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Abstract

By adopting PSS paradigm (Product-Service System), companies are growing to new business fields that require hard changes in the industrial practices. PSS realizes smart integration of physical, cyber and organizational elements to deliver added value to the customer, through a long-term relationship and solution-centered offers. This complexity makes the management of whole PSS lifecycle challenging. The paper presents a new development aided tool, part of the ICP4Life European platform, as an innovative answer to this challenge. Designed as a collaborative knowledge-based solution, the platform originality is to support all PSS design, production and usage planning of industrial PSS, at both methodological and technical aspects. The main idea is to encapsulate a collection of potential verified solutions as knowledge fragment, able to achieve a product-service with certain performance value with regard to a set of requirements. This knowledge asset is then used to support collaboratively the stakeholders by several innovative functionalities along the PSS development project.

Keywords: PSS lifecycle; PSS Development; ICP4Life; Designer; Planner;

1. Introduction

Industrial markets have become highly competitive and companies are narrowing their focus toward new business paradigms like Product-Service System (PSS) in order to survive (Tukker 2015, Tan et al. 2010). A PSS can be defined as an integrated system of interconnected elements which provide and agreed-upon functionality for customers, as stated in (Cavalieri & Pezzotta, 2012). Furthermore, a PSS is considered as an extension of mechatronic system (Müller, 2007), on which additional tangible and intangible modules are integrated (Mikusz, 2014). According to the adopted development strategy, a PSS can be product-oriented, use-oriented or result-oriented (Tukker, 2004) and therefore, the integration level between service and product components may not be the same (Müller, 2007).

PSS requires a long-term relationship with various stakeholders such as clients, ICT (Information and Communications Technology) companies, suppliers, and other service providers that handle the usage stage. However, building a PSS design framework is challenging due to its solution-centric character and the high possibility of customization that can be associated to a PSS offer. The adoption of a PSS-centered strategy requires a development process shift to connect various system engineering processes during the design stage, and all processes related to the PSS manufacturing, usage and end of life stages (Reim et al., 2015). Comparing to the product development, the PSS development process represents an extension of activities as stated in (Hinz et al. 2013). Even it exploits the classical CAD/CAM (Computer Aided Design/Manufacturing) tools integrate the physical components; the current collaborative tool lacks integration of all PSS specific constraints (Cavalieri and Pezzotta 2012).

In this paper, a new knowledge-based framework is proposed to support the design and production activities of industrial PSS. This work is conducted within the European project “ICP4Life” that aims at developing a collaborative framework for the management of the whole PSS lifecycle (Matsas et al., 2016). The paper focuses on two main phases of the PSS development: design and production. Theses phases are supported in the ICP4Life by the Designer and Planner modules. The Designer assists engineers from different disciplines to find optimal solutions for PSS components and their integration in a unique system. The Planner module helps to assist the planning and decision-making activities for the PSS production. It includes supplier network design functionality through a smart assistance for supplier identification, matching, evaluation and optimized selection. In addition, comparing to classical manufacturing process management (MPM), the Planner can help defining the processes and resources for the PSS usage phase.

The proposed framework is mainly tailored to support product-oriented PSS, where the core business of the provider is the product. The service is added as a solution to increase the added value for the customer and consequently, its loyalty. This kind of PSS allows low investment rate comparing to the other ones because of the slight adaptations requested on the product structure. For example, in the case of industrial machinery as a product, the OEM (Original Equipment

Manufacturer) generally wants to deliver standard PSS offers to be included in their catalog. Solution feasibility and initial cost estimation should be checked before proposing the offer to potential customers. However, the final client order should be treated as a specific PSS due to the solution-centric property of the PSS and the specificity of the target working constraints that could require some customization of the PSS solution. In addition, the customer could request several services associated with the same machine.

At the methodological level, the concepts of "Pattern" and "Instance" have been adapted from the literature to deal with such a problematic by proposing a unified representation of both standard and customized PSS solutions. These concepts are used to organize knowledge fragments, which are stored in a common repository, shared between ICP4Life components.

The remaining of the paper is organized as follow. Section 2 sets up the main foundations of the PSS development support framework. The literature is reviewed to describe the main characteristics of the PSS concept and the related development support frameworks. Section 2.3 introduces the ICP4Life framework as a context of this research work. PSS design and plaining activities within the Designer and Planner components are then detailed in sections 3 and 4 respectively. Software implementation issues are given in section 5. Finally, a conclusion about the advantages/limits of the proposed approach and further research perspectives are discussed in the last section.

2. Research background

2.1. The PSS lifecycle

In the first general definition of PSS given by Goedkoop et al. (1999), PSS is defined as a system of product, service, actors' network and supporting infrastructure to satisfy customer needs (Goedkoop et al. 1999). Afterward, "supporting network" by Mont (2002) or "service support system" by Alonso-Rasgado et al. (2004) are bolded. Manzini and Vezzoli (2003) mentioned the innovative nature of PSS design which was implied in the previous definitions. Tukker (2004) implied "function-oriented business model" for PSS. Thereafter, Brady et al. (2005) put the lifecycle design in their definition of PSS. Software has been added to the definition (Cavalieri et al. 2012) and evolved by Boehm et al. (2013) to the cyber-physical system (CPS). Mikusz (2014) bold the integration of CPS with PSS by mentioning software-product-service triangle. Recent definitions are based on innovative interactions between the stakeholders involved in the system of value proposition (Vezzoli et al. 2015).

Considering all above and inspired from various definitions of PSS in the literature, PSS concept is considered in this work as a "knowledge-intensive socio-technical system" (Meier et al. 2010) that aims to fulfil the customer demand by providing an "agreed-upon level of availability" (Lindström et al. 2015) "where the economic and competitive interest of the providers continuously seeks environmentally and socio-ethically beneficial new solutions" (Vezzoli et al. 2015).

Regardless of various terminologies defining the concept of PSS, there are meaningful similarities in PSS typologies. Tukker (2004) classification, as the most preferred one in literature, distinguishes three main typologies of PSS as "Product-Oriented Services, Use-Oriented Services, and Result-Oriented Services". In this context, PSS is considered as the convergence of "servitization of product" and "productization of service", which in the PSS is in the top of the pyramid of this convergence (Baines et al. 2007). What is mutual in all represented PSS typologies is that the most developed PSS is providing a user-centric solution that can be derived from standard PSS. This means that nor product nor service is alone the point of focus but the final solution which is a simultaneous combination of the products and services is the target of system. Thus, to move towards the adoption of PSS business model, industries need to create a new integrated system of solution providing (Schnürmacher et al. 2015).

These integrated solutions should create an additional value for the customer through a long-term relationship covering a large part of the PSS lifecycle (Vasantha et al., 2012). Comparing to classical products, the scope of PSS lifecycle consists of five similar phases: planning, development, implementation, delivery and use, and closure (Rese et al., 2012). However, the PSS lifecycle is built on the connection of at least two interdependent lifecycles (the product and one service) (Tran et al., 2014).

