortium identified three basic steps: (i) identifying the trend of each opinion as positive/negative or neutral; (ii) the identification of which product, or part of it, is the opinion referring to; and (iii) extract additional information that can lead to an innovative design reaction. The key factor for the success of this step is the possibility of segmenting the opinions based on context. Thus, the availability of contextual information must be ensured while gathering the raw data.

Finally, on the third stage, the detection of an opportunity or need for creating or updating a product-service system design arises from the statistical concentration of the opinions on specific features or functionalities and derived products.

The outcome of this scenario is a package of information with an identified market "need" to support the possible initiation of a product-service system design process.

3.2. Search a design opportunity

The second general scenario represents an active search for an opportunity for a new product-service system or improvements for updating an existing one. The feedback provided by business customers and consumers, and all KPIs related to product-service systems are available for consultation using different types of filtering (see Fig. 4).

This general scenario includes three stages. The first stage defines the search scope, where the user selects the type of products or/and services available in the company's repository. For instance, the user can put the emphasis on a particular service that is horizontal to several different products; or put the emphasis on a particular feature of different products e.g. main color, independently of the product end-purpose or attached services.

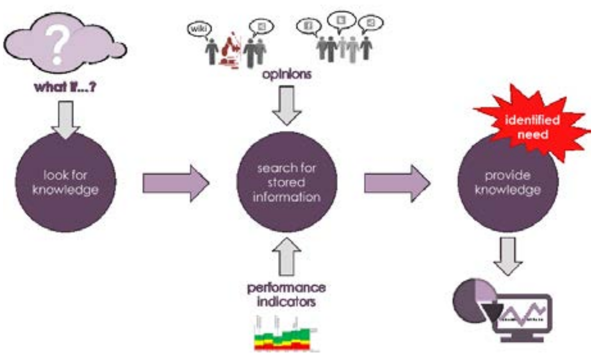

Fig. 4: General scenario of searching a design opportunity.

From this stage results a collection of product-service systems that will be analyzed in an aggregated way. In the second stage, DIVERSITY gathers all available feedback and key performance indicators related with the previously collected product-service systems. The user can then use filters to narrow the views and find specific data patterns. For instance, what is the evolution of a particular key performance indicator e.g. time-to-market, in all product-service systems that have a call-center service included; or what is the consumer likability of products that go in color red. Finally, the third stage is about packaging all created knowledge and reporting what has been identified as an opportunity, again, either for a new product-service system or for updating an existing one.

3.3. Design process

The third general scenario follows the main sequence of the product-service system design process, enhanced by DIVERSITY (see Fig. 5).

The process is triggered by the identification of some market need or opportunity that leads to a decision to design a product-service system. It can result from the functionalities described in the previous scenarios or from a direct business decision, e.g. a new idea for a new product.

The DIVERSITY support starts in the analysis of the product-service system history. In the case of an existing product-service system to be updated or modified, the designers have access to the evolution of the performance indicators, e.g. lifecycle parameters of the production unit, and the existing stakeholder's feedback. This last can be in the form of some aggregated metrics, e.g. percentage of operators happy with the new interface, or in the form of textual comments provided by the users, e.g. "the emergency stop button is difficult to reach by tall people". To create a new product-service system, the analysis is based on the information gathered for similar or related product-service systems available in the company repository. In any case, the outcome of this stage is the identification of the extent and scope of the product-service system design process.

The next stage is the design itself based on existing design tools, external to DIVERSITY. The added value here is:

- provision of lean design rules, if possible, in a contextualized way;

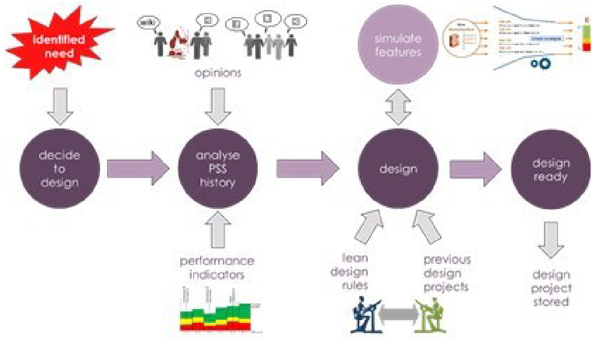

Fig. 5: General scenario of designing a product-service system.

