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Abstract

Purpose – The purpose of this paper is to propose a method for adopting an Internet of Things (IoT) enabled product-service system (PSS) considering business model and product enhancements. The method focusses on business process implications of IoT. The paper also discusses a real application of the proposed method to the machinery industry.
Design/methodology/approach – Considering the IoT technologies available, failure mode and effects analysis is applied to identify what should be monitored in the product to minimize potential product failures. In parallel, in order to assist the company in deciding which PSS strategy to be followed, a Configurator of PSS proposals is applied. The results are derived to define the IoT architecture and the business process design supported by the selected IoT technologies.
Findings – The main findings include the proposed IoT-enabled PSS adoption method, illustrated by the description of the application and its assessment. In addition, the identification of key process areas that are impacted by IoT is offered, namely: remote machine setup; corrective and predictive maintenance; material supply; product pricing; and information reporting.
Research limitations/implications – The application of the method proposed is limited to one company. Future work includes extending the application of the method to other units of analysis.
Practical implications – The method proposed can be considered by companies willing to increase product-service revenues based on IoT technologies.
Originality/value – The IoT-enabled PSS adoption method is an approach grounded on the intersection theories of PSSs and the more technology-oriented IoT developments.

Keywords Business process redesign, Internet of Things (IoT), Product-service system (PSS), Machinery industry
Paper type Research paper

1. Introduction

Information technology adoption has generally caused great impact in the business processes of companies. However, novel Internet of Things (IoT) technologies impact companies processes in an unusual way and, therefore, demand a revised adoption approach. IoT comprises hardware and software to enable objects to interact and to communicate with each other, supporting the development of new services. In this sense,

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IoT primarily affects the objects (products). Object enhancement, in turn, opens the opportunity to process design.

While IoT technologies are widely available and mature today, its adoption needs to be justified by business purpose. One major opportunity for IoT adoption is the servitization trend, which can be observed in many industries, such as machinery. By bundling products and services, in so-called product-service systems (PSS), companies try to differentiate from competitors by a combined product and service offering. In many cases, service offering can be extended if the company is able to monitor and to gather data from its product during the client usage lifecycle phase.

In this context, the aim of this paper is to propose a method for adopting IoT-enabled PSS considering business model and product enhancements. The proposed method focusses on business process implications of IoT. The paper also discusses a real application in the machinery industry.

The paper is organized in six more sections. Sections 2 and 3 present the literature review concerning IoT and PSS, by focussing on the implications for business processes. Section 4 describes the research design and the proposed IoT-enabled PSS adoption method. Section 5 presents a real application in the machinery industry. Section 6 presents the discussion of the results. Section 7 draws the concluding remarks and outlines future research opportunities.

2. IoT and its impact on business processes

2.1 IoT

IoT is defined as a new paradigm in which things or objects provided with radio-frequency identification, tags, sensors, actuators, etc. – through unique addressing schemes – being able to interact with each other and cooperate with their neighbors to reach common goals (Giusto *et al.*, 2010). In more technical terms, IoT may be defined as "a world-wide network of interconnected objects uniquely addressable, based on standard communications protocol" (INFSO, 2008). In a more application centric vision, IoT enables "a world where things can automatically communicate to computers and each other providing services to the benefit of the human kind" (Casagras, 2009).

Nevertheless, IoT itself is not sufficient to generate value, making it necessary to transform considerable volumes of data into useful knowledge. According to Rifkin (2014), "people, machines, natural resources, production lines, logistics networks, consumption habits, recycling flows, and virtually every other aspect of economic and social life will be linked via sensors and software to the IoT platform, continually feeding Big Data to every node – businesses, homes, vehicles – moment to moment, in real time. Big Data, in turn, will be processed with advanced analytics, transformed into predictive algorithms, and programmed into automated systems to improve thermodynamic efficiencies, dramatically increase productivity, and reduce the marginal cost of producing and delivering a full range of goods and services to near zero across the entire economy." Aazam *et al.* (2014) introduced the concept of Cloud of Things, in which IoT and Cloud Computing are intertwined in order to deal with the volume of data required in this new paradigm.

There are several related topics important to enabling IoT, in the technological point of view (Vermesan *et al.*, 2011): identification technology; architecture technology; communication technology; network technology; software, services and algorithms; cloud computing; hardware design; data and signal processing technology; discovery and search engine technologies; relationship network management technologies; power and energy storage technologies; security and privacy technologies; standardization.