Looking to the characteristics of the PSS, the companies should rethink their current processes as well as their business relationships with both customers and suppliers (Großmann et al. 2016). To do so, the scope of the PSS development process has to cover both the design and production stages but also all planning activities for the usage stage (Maleki et al., 2017a). The long-term relationship and the extension of the development process scope are very important for our work.

In addition, the interdisciplinary nature of this new phenomenon increases the number of interactions in the development process (Schenkl, 2014). As a result, the development implies the need for robust coordination and collaboration efforts (Reim et al. 2014). These efforts should be able to facilitate knowledge sharing among different experts (Trevisan & Brissaud, 2016). However, while the PSS literature highlights the importance of setting-up collaborative partners network outside the company (Xing et al., 2013, Pezzotta, 2012) as well as inside (Wallin, 2013) and increased need for communication and coordination of activities, only few initiatives succeeded to define the best organization structures and to address all stakeholders' requirements in such collaborative situations.

2.2. *PSS dedicated frameworks*

The transition toward a PSS centered business requires the need to develop original frameworks that support the management of the PSS throughout its lifecycle. For instance, in the planning and design phases, the theoretical background is reached as it draws from the separated design approaches and dedicated studies that attempt to close the loop and integrate PSS lifecycle feedback in its design (Mourtzis et al.

2016). Different business models (e.g. Lean Manufacturing) have also been integrated together with PSS giving highly interesting results (Mourtzis et al. 2017).

To monitor the performance of the developed PSS it is also important to define a set of relevant KPIs that will monitor its use phase performance (Abramovici et al. 2013). Towards that end, other approaches also consider customers' perspective in this evaluation giving a more holistic approach (Kim et al., 2013). Lifecycle Assessment for Value Assessment through measures of lifecycle performance, life-cycle cost, and life-cycle environmental impact through a sustainability-oriented value assessment model is proposed in (Abramovici et al., 2014). In the direction of the entire PSS lifecycle evaluation as a platform that integrates both sides, an evaluation scheme is developed in the literature, in which all the phases of the PSS lifecycle are taken into account, from both customer and company perspective (Xing et al. 2014), by using appropriate key performance indicators (KPIs). Other PSS frameworks are proposed with the aim to support the customization of the PSS characteristics driven by the customer preferences. For instance, Song and Sakao (2017) prosed a customization-oriented framework for the design of sustainable PSS. In this Framework modularization strategy is used to cluster and then select PSS components that meet specific customer requirements. To do this, an intermediate step is the extraction of technical attributes and the resolution of conflicts based on a strong requirement analysis.

At the international level, the European Union and the United Nations Environment Programme (UNEP) have funded various projects (Vezzoli et al., 2017) with the aim of creating methods and tools for PSS design and manufacturing. Considering that today there is not a solution that integrates customer, manufacturer and supplier in a single platform, this work proposes an integrated, collaborative platform for the design and development of product service systems for SMEs and equipment manufacturers in order to maximize the impact in the European industry. As part of the European initiatives, the ICP4Life Framework proposes a collaborative tool for supporting the creation and the lifecycle management of industrial PSS as an answer to the above limitations. This paper gives an overview of this Framework and focusses on the modules supporting design and realization of PSS. In addition, the proposed solution offers full consideration for the integration CAD models for the design and validation of the PSS solution, since this last aspect is very important (Sakao et al., 2009) but yet it is not really well explored in the PSS community.

2.3. The ICP4 Life framework

Considering that Product-service offerings allowing the creation of innovative business models to increase the competitiveness and the revenue of industries, ICP4Life framework comprise an Integrated Collaborative Platform for managing Product-Service across their Life Cycle.

The creation of a PSS is an iterative and collaborative process involving several stakeholders. Customer makes a request that is initially answered by the designer engineer and validated by the production engineer. This simple process becomes more complicate when the solutions proposed are not satisfactory to all stakeholders or not feasible due to some limitations of manufacturing or organizational capabilities. This leads to an iterative process of proposal and solutions that we have solved via permissions and requests. The final result should be a PSS solution that is valid for all of its life stages and accepted by all involved stakeholders.

ICP4Life has as main foundations the Design and Development of Product-Service Systems along with Lifecycle Feedback Integration and Collaborative Design. This feedback has to do with returning usage information of products and services back into the value creation processes of the providers (El Maraghy, 2014). Two kinds of feedback could exist: Product focused feedback (Product usage phase data) and also User-focused feedback (Acquisition of customer-centered usage information) (Matsas et al., 2016). This platform integrates customer's views towards direct customization to the phase of design.

ICP4Life collaborative platform is dedicated to managing the whole life cycle of industrial PSS. This collaborative platform consists of five modules namely Procurement, Designer, Customizer, Planner, and Services (Figure 1). Every module is dedicated to specific category of business stakeholders to cover the whole PSS development and customization process. Procurement module supports the data entry to the system from different users. Particularly, Procurement Module contributes to the PSS Design through providing the data entry input to the Designer module. Designer module supports the creation, management, and sharing of product and service data by engineers and designers of multiple disciplines, with different backgrounds through the use of a common product-service data model and a set of knowledge-based and collaboration facilities. Customizer supports the configuration of different types of products and services by customers of different profiles. Planner supports the stage of process planning and production of PSS for the realization of the product-service considering critical sustainability aspects of the PSS. Finally, Services modules are dedicated to the management of the usage phase of a specific PSS providing useful feedback both to the end user and the provider of the PSS. The provided services are sensor-based and could be among others the machine health monitoring or the machine performance optimization (Alexopoulos et al. 2017). A common knowledge repository is used and supports the interactions between the modules.

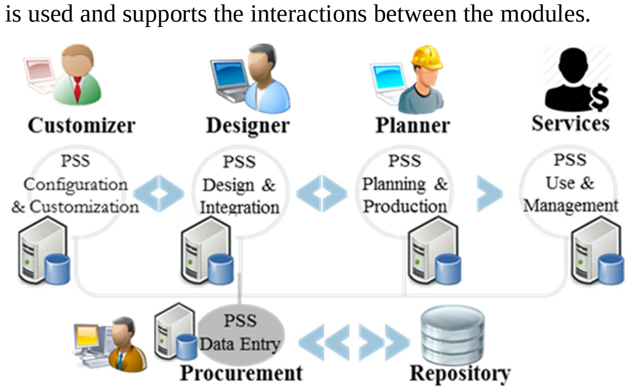

Figure 1. ICP4Life platform modules

This paper focuses on the development stage of industrial PSS, particularly standard PSS subject to customization from the client. In the next sections, the Designer and Planner modules, which contribute to the design, the production planning and the usage planning of industrial PSS are presented. The modules in charge of the management of customer ordering and PSS use are out of the scope.

3. The Designer tool

Usually, PSS offers propose some customized solutions 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. The reuse of PSS knowledge can then reduce the cost and time for PSS solution/offer development while at the meantime 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 are 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. In the literature, the pattern is defined as "a general, proven, and beneficial solution to a common, recurring problem in specific domain" (Rech et al. 2011). The focus of PSS pattern is similar to the definitions. However, the specificity of the PSS scope includes more than one potential solution principals, which are described in the "Integration solution". This consistently connects both the design and production solution for a given PSS. The elaboration and the refinement of the detailed PSS solution for one client are then handled at the instance level (Belkadi et al., 2017).