- effective identification of previous design projects, and associated knowledge, that are relevant to the current design process; and
- possibility of testing, by simulation, the acceptance of a specific feature to be incorporated in the design. The simulation is based on the extraction of contextualized opinions from the social media, including the wiki pages.

The scenario concludes with the finalization of the design process and its project stored in the repository for further reuse.

4. DIVERSITY engineering environment

DIVERSITY proposes an engineering environment following a service-oriented approach (see Fig. 6), combining services to extend PDM/PLM/CAD tools, knowledge provision, key performance indicators assessment, social networking, context-sensitive provision, security, setup, administration and ontologies.

4.1. Visualization

The *visualisation* component concentrates all the interaction between the engineering environment and the user. Each component in the engineering platform has its own set of visualization resources. This *visualization* component mashes-up the graphical user interfaces, showing results from all the other components.

4.2. PSDM/PSLM

The *PSDM/PSLM* group extends the conventional PDM/PLM tools, usually focused on the product design, to include the design of the service part of the PSS.

The *data modeler* supports the conceptual abstraction of physical model implemented in the PLM system. This component extends the data model implemented in the PLM system to include data and metadata necessary for the management of the service part of a PSS.

The *workflow modeler* manages the release process and approval of data entered in the system. This component enables modelling workflows in a usable and efficient way.

The *system configurator* allows the design team to select between different product families, starting with the algorithms and historical performance curves stored and modifying them to find the best solution.

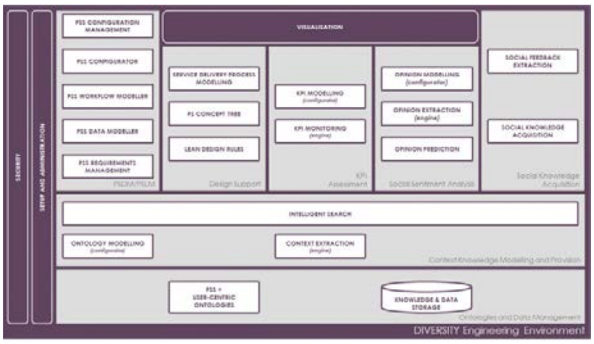

Fig. 6: The DIVERSITY engineering environment architecture.

The *configuration management* enables collecting hierarchical information of a PSS evolution throughout its life and use it to manage configuration.

The *requirements management* provides guidance to manage customers' requirements and product standards needed to make the product sustainable and competitive in the market.

4.3. Design support

This components group aims at providing the core support to designers, by implementing the DIVERSITY design methodology which has been developed based on SEEM [13]. This group includes three components covering functionality currently missing in classical PDM/PLM systems to specifically support the design of PSSs in a systemic way.

The *service delivery process modelling* supports the designer in specifying and modelling the delivery process for the process-service system. This includes identifying actors, activities, and organizations linked to tangible features of the product-service system and appropriate evaluation forms for the delivery process.

The *PS (product-service) concept tree* supports the representation of a tree, covering needs, wishes and solutions, for product-service systems. This component also enables to represent resources associated to product-service systems and supports the designer in extracting product-related knowledge from the PLM system.

The *lean design rules* supports the generation of content and development of process design rules for a specific product-service system, based on the DIVERSITY methodology.

4.4. KPI assessment

The components in KPI assessment group support modelling and monitoring key performance indicators (KPI) to assess the performance of the PSS design in several stages of their lifecycles, including the feedback from stakeholders.