However, the technology is only a part of the IoT solution. Understanding when, how, where, and why use the technology are key elements for successfully implementing an IoT in the business processes. These answers are better obtained in the application industries, which understand the value leverages IoT might bring to each sector, but have no expertise with IoT technologies. IoT will create novel and unprecedented forms of value by making fundamental changes in the way companies and industries operate (Prince *et al.*, 2014).

2.2 IoT impacts on business process

The IoT market can be segmented in three categories:

(1) Business to Consumer (B2C): e.g. connected people, connected pet, connected home, connected car.

(2) Business to Business (B2B): e.g. connected agribusiness, connected buildings, connected industry (industrial internet).

(3) Business to Business to Consumer (B2B2C): e.g. smart cities, smart grid, smart utilities.

This paper focusses on the business to business market, especially connected industry.

IoT applications are "event-driven and reactive, that is continuously reacting on a large number of events from the physical environment, from users and from other parts of the system. Additionally, they are dynamic and adaptive, meaning that applications, associations and collaborations are dynamically established and configured depending on the situation at run-time. The information gathered is often used to support human decision making rather than to only automate a predefined process. Interaction with human users is essential both to use the systems efficiently, and to effectively improve the systems over time" (Krogstie, 2011).

Atzori *et al.* (2010) provide examples of IoT applications in industrial business processes:

- Monitoring environmental parameters: monitoring conservation status in perishable food warehousing and transporting.
- Industrial plants: a wireless sensor mounted on the machine monitors the vibration and if it exceeds a specific threshold an event is raised to immediately stop the process (quality control). Once such an emergency event is propagated, devices and systems that consume it react accordingly.

In order to support IoT application, Sperner *et al.* (2011) introduce entity-based concepts to business process modeling in the context of IoT applications, such as the physical entity and the virtual entity, that when combined form an augmented entity, identifiable by a tag and which can perform actuation tasks or sensing tasks (for instance). Chen *et al.* (2012) also propose a process definition language specific for IoT enabled processes, based on three sections: services, sequence, and variables. Li *et al.* (2013) recommend methods for pricing information services provided by IoT applications, based on the game theory.

Considering the potential impact of IoT in PSS, Espíndola *et al.* (2012) present a case study of IoT application in PSS to provide scalability. They argue that for adopting the new paradigms related to PSS such as "(re)adding value, (re)use and customization, based on the different expectations from distinct agents, require new technologies for its implementation. New Information and Communication Technologies (ICT) infrastructures for acquiring and processing of information, such as smart devices, human-computer interfaces and computational models are required. These infrastructures must describe the relationship between product and service, and manufacturers and consumers, as well as allow the exchanging of knowledge among these agents throughout the product lifecycle."

3. PSS

3.1 PSS definition

A new way of delivering value to customers and to satisfy specific user needs is growing in importance in academia and in industry. Similar terms is known in the literature: servitization (Vandermerwe and Rada, 1988), service-dominant logic (Vargo and Lusch, 2004), and PSS (Goedkoop *et al.*, 1999), this approach focusses on delivering benefits through functionalities achieved by a bundle of products and services (Manzini and Vezzoli, 2003; Mont, 2004; Baines *et al.*, 2007).

The term considered in this paper, PSS, was first mentioned by Goedkoop *et al.* (1999) in a study named "Product-Service Systems – Ecological and Economic Basics." The authors defined PSS as a system of products, services, infrastructure, and networks that continually strive to be competitive, to satisfy customer needs, and to cause lower environmental impact than traditional business models. In a more recent study (Boehm and Thomas, 2013), PSS is considered an integrated bundle of products and services the main aim of which is to create utility for customers and to generate value.

As the mentioned concepts showed, an important aspect of PSS is to meet customer needs through product and service combinations. Another important issue is the partnership and involvement of different actors to create and to deliver value (Mont, 2000; Manzini and Vezzoli, 2003). Each of them can focus on its core competencies to perform processes and activities. Therefore, the value is generated by means of co-creation and co-production among different actors, such as provider, customers, and partners (Vargo and Lusch, 2004; Lusch *et al.*, 2007; Jacob and Ulaga, 2008; Grönroos, 2011).

Thereby, PSS does not address only rethinking about services and products, but also covers the reconfiguration of the business models (Gelbmann and Hammerl, 2014) and, as a consequence, the modification or creation of new business processes (Baines *et al.*, 2009).

3.2 PSS processes

New principles, organizational structures, and processes are required if a company wishes to succeed in adopting PSS (Baines *et al.*, 2009). The business processes are one of the elements of a business model that are affected by PSS implementation. The previous authors pointed out some examples of processes that are affected by improving or creating a PSS business, such as performance measurement, customer management, and stakeholders' management. The adoption of PSS mainly influences human resource management, product and service design and customer management (Gebauer *et al.*, 2010). The characteristics that might change in these processes when adopting PSS business models are discussed next.