3.1. Knowledge description using PSS pattern

Actually, the knowledge can be splitted in fragments: the product characteristics, the service model and the technological solution able to support the realization of the service with a given performance and limitations. All that are not already well integrated in a single system. PSS pattern concept involves the generic description of these knowledge fragments in a consistent way for optimal reuse in future projects. The aim is to create an integrated system where all aspects are fully compatible and this compatibility is confirmed through all PSS life stages.

Industrial companies want to create standard PSS as complementary offers to their products. However, in several domains, like industrial machinery construction, the standard PSS solution should be adapted to meet with the customer preferences or to consider some constraints related to the usage conditions of the PSS at the customer facilities.

By using the modular conception, PSS solution/offer is also regarded as a composition of key modular elements that can be grouped in various configurations to meet specific customer requirements (Song and Sakao, 2017; Kuo 2013). These elements can be used in several PSS offers following the principle of product catalog. Indeed, Modularity consists of decomposing complex systems into independent but interconnected elements that can be functional or physical units (Jiao et al., 2007). The system architecture is obtained as a set of interconnected modules coupled with configuration mechanisms for the generation of multiple variants (ElMaraghy et al., 2013). Variants of architectures are possible if multiple implementation solution alternatives can be identified for some functions of the system (Agard et al., 2013).

Based on the above assumptions, the main logic of the proposed 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. Formally, **A PSS pattern is defined as a combination of only one product and one service with a collection of potential integration solution alternatives.**

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 sensing systems composed by sensors and additional equipment) able to collect and/or to analyze/compute the requested information. The whole PSS solution is then obtained as a combination of one product, one service with related list of information, one or several sensing systems and a collection of integration solutions describing at a conceptual level how the selected sensors (and additional equipment) can be connected to the product components. Each integration solution is colored by a set of performance indicators tailored to nominal working conditions (as specified by components' providers). The next section detailed this last concept.

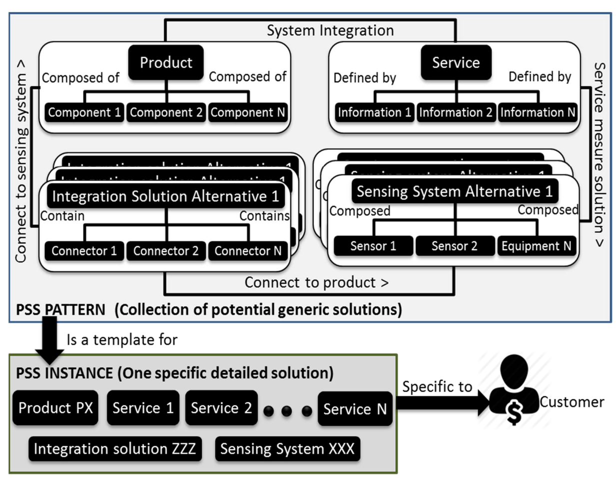

Figure 2. Main concepts to be managed with the concept of PSS Pattern

3.2. The Integration Solution

In case of product-oriented PSS, when the OEM wants to add new service into an existing product, engineers have to know the mutual impact between the sensing system and the product components where these sensing systems are fixed. This depends on the chosen integration solution as well as the compatibility between service and product components features. 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 sensor is needed to measure information?
- What kind of measure technology is possible for the measurement of specific information?
- What type of Data processing and analysis methods?
- What are the sensing systems needed to support measure performance, depending on product working conditions?
- What is additional equipment 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?

The integration solution could also include useful information about the potential manufacturing solutions for the designed PSS. In addition, when the service realization requires to measure heterogeneous information with various sensors, a critical question is to identify the best sensors combinations but also to verify the compatibility between these sensors in order to avoid any malfunction in case these sensors are placed together in the same area.

Practically, the definition of the integration solution is achieved progressively by several actors and by using a set of decision-making facilities as it is explained in section 3.5.

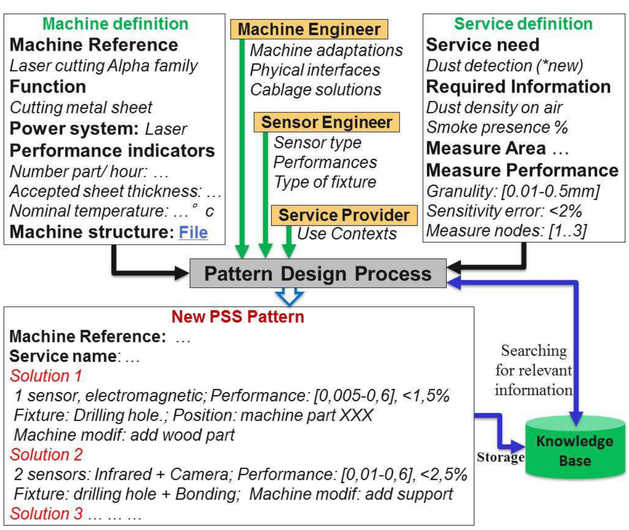

Figure 3. Example of PSS pattern (Belkadi et al. ,2017)

To illustrate the potential of the pattern concept within the integration solution, Figure 3 shows the definition of an industrial product-service system: Dust detection for Laser cutting machine (Belkadi et al., 2017). The product (machine) is defined by a set of functions, key modules and performance indicators. The service is defined by the required information and the related measure performance. The integration solution intends to identify suitable sensor alternatives and search how to connect these sensors to the laser cutting machine for providing the defined service. It includes all additional equipment and resources needed to make the PSS solution ready (not illustrated in the figure).

3.3. Knowledge reuse with PSS instance concept

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 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 the 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 will enrich and update the current PSS patterns definition.

Figure 4 shows an example of PSS instance with two services requested by the customer: Dust detection and temperature control at laser head. These PSS are characterized by different information: frequency of measure, number of measure nodes, possible co-existence of interconnected machines or Wi-Fi waves or also temperature and humidity conditions, etc. Depending on these requirements, one PSS instance is proposed as a combination of best solutions extracted from the suitable patterns, defined previously as generic solution for such services. A refinement process is followed to fix the final number of sensors as well as their positions and fixture options. The aim is to ensure the compatibility between the various solutions in a unique system, since they are coming from separate patterns. Slight adaptations can be achieved on the machine structure to take in consideration these constraints.

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.

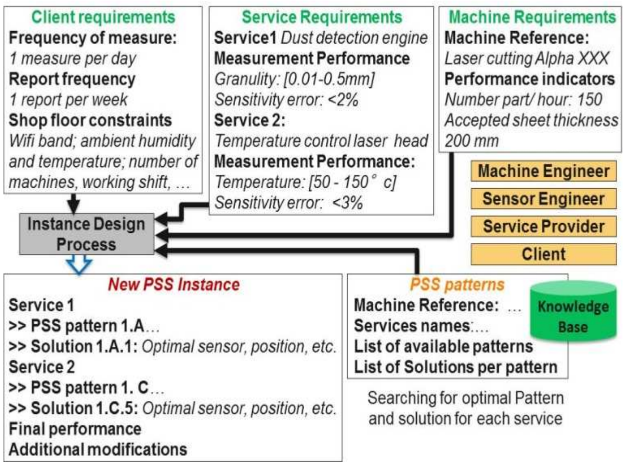

Figure 4. Example of PSS instance (Belkadi et al., 2017)

In the ICP4Life platform, the definition of the integration solution is achieved by both manual operations and semi-automatic facilities supporting the decision making process. These facilities include PSS components selection and compatibility checking software modules as it is shown in the Designer architecture presented in the next section. The algorithms behind these modules are out of the scope of this paper.

