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Abstract. In product-oriented Industrial Product Service Systems (IPSSs) the customers benefit from the combination of a product which offers some functionalities and a set of services. IPSS supports the provision of services which can be offered by the product manufacturer. The services can offer a wide range of functionalities that can range from ensuring the product's original functionality to augmenting the original functionality of the product. The shifting of a company to IPSS poses many challenges such as the changing of the company's business model. One of the most important challenges for the establishment of IPSS is the appropriate planning of the resources for production, deployment, and installation into the customers' site. However, companies that provide IPSS solutions are lacking the proper tools for resources' planning in a dynamic environment. In this work, a multi-criteria resource planning method and tool for optimizing the production, delivery, and installation of IPSS is presented. The proposed solution generates alternative IPSS's production and installation plans and evaluates them on performance measures for production and installation such as time and cost. Moreover, through the integration of the planning tool with the IPSS design phase, information for generating the Bill of Process and Materials is presented. The planning tool has been designed using the Software-as-a-Service (SaaS) approach and has been applied and validated in a pilot case from the laser cutting industry.

Keywords: Industrial Product Service Systems (IPSS), Resource Planning, Decision Making.

1 Introduction

In the new manufacturing revolution called Industry 4.0, the digitization of all the systems that comprise a manufacturing system is a key objective. The Industry 4.0 paradigm proposes the expansion of existing products, for example by adding smart sensors or Internet of Things (IoT) devices that can be used in tandem with data analysis tools, and delivers a completely integrated solution to the customers. Also, customer demand and globalization impose constantly new requirements to industries, making the manufacturing environment more complex and dynamic than ever [1]. The Product-Service-Systems (PSS) concept is the solution for providing services together or instead of a product's ownership, aiming to increase the adding-value of the products [2]. This solution promises improved competitiveness and sustainability. In the industrial sector, the servitization of manufacturing equipment has shifted the attention to the Industrial Product-Service Systems (IPSS). This strategy is satisfactory adequate considering an industry which requires being agile and getting full advantage of the complex integration process of mechanical parts, sensors and IoT components, which are critical elements for the control and monitor of the production lifecycle [3]. Following Meier's definition [4], an IPSS is the hybrid combination of a product and services e.g. a laser machine together with sensor enabled services that increase the value of the machine. IPSS aims at fulfilling contractually defined customer needs by the provision of product as well as service shares and moreover, the operation of an IPSS includes strategic and operative scheduling of processes and resources [5]. IPSS are characterized by five knowledge dimensions relative to the product, service, infrastructure, network and customer [6].

However, designing and planning the production of an IPSS is a complex task that requires the development of proper engineering, production and installation planning methods. IPSS is not the result of the simple connection of product with services. It is a rather complex integration process of mechanical, sensors and IoT components and software with the involvement of heterogeneous stakeholders along the whole IPSS lifecycle. In IPSS design and implementation, the resources related to the integration and configuration of the services, have an important contribution to the efficient development and use of an IPSS. This work presents a method for planning the production, deployment, and installation of IPSS taking into account various types of aspects such as availability of resources in IPSS provider side and resources on the services and sensors supplier side. The planning of resources should be taken into account both during the phase of IPSS design as well as in the phase of IPSS production and delivery. Planning is evaluated through a set of Key Performance Indicators (KPIs) which quantify the efficiency of alternative planning scenarios. The solution presented in this work can be used by IPSS solution providers to plan the resources of the IPSS ecosystem so as to improve the efficiency of IPSS delivery to the customers.

Regarding the design of PSS, the main focus comes to be the evaluation of the design [7], [8], [9]. The last decades, great effort has been devoted to the study of planning and scheduling problems encountered in the production systems [10]. There are several approaches regarding planning and scheduling [11] in the literature. The proposed approach for the IPSS planning is an artificial intelligence method (ISA) [12]. This one compared with other existing approaches outweighs in the direction of computational time and of multiple criteria consideration. Existing planning methods have been developed focusing on capacity planning for the delivery of IPSS, like the work presented in [13]. Additionally, relative research has been focalized on the different ways of resource planning in both centralized and decentralized networks [14]. A hierarchical planning for IPSS is proposed by [15] by focusing both on the strategic and operative planning level after identifying the planning problems concerning IPSS. Along similar lines, the work of [16] presents a heuristic resource planning approach to the resource planning of IPSS.

This work is part of the EU project ICP4Life that aims to develop a collaborative framework for supporting the entire development process of industrial PSS [17], [18]. The proposed approach is focused on the "Planner" software module. Based on the approach presented in [14], this paper aims to tackle the issue of providing a planning methodology for the production and installation of IPSS and also present a related software implementation.