Direct relations and intensified contacts with customers (Mont, 2004) through increased operational links, information exchange, legal ties and the establishment of cooperative rules (Matthyssens and Vandenbempt, 2010), long-term relationships (Williams, 2006) are PSS characteristics that influence customer management (Barquet *et al.*, 2013). Contracts define the responsibilities of the parties involved (e.g. between a PSS provider and customers) during a given period. The contract management in a PSS business should address all aspects related to providing services and clearly state the rights and liabilities of the parties involved, such as product ownership and responsibility, terms of agreement, level of formalization and complexity, incentives, and risk level (Reim *et al.*, 2014).

Human resources management is affected mainly because adaptations are required in the front line roles to cope with the complex market and value proposition (Gebauer *et al.*, 2010). Since PSS offers tend to be complex and include physical and service components, focussing on communication and showing the benefits of the PSS offer are central issues, e.g. by ensuring functionality and durability at the point of sale. This is relevant because the customers are buying a solution with a new configuration compared to earlier experiences (Mont, 2002).

The importance of adapting product and service design should also be pointed out. The entire lifecycle of the product should be considered (Sundin and Bras, 2005; Aurich *et al.*, 2006). Additionally, requirements such as functionality and customization (Reim *et al.*, 2014), ease to maintain, upgrade, and reuse (Sundin and Bras, 2005) should be taken into account. In addition, ICT should be considered during the planning and design phases, in order to be correctly introduced and utilized in the use phase of the PSS (Opresnik and Taisch, 2015).

Because the companies cannot usually perform all PSS tasks independently, they must develop networks and partnership (Baines *et al.*, 2007; Gao *et al.*, 2011). Then, by means of these networks and partnership, PSS providers may ensure that PSS business models are implemented successfully (Reim *et al.*, 2014). Therefore, stakeholders' management is an essential process of the PSS business model that addresses the relationships and interactions with different stakeholders, e.g. customers, dealers, service partners, and suppliers (Barquet *et al.*, 2013).

Financial and accounting might need modifications, and an adapted financial incentive system is required (Gebauer *et al.*, 2010). The time scale of financial flows changes from an immediate return of capital (in the traditional sales process) to an extended usage period, which is the case of PSS (Mont, 2004). Therefore, new revenue models based on performance-based pricing must be created (Matthyssens and Vandenbempt, 2010).

A PSS business model enables the collection of "product or service in use" data through increased interaction with customers and product monitoring in the use phase. Because of the increased data volume that can be acquired, organizations require continuous processes for gathering, analyzing and interpreting data (Davenport *et al.*, 2012). The data can be utilized to identify opportunities to improve the product as the entire system and also the contracting terms to increase benefits for both sides (Reim *et al.*, 2014). For this purpose, new activities should be incorporated in the knowledge management process to ensure that data will be correctly stored and utilized.

4. Research design

This paper reports an application of a proposed method for IoT-enabled PSS adoption to a real case situation in the machinery industry. The research design is divided into three stages: first, a literature review to establish the theoretical background of this work (Sections 2 and 3); second, the development of the proposed method, detailed in this section; and third, the application and evaluation of the method in a real situation (Section 5).

Generally, IT tools directly impact the company business processes. In this study, IoT is considered as an enabler that impacts both the product and the processes. Figure 1 presents an overview of the method proposed. Considering available IoT

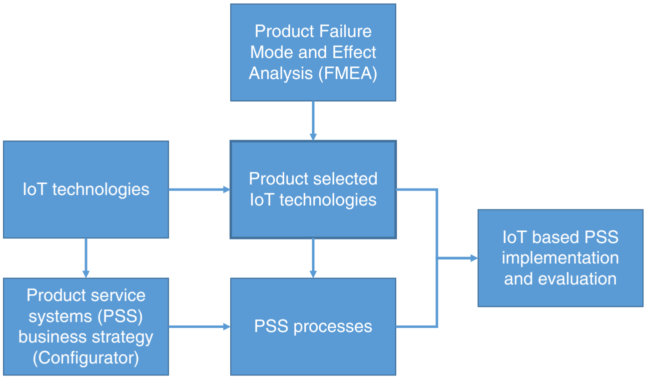

Figure 1.
Framework for research design and proposed method

technologies, failure mode and effects analysis (FMEA) is applied to identify what should be monitored in the product to minimize potential product failures. This step leads to selected IoT technologies to be installed in the product.