3.4. Functional architecture of the Designer component

The ICP4LIFE architecture is designed as a modular and service oriented, aiming to provide robustness and flexibility in the development, maintenance and runtime of the ICP4LIFE Integrated Platform. In particular, the ICP4LIFE components are designed so that their implementation could be divided into three main parts. Namely the User Interfaces, the offered functionality and the integration clients. The user interfaces (UIs) of the components run as Java Portlets in the ICP4LIFE Portal that is one of the ICP4LIFE Integration Components. The ICP4LIFE Portal is responsible for offering management of: users' profiles, access rights to software functionalities, the consistence of the main infrastructure and graphical layout of the ICP4LIFE Platform.

Following the conceptual framework described in the above sections, the Designer component offers a set of functionalities to implement the Pattern-based design process. The role is to provide all engineers involved in this process by knowledge-based decision making facilities to help them to find the best combination of PSS components at both pattern and instance levels. Thanks to the integration services and set of legacy tools connectors, The Designer allows the engineers to collaboratively test and validate the proposed solutions and to communicate with the Planner component to consolidate the design solution of a Pattern with relevant production plan information. Thus, following the global architecture of the defined for the ICP4Life platform, the Designer architecture is composed of three interconnected layers as shown in Figure 5.

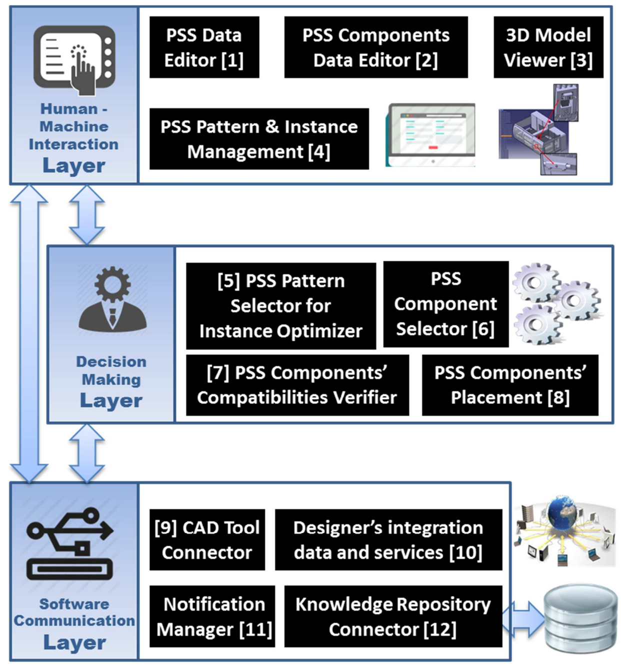

Figure 5. Global architecture of the Designer component

The central layer (i.e. second layer at the middle of the figure) is dedicated to support several internal decision-making functionalities required to manage PSS Pattern/Instance data and components. It consists on: searching and selection services to find the suitable sensing systems for a given pattern and the suitable patterns to be instantiated to build a specific solution for a given customer; optimization engine to help identifying the best solution from the suitable solutions proposed by the searching services; the compatibility verification facilities to check the respect of integration constraints between heterogeneous sensing systems in the same product; the placement services to help engineers testing several positions of the selected sensing systems before validating the optimal solutions.

The Human-Machine Interaction layer contains all facilities dedicated to support the communication between the Designer and users from several business fields. It consists on PSS and PSS components data edition to visualize the global properties of different elements; PSS Pattern and Instance management services that support the actions of creation, deletion and configuration of a PSS structure or one of its components (as well as the integration solution); 3D model light viewer that allow to display the global geometry without detailed dimensions that as the engineers can collaborate easily for the review and validation of potential solutions.

The last layer contains integration services of the Designer with other components of the ICP4Life platform. It includes also different services that allow the connection with legacy

CAD tools and the common knowledge repository. Integration services are used to support the communication with the other components while the Notification manager is especially useful to inform the Planner by the request to check the feasibility of new Pattern or instance. It is used also to inform all components that one solution is ready to use and to read requests from customizer for the design of new PSS.

3.5. The Pattern-based design process with the Designer

In practice, when a new PSS is requested, the ICP4LIFE platform analyzes similar PSS and proposes the most suitable solutions according to previous PSS patterns or instances. The similarity can be based on common products components, common service units, common customer constraints, etc.

Figure 6 shows a simplified nominal scenario of the creation of PSS pattern. The scenario is achieved through multiple interactions between the user and the Designer tool, between the Designer software modules and between the Designer and the Planner tools. This process starts with a creation of a new PSS pattern as a request from the engineer to the "PSS pattern and instance management" module. The user fulfills the key characteristics of product and service in the PSS data editor. This action is materialized by the creation of semantic link between the product and the service items in the knowledge repository.

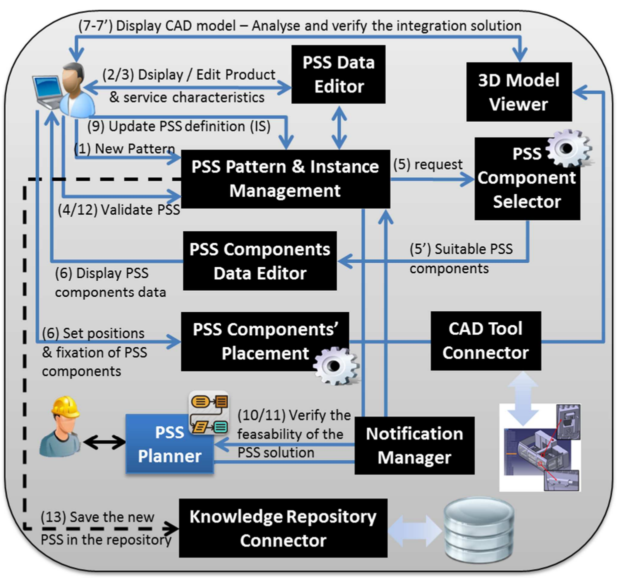

Figure 6. Nominal scenario of PSS pattern creation process

The design process starts by the selection from the knowledge repository of suitable PSS solution alternatives for every product or service function (for example list of possible sensors able to measure a certain range of temperature). The identified components are edited to allow the user choosing a final set of potential solutions. Then, the "PSS Components' placement" module is solicited to suggest the positions of PSS components and their fixation modes in the product structure (For instance, potential positions and fixture types for sensors in the machine components) to avoid time loosing when defining the suitable solutions in the detailed design stage.). This last step is realized iteratively and requests the 3D Model viewer connected to the CAD software with specific connector to allow the engineer analyzing the various resulted PSS configurations. The integration solution is then defined.

