Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Corso di Dottorato in Ingegneria Industriale
Curriculum in Ingegneria Meccanica

Study and development of a methodology for Product-Service System engineering

Ph.D. Dissertation of:

Eugenia Marilungo

Advisor:

Prof. Michele Germani

Curriculum supervisor:

Prof. Ferruccio Mandorli

XV edition - new series

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Studio e sviluppo di una metodologia per la progettazione di Sistemi Prodotto-Servizio

Tesi di dottorato di:

Eugenia Marilungo

Tutor Accademico:

Prof. Michele Germani

Coordinatore del Corso:

Prof. Ferruccio Mandorli

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Università Politecnica delle Marche
Dipartimento di Ingegneria Industriale e Scienze Matematiche (DIISM)
Via Brecce Bianche — 60131 - Ancona, Italy

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Chapter 1. Introduction

1.1. The Industrial Manufacturing in Europe

Nowadays, the international manufacturing context is in continuous changing in order to find more business opportunities, improve the sustainability of the value proposition, be more efficient and effective on the market, and satisfy the user needs. Indeed, manufacturing industry aims to have impact on both economic growth, addressing the citizens' needs, and the environment respect. Therefore, producing innovative products that address these purposes will be a major challenge for the future manufacturing companies that want to play a key role in industrial world. This is possible because manufacturing enables technological innovations to be applied in goods and services, which are marketable in the marketplace and allows making new products affordable and accessible so as to multiply their societal and economic benefits, achieving the desired impacts. The main significant emerging technologies discussed in literature researches are a networked and smart environment connected by Internet of Things (IoT), wearable technologies, tangible interfaces, human-robot collaboration, evolving tools, processes and interactions, avatar-quality Virtual Reality (VR), ubiquitous usage of machine learning and deep learning algorithms.

According to this trend, European industry, in order to maintain its market-share in the global competitive industrial sector, needs to innovate its industry, making the "Factories of the Future" able to produce innovative products at the right time, price, and according to the customers' needs. Moreover, without competitive replication technologies, the deployment of better products will be limited and the expected impact on challenges will not be achieved.

The technical objectives described by European commission about the Factories of the Future in Europe are highlighted below:

- Improve high tech manufacturing processes for both current and new materials or products, including 3D printing, nano and microscale structuring;
- Improve adaptive and smart manufacturing equipment and systems, including mechatronics, robotics, photonics, logistic and monitoring systems;
- Improve ICT for resource efficient factory design, data collection and management, to increase production performance through operation and planning optimisation;
- Improve collaborative and mobile enterprises, networked factories and dynamic supply chains, for locally adapted production;
- Improve human centred manufacturing, enhancing the role of people in factories and designing the workplaces of the future;
- Improve customer focused manufacturing, from product process to innovative services;
- Reduce energy consumption in manufacturing activities (up to 30 %);
- Reduce waste generated by manufacturing activities (up to 20 %);
- Reduce consumption of materials (up to 20 %).
- Create sustainable, safe and attractive workplaces;
- Create sustainable care and responsibility for employees and citizens in global supply chains.

These objectives are in line with the main areas which drive the structural changes in manufacturing (described in the following) and that involve nearly all manufacturing sectors. These areas are analysed in the following:

- *Changing demographics* (e.g. growing world population, ageing societies). This area of innovation aims to improve the people conditions and habits, in order to design new products and services tailored on the new customer needs that evolve together with the world population development. For example, considering innovation in the elderly people segment, a better home care customised for elderly requires smarter electronic products which imply the consumption of fewer materials and energy resources during their production. Time, cost and quality require that these products be manufactured in Europe, close to the consumer and in urban environments. Furthermore, better medical care will include highly individualised pharmaceuticals produced, on demand, through advanced manufacturing in urban pharmaceutical factories.