In parallel, in order to assist the company in deciding which PSS strategy to follow, a Configurator of PSS proposals is applied. The Configurator aims at supporting companies to create their PSS positioning during the innovation planning. The Configurator comprises steps that should be followed by companies aiming at improving a current business through PSS or starting a new business by creating a PSS proposal (Barquet, 2015). According to the previous author, the PSS Configurator application consists of eight steps: first, understanding company business model (decision making to maintain the current business model or creating a new business for PSS); second, chosing value proposition (deciding which mix of products and services to offer customers); third, identifying customer target (gathering market data to understand current or potential customer attracted by the PSS proposal); fourth, characterizing customer relationship (developing alternatives to relate with customers considering different phases of a PSS lifecycle); fifth, putting together processes and partnerships (identifying and defining PSS processes and activities of the actors, and ways in which PSS offer should be delivered to the customer); sixth, identifying resources (acknowledge assets required to run the business, such as: knowledge, technology, competence, and human resources); seventh, defining cost structure (finding out different elements of costing); and eight, identifying possible revenue streams (evaluating revenue alternatives). As can be seen, each step covers different activities that should be performed to create the PSS proposal. Specifically, Step 5 results in defining the business processes supported by the selected IoT technologies.

Finally, considering the PSS processes enabled by IoT to be installed in the product, the proposed solution is implemented and evaluated (Figure 1). One case application of the proposed method to define business process support for IoT based PSS is presented next.

5. Application case

5.1 Company description

The case company is a technology-based startup incubated at the University of Sao Paulo in Brazil, called Rochmam, which develops and manufactures solvent and diluent recycling machines for various industry sectors, such as cosmetics, paint, graphic, and chemical factories. Solvents are one modality of industrial waste, and their incorrect disposal has adverse effects on both the environment (air and water pollution) and human health (skin and respiratory implications) (Lau and Koenig, 2001). The most common method of solvent recycling is distillation. After a filtering process to retain the remaining solid material, the solvent is sent to a distilling machine where it undergo an increase in temperature until it reaches its boiling point. This way, the solvent turns into steam form, while its contaminants remain in the distillation machine. Then, the steam is delivered to another chamber, where goes through a condensation process to turn the solvent back to its liquid form, but without its contaminants (Shinozaki, 1987). Rochmam value proposition is to recover valuable solvents and diluents for reuse in the industrial process as well as separating environmentally harmful residue for proper disposal.

Rochmam business model is based on selling or renting the machines. A preliminary technical and cost/benefit analysis is performed for each customer in order to define the machine specifications and to demonstrate the economic feasibility of the customers' investment. The company focusses on quality and safety as well as superior service to differentiate from its competitors.

The short- and medium-term strategic vision is to strongly increase the number of customers and also to enhance the share of the PSS model in the company's revenue. In order to achieve this goal and to maintain the competitive advantages of quality, safety, and service, Rochmam understands that it is mandatory to increase operational efficiency and bidirectional communications with the customers. This is a scenario in which an IoT solution might be especially suitable, allowing remote monitoring and control of the company's machines.

5.2 *PSS configurator application*

In order to increase knowledge about different possibilities for the content of an IoT-based PSS business model for Rochmam, a Configurator of PSS proposals was applied. Each of the steps of the Configurator in research design (Section 4) and the corresponding results of the application are presented next. Implications for the company IoT adoption are also highlighted.

Step 1. Design of the business model. By means of the structure of Canvas Business Model, a description of the current business model of the company ("as-is"), which represents the one that should be modified with IoT-based PSS characteristics ("to-be"), has been developed. The business model dimensions considered are:

- Value propositions: the value of the business is based on "How much the customers can save by recycling (distillation) the solvents safely instead of disposing them." If the customer perceives a cost saving opportunity with the company's machine, both will win. This way, the company also helps its customers to be more eco-friendly, once they are not disposing the pollutant. The company is known for its products quality and safety. However, its price is also higher in comparison with that of competitors. To maintain this status, the company is constantly looking for ways to improve its product. Service offering covers: installation, training, maintenance, repair, upgrade, optimization/improvement, service technicians on call, on-site inspections, spare parts supply, diagnosis plus recommendations, planned overhaul. At the product end of life, product tack back and recovering strategies (e.g. recycling, remanufacturing, and/or reconditioning) are also services performed by Rochmam. The "as-is" benefits offered through the value proposition are: cost reduction, low environmental impacts, improved functionality, better safety, and quality.