The work for this stage is mainly managed by PSS project leader and involves several engineers from various business domains. 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.

Along the development process, 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 classical product development process. This last step is fulfilled in the Planner module as it is explained in the following section.

4. The Planner module

4.1. Concept

A challenge for the establishment of PSS is the appropriate planning of the resources for production, deployment, and installation into the customers' site. Companies that provide PSS solutions are lacking the proper tools for resources' planning in a dynamic environment. Following the aforementioned gaps, ICP4Life Planner introduces a resource planning method and tool for optimizing production, delivery, and installation of IPSS (Alexopoulos et al. 2017). Planner module generates alternative PSS's production and installation plans and evaluates them on performance measures for production and installation such as time and cost. The planning tool has been designed using the Software-as-a-Service (SaaS) approach.

Planner module is responsible for the Semi-automatic configuration of the suppliers' network and production plan for the realization of the product-service considering critical sustainability aspects of the PSS, supporting in that way the PSS production process. The main scope of the Planner is to find an optimal solution that decides which PSS equipment (e.g. sensors) suppliers need to be selected, which resources (e.g. IPSS service installation technicians) need to be occupied when they should perform which processes/tasks at PSS provider site. Key objectives among others are the reduction of lead times in product development and process planning for modular product-services, the improvement of sustainability and the decrease of time-to-market time and the reduction of set-up and ramp-up times by through seamless exchange of process information and knowledge reuse from previous projects.

The approach which is followed is the assignment of a set of tasks to a set of resources under multiple and often-conflicting optimization criteria. The decision-making process can be formalized as a decision matrix. An intelligent search algorithm (ISA) has been developed and used in order to obtain a high-quality solution (high utility value) to the resource planning problem in a timely manner. ISA has three adjustable control parameters, namely the maximum number of alternatives (MNA), the decision horizon (DH) and the sampling rate (SR). The implemented method is composed of a sequence of steps (Alexopoulos et al. 2017).

- Step 1: Generation of a maximum number of alternatives
- Step 2: Calculation of decision-making criteria in order to satisfy a set of manufacturing objectives
- Step 3: Weight definition of criteria
- Step 4: Calculation of the utility value of each one of the alternatives
- Step 5: Selection of the best alternative with the highest utility value
- Step 6: Ranking of the alternatives aka selection of the best resource plan

The aim of the Planner is to address the consequent changes in production planning in order to tightly integrate products and services, as well as suggest an optimal way of resource planning. The Planner will support the efficient, adaptive and responsive planning and decision-making phases, for managing the dynamic operation of the plants and the supply chain. Planner receives requests from designer and sends back its response in one hand contributing to the design process through the provision of estimations and on the other hand by providing the planning for the PSS production (Figure 7). The same functionalities are used for the planning of the usage stage.

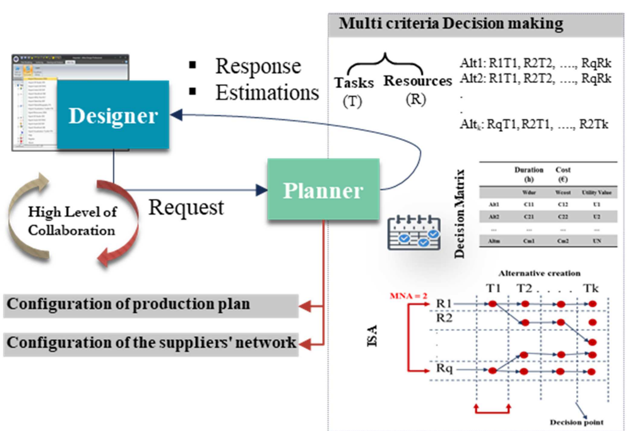

Figure 7. Planner - Designer Interaction

4.2. Planner Functional architecture

Planner consists of the subcomponents presented in the Figure 8. Entering the Planner module, the user can have a summary of all the useful data. The Process Plan Request Manager is responsible for providing the functionality of managing the incoming process planning requests from the Designer component. Creating a response to a specific process plan request, all the available data for it appear in the tab. Here the user is enabled to select the appropriate tasks together with their sequence in order to build the BOP. After saving the Bill of Processes, the Planner Module triggers the planning software that takes as input the bill of processes along with the available resources of the company and the suitability properties of each resource, it plans the tasks and presents them in a Gantt chart. The Estimation Request Manager is responsible for providing the functionality of managing the incoming process planning requests from the Designer component. At the Orders Manager for each order, the user to can see its description, its order date, and its due date and can select “Accept and allocate resources” in order to accept the process plan and send the order to production. The Task Manager subcomponent is responsible for handling the tasks that the company can execute. Respectively, the Resources Manager subcomponent is responsible for handling the resources of the company. The Suitabilities Manager subcomponent is responsible for managing the suitabilities between the tasks and the resources of the specific company. Finally the time and cost needed for the production and transportation of the final product are computed by the related calculator.

Figure 8. Planner Subcomponents

When the PSS is developed and deployed, the critical stage is then the planning and the management of the use stage as well as the involved resources. Indeed, this stage has many more interactions including operations optimization and partial asset renewal. So, it is important to anticipate in the design stage the definition of operational scenarios alternatives and related organizational capabilities to cover different potential situations within the usage stage. Even if the planning modules of the ICP4Life Framework are mainly dedicated to the production stage, the algorithms can be used as well for the organization of operational activities at the usage stage. Supplier network design is a generic tool that helps the identification of best organizational resources for the outsourcing of some product parts or services. During the usage stage of the PSS, the PSS provider could select some external suppliers to realize some operational activities or to provide logistic assistance. For example, depending on the location of the customers, the transportation solution for delivering spare parts or equipment to repair a machine or a PSS infrastructure could be different: local supplier, the own logistic facilities of the provider or other low cost companies, etc. So, the building of the network of actors/providers needed to make the service operational is similar to the selection of best supplier for the production stage. However, more attention is given to the location criteria and trust between actors because of the long relationship the partners have to maintain during the whole usage stage. This contribution is not the core proposition of this paper and will be further detailed in other research work.

5. Implementation scenario

In this section, an implementation scenario is presented with an equipment manufacturer (OEM) to use this web-based collaborative platform to design and produce a product-service according to the requirements set by the customer. There is the need for shorter time to deliver a PSS solution, the need for strong interaction driving to co-design as well as simplification of the PSS Lifecycle management. Through the proposed framework, the equipment manufacturer aims to their Digitization, Customization and Servitization. The actors here are found to be the Product Designer who configures the requested equipment and designs the PSS using the web-modeler with sensor provider and the Production Engineer which configures the supply of the components and selects the best production plan. In particular, the workflow of this implementation scenario is presented in the Figure 9.