The remaining of the paper is organized as follows: The proposed methodology is discussed in Section 2. Section 3 is devoted to the IPSS planning tool software implementation. Section 4 presents a pilot case from a laser cutting machine industry. Finally, the conclusions are reported in Section 5.

2 IPSS production and installation planning

In this section, the problem under investigation is defined and the proposed methodology is presented. IPSS planning in real industrial practice is a complex problem that involves several actors and constraints. In this work, the IPSS planning problem considers the following generic scenario. The process starts when an IPSS provider receives an order for an IPSS solution from a customer (Step 1). Then, the IPSS provider starts designing an IPSS solution that meets the requirements. During the design phase, a number of alternative designs are being developed. A design is a solution that integrates a product and a number of services that are implemented through the utilization of hardware (e.g. IoT devices) and software (e.g. data analytics) (Step 2). Every new alternative IPSS design, before it starts being produced, needs to be evaluated with respect to the production feasibility (i.e. there is a feasible process plan that can actually produce the conceived design) and KPIs, such as delivery time and cost (Step 3). A production engineer takes as input the IPSS design and, using some process planning method and tools, develops a feasible process plan (Step 4). The IPSS planning method proposed in this work is used to provide a rough estimate on the time and cost KPIs to implement the process plan. The proposed planning method takes into account the fact that there is a limited number of resources to implement the new IPSS order and that there are already IPSS orders scheduled (Step 5). IPSS designer receives input from the IPSS production engineer and decides if the design solution is acceptable or not. The IPSS designer and production engineer may repeat the whole process several times until a satisfactory result is achieved (Step 6). Those generic steps are depicted in Fig.1 below. This work focus on proposing a planning method and also its implementation for addressing Step 5 in the workflow presented in Fig.1.

The planning problem considers the following constraints and assumptions. It is assumed that the IPSS provider is also the supplier of the product part of the IPSS. This makes planning simpler since there is only one supplier option for the product delivery and moreover the transportation of the IPSS solution is only transported from the IPSS provider to the customer. Another constraint is that the IPSS is composed of a product and a number ***S*** of services. The planning problem does not include the production of the product which is assumed to be available. In many IPSS cases the product is produced separately, as a first step, and then the tasks that integrate the services to the product take place. The process plan describes a number of ***N*** processes and the order in which they are executed. A process, for example, such as making a drill to mount a sensor or the process of mounting a sensor in a specific location in the product can be performed on the IPSS provider site. There are a number of ***R*** resources that can perform one or more of the ***N*** processes. Resources are possessed by IPSS suppliers, product suppliers and service suppliers on the IPSS manufacturing network. There is a transportation attribute related to a resource since a resource may need to travel to the IPSS provider site or to the customer's site in order to perform a task. Finally, there is a number of ***M*** of IPSS orders already scheduled in the IPSS provider's ecosystem. This practically means that one or more resources within a given time horizon are already scheduled to support the implementation and delivery of other IPSSs.

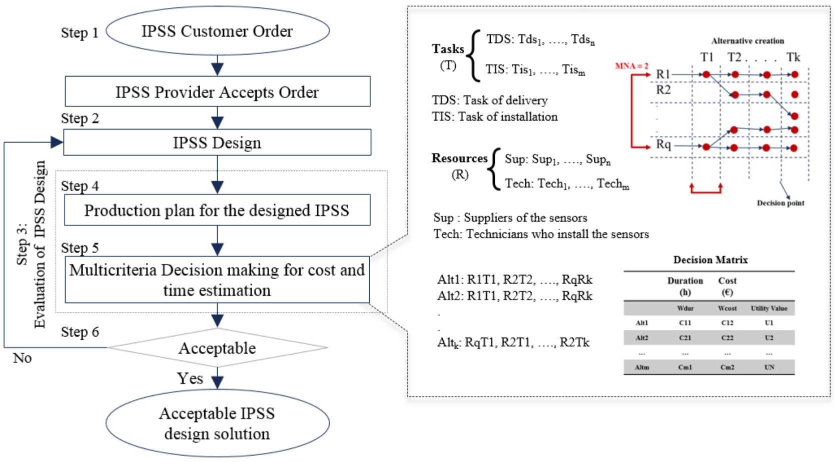

Fig. 1. IPSS production and installation planning flowchart

The objective of the planning method described below is to find an optimal solution that decides what IPPS equipment (e.g. sensors) suppliers to select, which resources (e.g. IPSS service installation technicians) and when they should perform which processes/tasks at IPSS provider or customer site.