- Customer segments: B2B customers are mainly from four types of industrial sectors: metal/mechanical, printing, repair shops (automotive), and paint industry.
- Customer relationships: the company maintains a long-term relationship with its customers based on providing cost saving which comes from the trade-off of the storage and disposal cost of the solvents and the machine recycling process. Rochmam offers two different types of contracts: one based on selling the machine and another one based on the use of the machine. Customers usually prefer to lease rather than buy. The sales system is a regular sales process. The customer gains the property of the machine and a warrant contract. The lease system is based on how much the customer would potentially save from the use of the machine.
- Key partners and activities: company key partners are mainly the suppliers of the machine parts. They are important for the production itself as well as for the supply of spare parts. The company controls its supply chain since purchasing the machine parts.
- Key resources: the sales department is a key area, once it has to communicate the benefits of the products that have a comparatively higher price.
- Revenue stream: the revenue comes almost completely from the two types of contract the company offers, which covers sales or rent of the machines, based on a fixed monthly fee. Other minor sources of revenue might come with the sales of spare parts or corrective maintenance not covered in the contract.
- Cost structure: the most important costs are from the production of the machine. The daily basis costs come from customer service.

The analysis of the "as-is" business model lead to the identification of opportunities considering IoT-based PSS adoption to increase competitive advantage. Applying IoT, the performance of machines can be measured during the use phase, which facilitates the acquisition of data and results in a higher response to customer needs (e.g. preventive maintenance and repair). In addition, the same data support the company in identifying improvements in the product and, therefore, an increased amount of benefits could be offered to its customers. Moreover, real time machine usage data can be applied to improve rental pricing calculation based on real machine utilization, instead of charging a fixed monthly installment.

The next steps present the improvements in the business model according to the results of step 1.

Step 2. Configure customer segment. The customer segment remains the same of the "as-is" business model.

Step 3. Configure value proposition. The product of the PSS is enhanced with the addition of IoT, allowing the machine to be connected via internet. The main modification in the value proposition concerns the addition of new service elements: remote monitoring, remote operation, and new maintenance processes. Remotely, the company will be able to access and to configure the machine according to specific customers' needs, e.g. the type of solvents distilled.

Step 4. Configure customer relationship. In the improved business model, the communication with customers becomes more frequent and easier, as the performance of the machine is tracked thought IoT. Considering continuous machine monitoring and the advantages of pricing based on machine utilization, the pure sale of the machines might be discontinued.

Step 5. Configure network. With the adoption of IoT, new suppliers of IoT hardware, software, and services need to be added to the business, as knowledge not yet available is required. High level of information sharing is expected between the company and the IoT suppliers.

Step 6. Configure resources. Employees need to be trained to fulfill customers' needs regarding the new maintenance processes that are created and to support the remote configuration of the machines.

Step 7. Configure revenue streams. The company already charges the customer based on a monthly fee. Nevertheless, additional revenue is expected when the customers use the machines more frequently as formalized in the contract.

Step 8. Configure cost structure. The initial investments considered to improve the business model include IoT hardware and software development, and implementation in the machines. Human resources to perform remote maintenance, follow the machines monitoring, process the acquired data by the device, and execute software changes and updates are new recurring costs. However, cost with field services and corrective maintenance shall be reduced.

Advances in the business model indicated by the PSS Configurator lead to the identification of impacted business processes, which are discussed later in Section 5.5.

5.3 FMEA application

As noted in Section 5.2, reduction of maintenance costs is a key aspect for business escalation in the studied application. This fact led the research team to deeper investigate the modes of failure. Thus, a FMEA analysis was applied. The results of the FMEA application are shown in Table I.

In general, all failures are currently hard to detect (in fact, the company only gets aware when the damage is irreversible or when customers are already dissatisfied). As IoT is based on the remote monitoring of different variables of the machine, it has the potential to dramatically improve early detection of problems before costly maintenance procedures or customer complaints take place.

As the number of sensors directly affects the costs of the IoT solution, the total risk calculated (risk column in Table I) was used to prioritize functionalities for the technical specification. It was possible to identify the most prominent opportunities which were addressable by the IoT technologies.

5.4 IoT solution architecture

The IoT solution architecture consists of the following:

- hardware and firmware: sensors, actuators, communications, and microcontroller;
- middleware: cloud server, MQTT protocol, and time series database;
- application software: web services (access through browser), and dashboard; and
- remote access: computer, tablet, and smartphone.

The architecture is illustrated in the diagram of Figure 2.

Table II shows the strategy adopted to address each of the most relevant failure modes (risk score above 50 in Table I) as identified in Section 5.3.