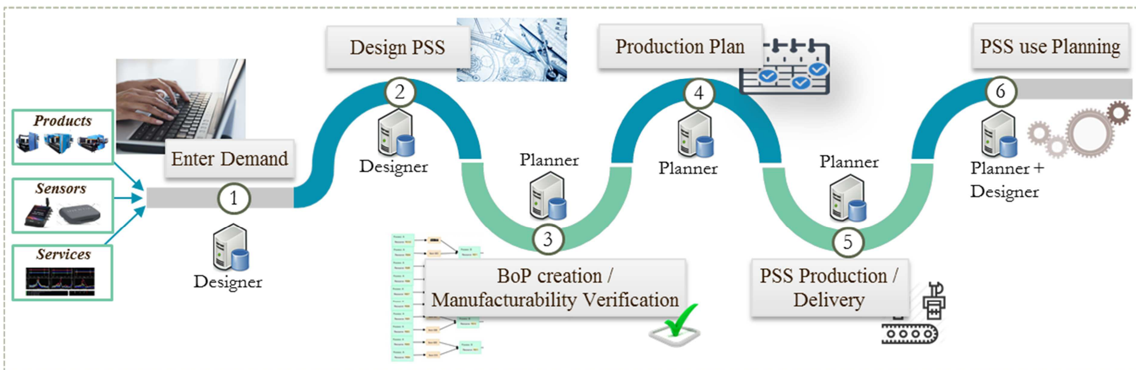

Figure 9. Implementation Scenario Workflow

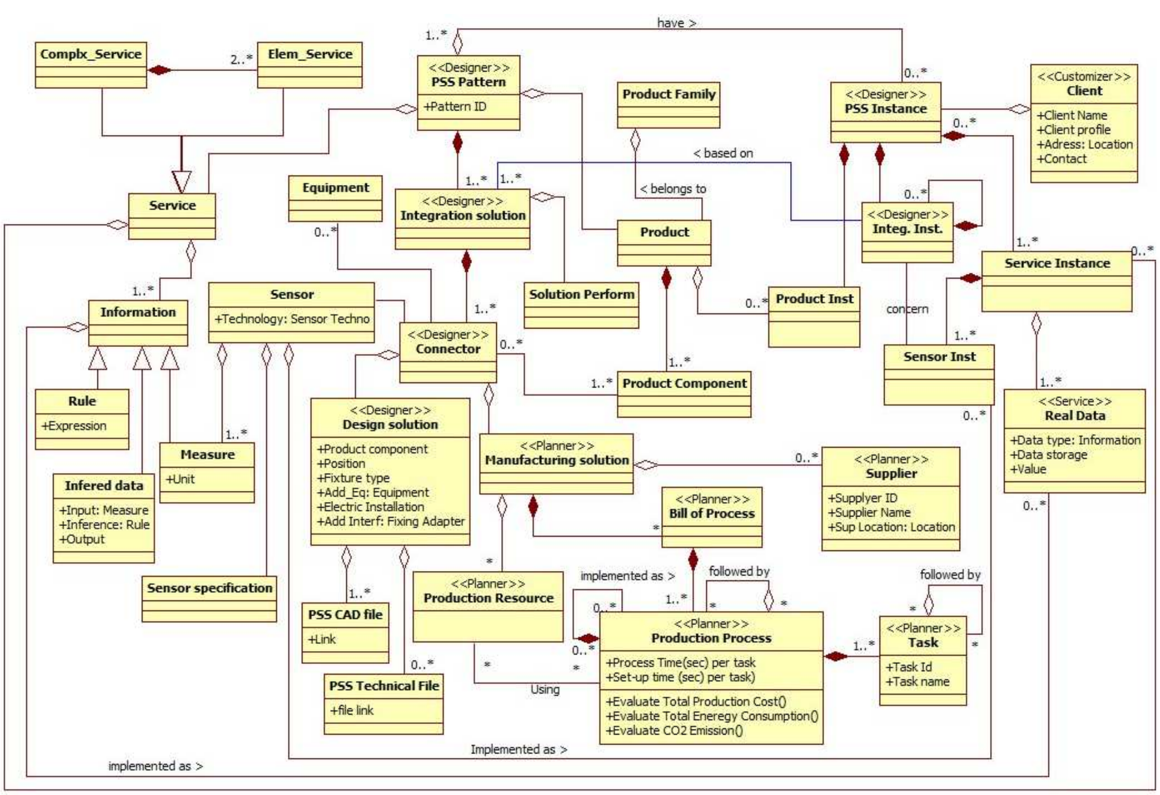

Figure 10. Global data model for PSS repository structuring

The PSS Framework has been designed and implemented with scalability and performance in mind in order to be able to address the challenges of an IoT environment. In particular, the raw data coming from the edge tier is collected and stored in a database built using the Apache Cassandra. This database is optimized for operation with timestamped data, such as the measurements of a sensor. The Integration Framework and PSS Framework share a java modeling based on the ontology used in the Knowledge Repository that enables this functionality. The Knowledge repository itself can be accessed using SPARQL queries and has been developed using the Apach Jena Framework, which is a free and open source Java framework for building Semantic Web and Linked Data applications.

The first step for the implementation of such framework is to set-up the structure of the common repository that includes both Designer and Planner data among others. Figure 10 shows an overview of main data connected to the Designer and the Planer respectively. The logic is that the integration solution covers the design and the production solutions. The first one is to identify the PSS Bill of Material and the second is to manage the Bill of processes with related resources and suppliers. From this meta-model, an extended model is developed and translated as an RDF ontology file to serve the PSS Framework to get access and organize the large set of information, which is linked to time-series instances and knowledge shared between ICP4Life components. More details about this ontology are given in (Maleki et al., 2017b).

The first step after receiving a demand from the sales or marketing representative departments is the design of new PSS pattern that meet with the specificities of the target market/customers. Figure 11 shows the main GUI of the Designer component. The web portal Liferay usage arose as an integration requirement, to maintain a common and single web page between all the ICP4Life tools. With that basis the first Designer and Planner Prototypes have been created.

The main view of the Designer module is divided into several sections depicted in red in the previous figure:

- **Liferay menu** used to customize the portal view, add/remove portlets, users login, etc.
- **ICP4Life main header** gives access to the different applications' portlets
- **Designer menu** allows the design engineer to change between the different aspects and stages of the PSS Patterns and Instances creation. They are explained in detail in the following sections of this document.
- **Designer work area** where the data is presented, choices are made, etc. the functionalities of this section changes according to the Designer menu's selection.