The planning method proposed in this work, is based on the approach proposed by Doukas et al [12] and it defines the approach for assigning a set of resources to a set of tasks under multiple and often conflicting optimization criteria. The planning method is composed of the following steps. The first step is the generation of a maximum number of alternatives (MNA). The second step is the calculation of decision-making criteria in order to satisfy a set of manufacturing objectives (CR_1… CR_n). Step 3 is the weight definition of those criteria. Subsequently, the calculation of the utility value of each one of the alternatives with respect to the selected criteria takes place. It is important to mention here that the utility value (U_1… U_m) where m ϵ [1, MNA] is the weighted sum of the normalized values of the criteria and takes its values in the range 0 to 1. The final step is the ranking of the alternatives (ALT_1… ALT_m) and selection of the best alternative with the highest utility value]14], aka the best resource plan. In order to obtain a high-quality solution (high utility value) to the resource planning problem in a timely manner, the intelligent search algorithm (ISA) has been developed. ISA uses three adjustable control parameters, namely the maximum number of alternatives (MNA), the decision horizon (DH) and the sampling rate (SR). MNA controls the breadth of the search (i.e. the number of alternative trees to be created), DH controls the depth of the search (i.e. the layers searched forward) and SR guides the search through the solution space for the identification of high-quality paths (i.e. number of branches created for each alternative defined by the MNA). It should be noted that all assignments made by the ISA are random. The decision-making process can be formalized as a decision matrix (Fig.1).

3 IPSS planning tool implementation

The IPSS planning method has been developed as a Software-as-a-Service (SaaS) oriented web application. The IPSS tool consists of a user interface and the REST service oriented module. The user interface is developed as a Java portlet, following the JSR 168 specification that allows the user interface to be deployed in compatible Java portals, such as Liferay. The portlet has been developed using the Vaadin Java framework and exposes the functionality of the IPSS planning tool to the users. The IPSS Planning Tool Portlet can access a knowledge repository where all required information is stored in an Apache Jena semantic repository. In particular, the repository contains information such as manufacturing resources, existing manufacturing schedules, designed PSS systems, sensors and product descriptions. The module receives as input all the information needed by the IPSS Planning algorithm and produces as an output the result of the planning which includes calculations on the requested KPIs (such as cost and time) and a plan for the production of the IPSS. The input of the service is provided in a specific XML format, and in a similar fashion, the output is provided in an XML format. IPSS Planning Tool Architecture is presented in Fig.2.

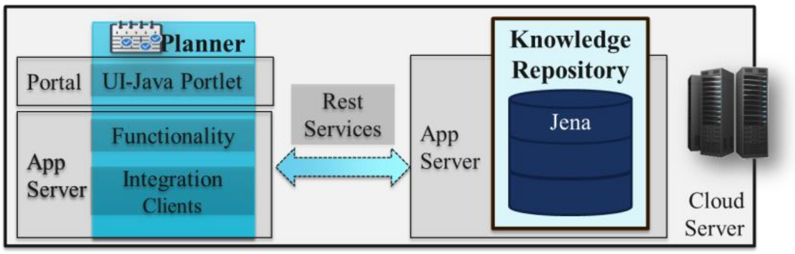

Fig.2. IPSS Planning Tool Architecture

4 Pilot Case: Laser Cutting Industry

The proposed method has been applied and evaluated in the case of a laser cutting machines provider. The IPSS under investigation is a Laser Cutting machine (product) together with a set of services which are implemented through the integration of sensors and software. An evaluation scenario has been setup with the following aspects:

- An IPSS provider receives a new customer request for a Laser Cutting machine with three different services namely a) machine performance monitoring using vibration sensors, b) process quality monitoring using vision sensors and c) machine health monitoring using temperature sensors.

- The integration tasks of a service are executed in two steps: a) sensor delivery and b) sensor mounting and service configuration. The modelling of the pilot is depicted in Fig.3.
- Each task can be performed by a number of alternative resources (i.e. sensor supplier and service technicians). Each one of the resources is characterized by their cost C (€), operation time OT (h) and also transportation TT (h). The aforementioned resources, as well as their attributes, are given in Table 1. Also downtimes are considered (e.g. non availability during weekends).
- When the new customer request is received a number of 10 IPSS orders are being produced. Thus not all resources are available to produce the new IPSS.