The communication strategy adopted was an Ethernet cable and WiFi (IEEE 802.11 protocol), because of the availability of these kinds of network connection in most customer sites. As the energy supply would be provided by the machine – connected to

Table I.
FMEA application results

Item	Failure mode	Effects	Severity	Causes	Probability	Current prevention	Current detection	Detection	Risk
Machine configuration	Temperature or cycle time setting not appropriate for the solvent or diluent to be recycled	Distillation process incomplete	2	Operator changed solvent but kept settings (10% of the cases)	6	Instruction manuals Machine startup along with operator in loco by the studied company staff	Client complaint about malfunction	6	72
		Residue in recycled fluids, clogging the machine	4		4			6	96
		Residue carbonizes and encroaches in machine	6	Operator changed settings to incorrect values (90% of the cases)	2			6	72
Machine opening mechanism	Machine is opened during operation	Loss of solvent or diluents Operator aspirates solvent or diluents	6	Imprudence of the operator	2	There are 6 analog temperature sensors for operator guidance	Client complaint about malfunction	6	72
	Machine is initiated with lid open		6		2			6	72
	Opening the lid while temperature is still too high	Gasket dilates and does not go back to original form. Machine cannot operate	6		4		Client request for gasket replacement	6	144
Residue	Accumulation of residue in the machine	Residue in recycled fluids, requiring more hours to clean the machine pipes or even clogging them	6	Operator does not clean machine with proper frequency	2	Cleaning instruction Recommend thermo plastic bags	Client complaint about malfunction	6	72
Thermic oil for heating	Oil does not provide enough heat for distillation	Distillation process incomplete	2	Oil loses thermal properties after a number of cycles and operator does not replace it	6	Oil change instructions	Operator warning (level of oil visible to operator)	6	72
		Thermic oil leakage	4	Operator sets temperature higher than needed, expanding the oil or gasket wears off	4	Instruction manuals Machine startup along with operator	Client complains about malfunction	6	96

(continued)

Table I.

Item	Failure mode	Effects	Severity	Causes	Probability	Current prevention	Current detection	Detection	Risk
Vacuum system	Insufficient vacuum in the machine	Atmospheric pressure over fluids, when vacuum returns evaporation happens too fast, possibly damaging the machine	4	Power outage deactivates compressor which produces vacuum	2	Analog vacuum gauge for operator monitoring	Client complains about malfunction	6	48
Sensors and actuators	Wrong reading	Accidents, short circuits, fire	6	Displacement during transport Vibration, corrosion due to environment conditions	1	Machine site recommenda-tions	Client complains about malfunction	6	36
Alarms	False positive alarm trigger	Alarm loses credibility Annoys client	4	Sensors not suitable for specific machine	1	Verification of specs prior to manufacturing	Client complains about malfunction	6	24
Lubrification	Mechanical wear	Breaking of lubricated mechanical parts	1	Lubricant below necessary level	1		Client complains about malfunction	6	6

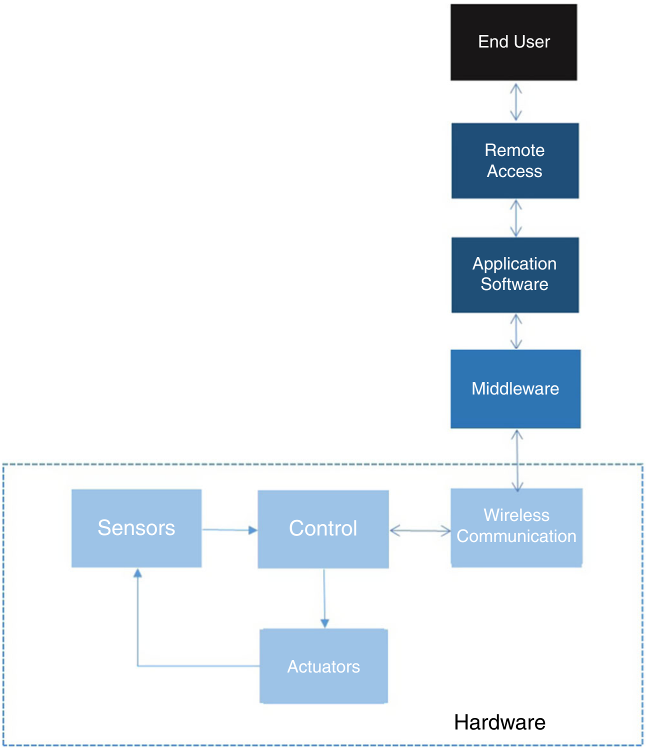

Figure 2.
Solution architecture

Table II.
Examples of IoT solution options to address the most critical modes of failure