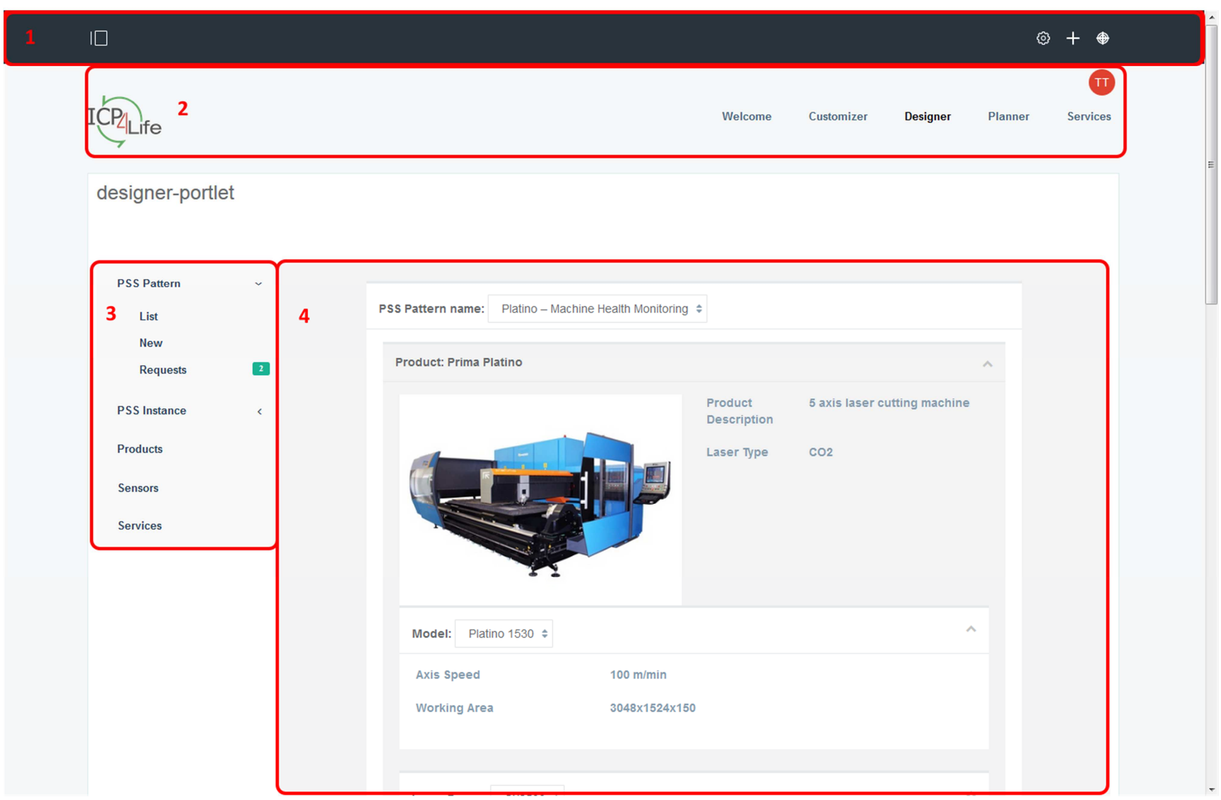

Figure 11. Main interface of the Designer component

According to the Designer global architecture presented in Figure 5, three main categories of data are managed within the Designer interfaces: Standard PSS components like sensors, machine, etc. this allows analyzing their technical features as specified by the providers. Service details as a representation of customer or market requirements to be considered for the design of new pattern or instance. Solution management interfaces to create, edit or modify PSS. For instance, Figure 12 illustrates the graphical interfaces for the Service management section. This interface contains all information necessary to identify the best sensing systems and to create the related pattern/instance answer. It includes all parameters to be used for customization perspective such as the type of analysis, the frequency of measure or the requested accuracy. At the bottom side, first list of available sensors is provided by the Designer so that the engineers can realize first filtering before selecting the suitable/best technical solutions.

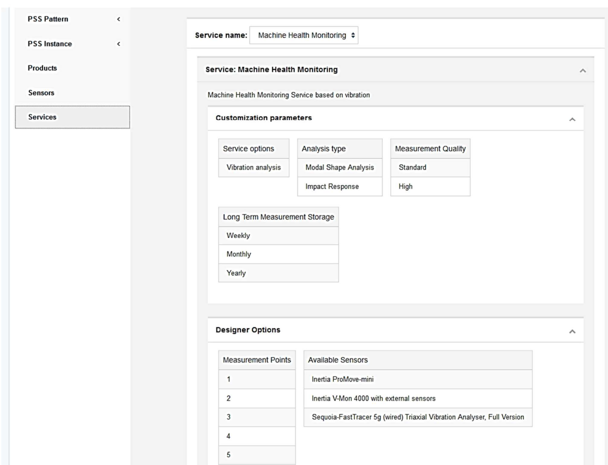

Figure 12. Service description as a PSS requirement

Within the PSS pattern/instance dedicated interfaces, engineers can display the list of existing patterns to edit their characteristics or to reuse some of its components, check at any time the new requests and, create new pattern or instances. Figure 13 shows a partial view of pattern data. It includes for instance the sensors selected reference and the chosen configuration to be adapted for the PSS of interest.

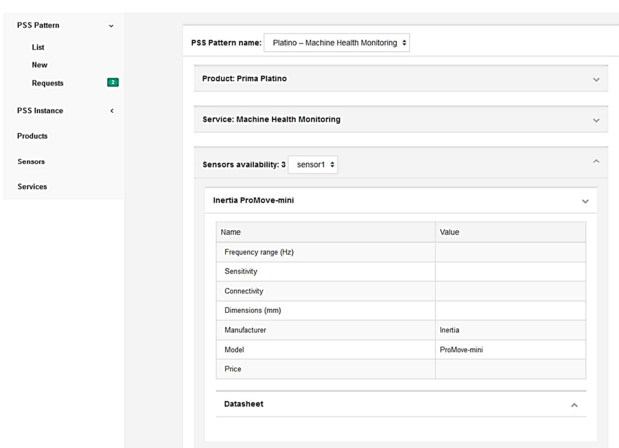

Figure 13. Partial view of PSS pattern solution

As far as the Planner is concerned, the following screens are presented below: List of Process-planning requests, request-response, Process plan view Estimation Overview. Planner Dashboard is the first screen the engineer views when he accesses the Planner portlet. Figure 15 presents the Process Plan Request Manager which is responsible for providing the functionality of managing the incoming process planning requests from the Designer component. Each one process planning request is classified based on its status (Pending, Accepted, and Rejected). In particular here the user can also have a view of the composition of the PSS (Product, Sensors, and Services).

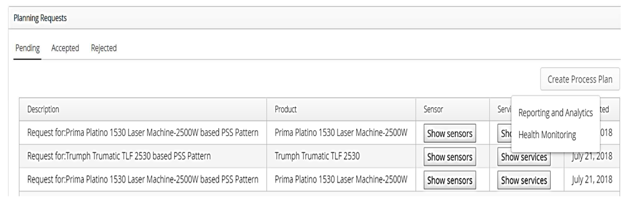

Figure 14. List of Incoming Requests

With the aim to address the incoming request, the production engineer is going to the Process Plan Response Creator. Here he could view the main information of the incoming PSS request the available suppliers and deactivate if necessary some of them and accordingly to create the process plan as it is presented in the Figure 15.