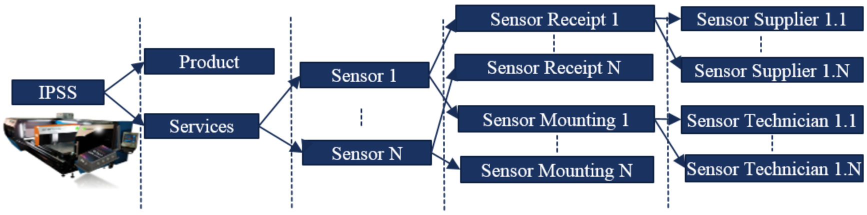

Fig. 3. Pilot Case Modelling

Table 1. Used Resources and their attributes

Resources per Sensor type	Attributes(C,TT)	Resources		Attributes(C,OT,TT)
Supplier 1 (Vibration S.)	94.55 €, 36 h	Technician (Vibration S.)	1	320 €,5 h, 2h
Supplier 2 (Vibration S.)	89.49 €, 48 h	Technician (Vibration S.)	2	335 €,6 h, 1h
Supplier 3 (Vibration S.)	96.15 €, 24 h	Technician (Vision S.)	3	450 €, 3.25 h, 1h
Supplier 4 (Vision S.)	560 €, 12 h	Technician (Vision S.)	4	460 €, 3.5 h, 2h
Supplier 5 (Vision S.)	610 €, 18 h	Technician (Temperature S)	5	350 €, 3 h, 1h
Supplier 6 (Temperature S)	647.28 €, 24 h	Technician (Temperature S)	6	370 €, 3 h, 2h
Supplier 7 (Temperature S)	660 €, 24 h			

First step is to add the new IPSS order in the workload and define its arrival and due date. The user may "lock" the tasks (see Fig. 4) of the ten PSS orders so they are not rescheduled for new resources and time frames. Then a new schedule is being generated including the tasks for the new PSS order. The results of the resource planning for the ten locked IPSS orders and the new one IPSS order, depicted with red borders, are presented in the following Gantt chart (Fig. 5) including the best alternative combination of resource planning for the scheduled IPSS accompanied with the estimation of time and the cost of the generated resource planning.

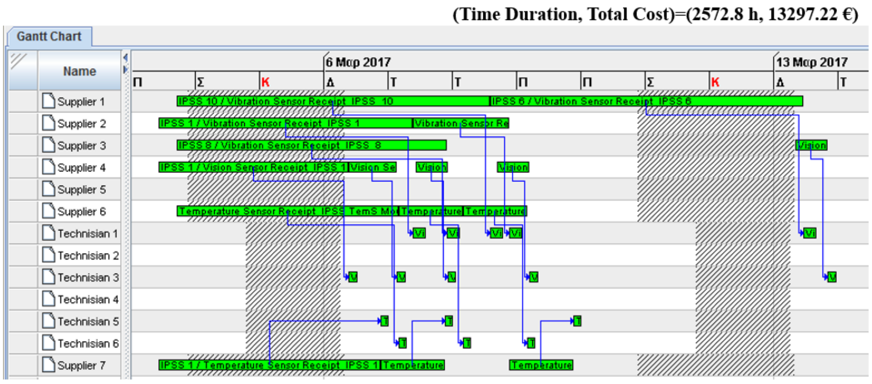

Fig. 4. Pilot case resource planning: 10 IPSS scheduled

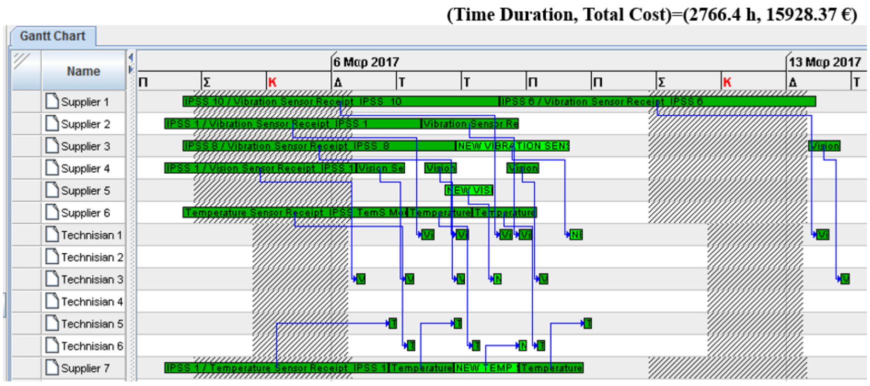

Fig. 5. Pilot case resource planning: 10 IPSS scheduled and 1 new IPSS order

In terms of competence, it is necessary to note that the industrial case modeling initially had been constructed taking into account more IPSS and more variations of resources and tasks in terms of validity of the results. A small scale industrial case was selected in order to give a comprehensive example of the implementation of the proposed tool. The proposed approach could be applied in several industries regardless their scale, considering the could-technology provided opportunities.

5 Conclusions

In this work, a multi-criteria resource planning method and a tool for optimizing the production, delivery and installation of IPSS is presented, with a demonstration case from laser cutting industry. The purpose of the planning tool is to provide decision support in the design and production of an IPSS order. The resource planning method generates a good plan by considering multiple and contradicting criteria such time and cost. Preliminary results gave a reduction of lead time and respectively cost per IPSS planning since all the available resources are occupied in the most convenient way based on the defined criteria. Future work will consider customer's time availability that adds a new constraint to the problem since the IPSS could only be delivered within the time window provided by the customer. Moreover, in the current study it is assumed that the product provider is the same as the IPSS provider. In future work, there will be alternative product suppliers from whom to optimally select the product.

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