Modes of failure	IoT solution options	Expected result
Temperature or cycle time setting not appropriate for the solvent or diluent to be recycled	Connected n-positions selectors for temperature and cycle time Connected display with selection of parameters	To be able to know the settings and change them remotely
Opening the lid while temperature is still too high	Connected pneumatic actuator with external sensor Connected pneumatic actuator with embedded sensor Connected electrical lock	To be able to lock the lid when necessary
	Sensors (hall effect, infrared or limit sensors)	To be able to know if the machine is open or closed in a particular moment
Accumulation of residue in the machine	Connected flow and level sensors	To be able to know the volume of residue in the machine
Oil does not provide enough heat for distillation	Connected oil level sensors (ultrasound or float)	To be able to know the volume of oil in the machine

the electric grid – low-energy consumption of the radiofrequency technology was not a main concern. Additionally, there would be typically only one machine at each site; therefore, a mesh network was also dispensable. These two reasons favor IEEE 802.11 technologies instead of a more expensive technology such as IEEE 802.15.4 (more suitable for multiple communication nodes and extremely low-power consumption scenarios). Each machine is identifiable by an IP and MAC address.

The dashboard shows each customer on a separate page:

- graphs with each sensor measurements per minute;
- current values of the configuration settings;
- total number of cycles and operating hours by period;
- history log with time stamp of operator inputs/activations as well as with time stamp of alarm triggers; and
- economy report per period (calculation of how much solvent/diluents were recovered in the period, in volume and corresponding cost savings).

The aforementioned IoT architecture designed to support improvement areas identified by FMEA (Section 5.3) and the new business modeling resulting from the PSS Configurator application (Section 5.2) led to business process redesign, as described next.

5.5 Process design

The innovation potential of IoT-based PSS requires process redesign based on "attraction forces" (such as: goals, expected results, and problem-solving criteria) which catalyze the participation of several partners (Morelli, 2006). As the company aims to create closer relationships with its customers, the partners network (IoT provider, company, and customers) require a differentiated management of the activities among them. Therefore, new forms of communication are required on a regular basis, as suggested by Barquet (2015).

In this study, five most relevant issues in which new processes or process redesign are needed were identified:

(1) machine setup;

(2) corrective and predictive maintenance;

(3) material supply;

(4) pricing; and

(5) information reporting.

The first four issues refer to processes redesign as the IoT-based PSS is initiated, while the fifth issue is a new process that the company is able to provide to its customers. Machine setup mostly benefits the customer, as it aids him in setting the suitable parameters to the machine, thus avoiding unexpected errors. Corrective and predictive maintenance and material supply benefit both PSS provider and customer, once the remote monitoring can predict when maintenance and new material for replacement are required. Pricing is a change to a more effective way the provider charges its customers. The information reporting is a new feature the PSS provider can offer. Each of the process issues are discussed in more detail next.

Machine setup. For a manufacturing company as the one considered in the application, developing PSS may improve the total value for the customer because of increased servicing and service components as suggested by Mont (2002). Without the PSS, customers must have operators with knowledge to setup the machine whenever it is to be used, which includes programming the right temperature and cycle time for a given amount of solvent. If the operators need any kind of assistance, the support can occur by telephone. With IoT-based PSS, the technical team can intervene remotely to set the appropriate parameters directly into the machine, using internet connection.

For the customers, this change translates into a more reliable recycling process; for the provider, it means a faster and better way to support its customers. For both, the result is a decrease in the total risk of having a future major problem.

Corrective and predictive maintenance. In use-oriented services, the PSS provider is also often responsible for maintenance, repair and control (Tukker, 2004). The IoT device permits the company to monitor its machines and to provide a better maintenance service.

The actual process only consists in a corrective maintenance when the customer requires it. With IoT based PSS, the provider can track the machine conditions (e.g. number of cycles completed) and act to correct or to prevent any current or further technical problem.

The customer is benefited in terms of machine availability, and the provider gets a better visibility of its maintenance plan. In the short term, the provider is expected to have a workload increase during the process change. However, in the long term, the predictive maintenance should decrease the amount and costs of corrective maintenance, which will also be more accurate, once the provider will have a better understanding of the machine conditions.

Material supply. An effective provision of PSS requires the co-ordination of manufacturing systems, maintenance, spare parts and logistics (Slack *et al.*, 2004). By monitoring the machine conditions, the PSS provider can anticipate the requirement for spare parts, increasing the ability to provision it on time.

The actual process of supplying spare parts occurs when the customer identifies the need, the provider requests them from its suppliers, and then it supplies back to its customer. In many cases, the customer is harmed, because the process takes long and the machine is not available in the meantime.