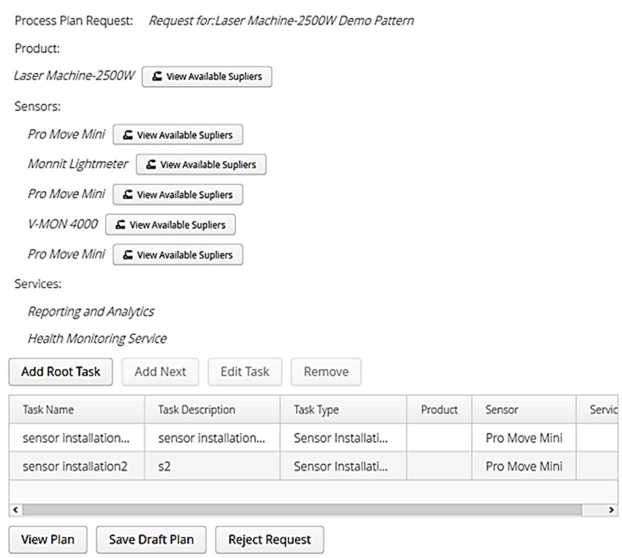

Figure 15. Process-planning response

After saving the Bill of Processes, the Planner Module triggers the planning software that takes as input the bill of processes along with the available resources of the company and the suitability properties of each resource; it plans the tasks and presents them in a Gantt chart. In the Figure 16 the process plan is presented with the grey zone days to be the days off. The option of rescheduling is available.

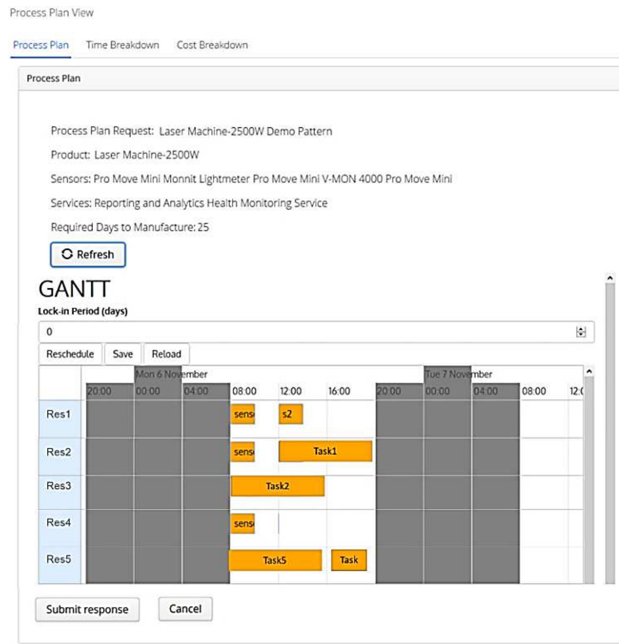

Figure 16. Process plan view

The Estimation Request Manager is responsible for providing the functionality of managing the incoming estimation requests from the Designer component. As it is presented in the Figure 17 below the user could have a time and cost estimation for the current request.

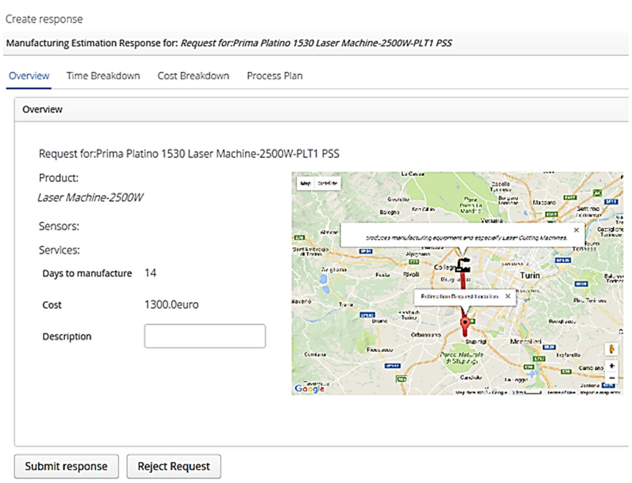

Figure 17. Estimation Overview

In that way, Planner will give a response to the incoming requests from the Designer component. Cost analysis and delivery time analysis are provided with the main output of this interaction to be a feasible production solution. Thus the manufacturing solution is connected to the whole integration solution, and the related Pattern or instance is updated as a solution ready to use. This solution is stored in the common repository and communicated to the Customizer component. The added value of the proposed solution is depicted on the provision of remote services & training from which will gain reduction to the costs and also on the delivery time decrement up to 30%.

The integrated prototype has been evaluated using real industrial data in an industrial pilot case. The integrated prototype was tested along the development timeline to complete the final verification of each component through distinct use cases scenarios. The objective of the evaluation is to provide qualitative evidence through feedback by the end-users that the concept has the potential to improve PSS design and delivery processes in production equipment industry.

6. Conclusions

PSS design through the shift from physical to Cyber-Physical Systems leads to several collaborations between heterogeneous stakeholders with various perspectives in PSS development, which made the role of collaborative systems invaluable. Towards that end, the management of different viewpoints of PSS engineers in considering the modularity while keeping the whole PSS system integrated is very challenging. Connecting the PSS system's main components and the related production enablers within a common development process are of great interest.

This research is mainly dedicated to the industrial manufacturers who offer additional services integrated with their current products to attract new clients. In doing so, they collaborate with various stakeholders for value creation. For this need, knowledge-based and collaborative facilities are provided as a supportive solution for the PSS development to reinforce the stakeholders to fulfill their daily design and production planning activities.

Using these facilities is well applied in the industrial domain for the support of product development. However, fewer initiatives are dedicated to the emerging paradigm of PSS. Furthermore, the current frameworks are generally developed to cover the specific scope of the product lifecycle. One of the originality of the proposed framework is its capacity to cover wide panel of the PSS lifecycle, including part of its usage stage. The idea is to propose a set of interconnected software modules able to separately address one of several needs. Moreover, the integration of all these components provides a common development process from the customer need to the usage management.

In this context, planning of the usage stage is made by the extension of Planner functions to define the necessary operational processes and related resources at this stage. By coupling the Designer solution with the Planner, the proposed framework intends to offer a new vision of PSS development process, allowing engineers to work collectively on the progressive definition of generic PSS offers, and on the answer of specific customer needs. At the conceptual level, the extension of the pattern and instances concepts gives an advantage for this purpose.

It is assumed that the proposed solution is mainly tailored to product-oriented PSS, where it is question to add new services on existing products or updating new version of these products to allow their adaptation for the integration with new service. Intentions for the future work are going to be the validation of the proposed framework. In doing so, a mixed approach to case-based test and the ontology-based test will be adopted. Consequently, the future work will concentrate to extend the sensor ontology to cover other business domains and to include additional sensor features. It is also question to study the application of the proposed framework for more complex use cases utilizing a combination of various sensors. The prospect of being able to make a common language to support PSS design serves as a continuous incentive for future research. Finally, the implementation and test of this proposal for the whole ICP4Life platform are in progress.

The aim of the ICP4Life framework is to develop the prototype that set-ups and testify all functionalities of a so called a PSS lifecycle management system, as an extension of current product lifecycle management (PLM) systems. Once the prototype finalized and tested, the industrialization stage will grow the proposed framework architecture to be exploited as a "Software as a Service" solution. For this further software development works are needed to generalize the solution with other business process alternatives and to enrich the knowledge repository with more standard components (like sensors) from market catalogs.

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