The KPI modelling supports the definition of new KPIs, the classification and grouping of KPIs falling into the categories of Design, Manufacturing, Customer, Sustainability and Leanness [14], including representative keywords and context sensitive filtering.

The KPI monitoring supports the real time monitoring of data from software and hardware sensors (e.g. energy consumption during machining), and it will include the capability of real time processing of data from various sources (such as sensors or other components and systems), in order to calculate and store actual values for KPIs.

4.5. Social sentiment analysis

This component group supports collection and processing of users' feedback about PSS.

The *opinion modelling* collects and structures relevant information about opinions provided by the users in social media tools.

The *opinion extraction* collects relevant posts under a specific context (segmentation), e.g. a specific PSS, and analyses the sentiment, relevance, strength and reach of the opinion of each post.

Opinion prediction evaluates the expected opinion of a PSS release using the current design context and models identified. This component estimates the acceptance polarity of a given feature, including a confidence index for the estimation.

4.6. Social knowledge acquisition

The *social knowledge acquisition* group is the entry door for the stakeholder's feedback. The *social feedback extraction* component periodically gathers post content and metadata from social media sources and store it in its local database. This component targets the consumers using the products. The *social knowledge acquisition* component supports business customers to gather knowledge about the PSS and related issue, using MediaWiki-based solutions.

The *social media connector* retrieves posts and respective metadata (such as user information, likes/retweets etc.) from social media sources and enables querying services.

4.7. Context knowledge modelling and provision

This group of components provides the engineering environment with context sensitivity capability.

The *ontology modelling* supports description of main concepts for the PSS and user-centric ontologies.

Context extraction identifies context of a data set based on the context model. This component monitors raw data, identifying current context, and enables data comparison based on context similarity.

Intelligent search enables search of information across the different components of DIVERSITY and connected systems. When there is a context model defined, this component requests extraction of current context and uses it to refine and filter search results.

4.8. Ontologies and data management

The DIVERSITY context model is an ontology describing various (dynamic) situations (collaborations) in which users use the engineering environment. The context model includes *PSS and user-centric ontologies*. The PSS ontology defines relevant entities to describe the product-service system. The user centric ontology models aspects to describe the current user situation, including actor, activity, geographical location, time, etc.

Knowledge and data storage is an object relational database engine to support replication of homogeneous and heterogeneous data. This hybrid solution provides adequate support for big data from several sources.

4.9. Setup, administration and security

All information needed to extract benefits from the DIVERSITY platform as to be set up and maintained. The *setup and administration* component provides the back-end access to the system. Finally, *security* provides the services allowing the user of the platform to interact with the system and its processes in a secure manner, namely, establishing the access permissions for different users and roles.

5. Conclusions

This paper presents the concept developed in the European project DIVERSITY to support the systemic design of product service systems. The concept includes a methodology for lean PSS design and an engineering environment to support the design process. To this end, the DIVERSITY approach aims to contribute to the limited works related to the collaborative platforms for design and evaluation of Lean PSS, considering feedback from several stakeholders who provide their opinion on social media.

The project includes three industrial companies, defining three business cases that have been driving the development. These companies have described the desired future design scenarios and detailed requirements in terms of expected functionality to support the design process.

The authors have abstracted the industrial to-be scenarios into three general scenarios associated to PSS design. Supporting these scenarios with the DIVERSITY solution, the needs of a wider industrial audience will be meet.

The authors present the proposed architecture for the engineering environment, describing the several components. The components are based on the general scenarios but aim to bridge state-of-the-art gaps identified in the project.

The project is currently specifying the results, particularly the engineering environment and initiating development. A first version of the engineering environment will be available later this year and initial evaluation in the beginning of 2017. The project foresees two development iterative cycles, using industrial evaluation as feedback improvement.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636692.

The content of this publication does not reflect the official opinion of the European Union. Responsibility for the information and views expressed therein lies entirely with the author(s).

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