Pricing. In use-oriented services, the provider can charge its customers for product renting, while in result-oriented services, a pay-per-service unit system can be used (Tukker and van Halen, 2003). In the application studied, the company already has a renting system; with IoT, the company can apply a mix pricing strategy of both renting and pay-per-service unit system. In the actual configuration, the company cannot know how much solvent the customer is recycling. In addition, as the renting contract is based on a pre-assessment of the probable amount of recycled solvent, the company loses the opportunity of receiving for the overuse of the machine. It is worth highlighting that the complete change to the result-oriented service was not considered by the company, because from an economic point of view, it still needs an assurance of constant cash flow every month.

Information reporting. With the new capability of gathering product information, the company can introduce a new service component. Productivity reports can enhance the visibility of the machine and highlight the impact it is causing on the customers' business. For instance, they can display the cost saving amount on each recycling cycle or even the amount of water not polluted. Productivity reports will also help the company to better understand the frequency of use of the machine, making it able allocate the right resources to it.

6. Discussion

IoT encompasses comprehensive concepts and technologies that open new business opportunities based on product and service enhancements. On the other hand, IoT adoption typically involves significant efforts in terms of knowledge acquisition, product innovation, and business process definition and deployment. The IoT related product costs increase with the number of sensors and hardware used to acquire and process product data. In this sense, an approach to prioritize IoT adoption and derive the related business processes is necessary to focus the companies' initiatives in this area.

The method presented herein aims at adopting IoT-enabled PSS considering implications for the business model, the product, and the related business processes. The method combines the application of an existing PSS Configurator and the use of FMEA. The PSS Configurator indicates servitization opportunities based on the initial "as-is" situation while FMEA ranks potential product failures to prioritize product data acquisition and monitoring. As a result of the business and product priorities (PSS Configurator and FMEA), IoT technologies are selected, and related business processes are derived.

The proposed method was applied to a machinery company, called Rochmam, which develops and manufactures solvent and diluents recycling machines. The company aims to increase its service offering and revenues based on IoT technologies and business processes improvements.

The application of the method at Rochman supported the company prioritization for IoT and business process developments. By applying the PSS Configurator, it was possible to map the "as-is" business situation and to define servitization opportunities. The FMEA application (Tables I and II) indicated priorities for field monitoring during the product use lifecycle phase. At Rochman, these drivers led to the identification of five business process areas impacted: remote machine setup; corrective and predictive maintenance; material supply; product pricing; and information reporting. The impacted business processes may vary from company to company as a result of the method application. Nevertheless, these five process areas are a preliminary indicative of potential business process areas that can be explored in IoT initiatives in the machinery industry in future research and practical work.

At Rochman, a significant challenge for applying the method was the need to combine knowledge from various areas, including a deep understanding of IoT technologies and managerial vision of PSS business opportunities for the company. In order to deal with this challenge, experts from academia and an IoT technology supplier were involved in the method application.

To our best of knowledge, the present work is one of the few studies that generated knowledge about the IoT-enabled PSS. The understanding obtained from this work can provide relevant messages for practitioners and scholars.

Practitioners, for instance, may use such results in a variety of ways, as there are important implications for them generated by this work: first, the demonstration of a true application of the proposed method within the context of machinery industry; and second, the identification of key areas in which new processes or process redesign is needed when considering IoT. The recognition of what sorts of issues concern the processes is relevant under the practical point of view.

As the current results may be replicable to other similar companies, the studied company has paved the way to extend the application for those companies in future research. Within the PSS context, the method may offer empirical contributions to PSS empirical knowledge, including the application of IoT to enable PSS.

7. Conclusions

This paper presents a method for adopting IoT-enabled PSS. The method was applied to the machinery industry. The application pointed out that this approach can be useful to support companies' adoption of IoT in a PSS context. The use of the PSS Configurator from the very beginning assures a better alignment of IoT technology and business process efforts according to business strategic priorities. The parallel approach focussing both on the product and on the processes is necessary considering IoT is in great extent implemented in the product itself.

The use of FMEA in this novel context revealed to be a valuable source of information in order prioritize IoT to more critical issues as well as to improve the early detection of problems before costly maintenance procedures or customer complaints take place. As the number of sensors directly affects the costs of the IoT solution, prioritization reduces costs and supports a focussed use of the technology. Conclusively, as a result of the method application, key process areas impacted by IoT were identified in the application: remote machine setup; corrective and predictive maintenance; material supply; product pricing; and information reporting.

Future research recommendations include extending the application of the method to more units of analysis in other companies and industrial sectors, as the method is limited to one application. It is also important to extend the understanding of the process areas affected, based on the five process areas identified in this work.

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