- *Scarcity of resources* (e.g. energy, water). This area of innovation aims to optimise the raw materials and the main resources usage both during the manufacturing and use phases of product lifecycle. For example, sustainable energy through solar, wind and tidal power solutions and energy storage, requires advanced and competitive manufacturing capabilities. This will enable Europe to generate more sustainable energy and increase its energy independence. Moreover, the scarcity of raw materials will mean that future products will have to be recycled to retrieve valuable materials.
- *Challenge of climate change* (e.g. increasing CO_2, global warming). This area of innovation aims to implement new strategies that are able to reduce the pollution during the manufacturing phase of product lifecycle. For example, recycled and re-manufactured solutions improve the reuse of valuable materials in a cost effective way, but require completely new types of factories.
- *Dynamic technology and innovation* (e.g. ICT and virtualisation, ubiquitous connectivity, sensing and digitalisation). This area of innovation aims to create solutions that provide new service functionalities able to simplify the customer usage by one hand, and the other one delivery solution in industry that improve the efficiency of automation systems, support the knowledge management and adopt energy efficiency policies. For example, ICT can easily create a higher service layer able to enrich simple products with new “intelligent” behaviours and communicating capabilities (i.e. monitoring the surrounding environment,

monitoring the users' habits, interacting with other connected devices, being adaptable to the user needs, behaviours and attitudes) [Yang et al. 2009].

- *Global knowledge society* (e.g. know-how base, gender gap, multiplication of data and information). This area of innovation aims to gather and manage all the information that can be collected or monitored in order to adopt different strategic actions for example to reduce costs, improve the energy usage, create more tailored products by customers' feedback, and so on.
- *Personalised customisation*. This area of innovation aims to create innovative products or services following user-oriented approaches, because customer is becoming a key actor of design and development processes. Also the supply chains should be revised and reorganised according to a new business model where customers, suppliers and producers are linked in a more direct way.
- *Shift to global cooperation*. This area of innovation aims to share knowledge, skills, competences, and information along all the actors involved in the development of innovative products and services, in order to be more efficiency, efficacy and promptly to answer to specific needs and requests. The globalization process of recent years has required enterprises to deal with more and more complex business and production scenarios in order to satisfy all their customer requirements and remain competitive. It means that collaboration across worldwide networks of enterprises as well as design and supply chain becomes an important capability to emerge in these highly competitive markets [Peppard J. and Rylander, 2006]. However, in order to be competitive, these networks need to understand and overcome the potential incompatibility problems amongst the particular information and manufacturing systems in the network [Ray and Jones, 2006].

The European scenario described above is the result of the new vision in industry, where the main issue to solve is to make factories and the relative production processes more and more sustainable, in order to decrease the environmental pollution and the processes emissions, optimise the costs to realise a product and thus the relative purchasing cost to be more competitive on the market, and finally have care about human condition during the production (e.g. clean workstation, safe actions, etc.).

Indeed, the modern Sustainability thinking considers three main dimensions: environment, costs and social wellbeing [Adams 2006], and each of them defines also a set of guidelines needed to drive manufacturing factories toward the sustainability.

From the economic viewpoint, sustainability relies on an optimal implementation of the whole range of technologies, in particular involving ICT and robotics mechatronics technologies, including embedded sensors connected to controllers, ERP, MES and predictive maintenance systems, enabling online, real time and full production quality control. Their implementation implies the creation of new market potentials and higher profit margins, and having higher productivity by means of reduced investment costs along the lifetime as well as reduced operating costs for the final users. To reach this economic sustainability, manufacturing industry should follow a set of guidelines promoted by European commission and that are listed below:

- Addressing economic performance across the supply chain. Actually, economic sustainability will require a redesign of products and production processes, in order to maximise the manufacturing efficiency by implementing, where adequate, automated, complex and precise manufacturing steps, which can be supported by advanced technologies and knowledge;
- Realising reconfigurable, adaptive and evolving factories capable of small scale production. In an economically viable way is needed to face better and promptly the uncertain evolution of the market or the effect of disruptive events. This involves managing the transition towards new

generations of products, allowing a stage of contemporary production of new and old products scaling up investments only when the market is proven;

- High precision manufacturing and micro manufacturing of complex products obliges precision manufacturing to increase the accuracy of machines and controls. This requires the introduction of new material processing technologies and novel measurement technologies;
- Resource efficiency in manufacturing, including addressing the end of life of products. Using less resources and reusing or recycling products or components of products generates economic savings and reduces the environmental impact of manufacturing.

From the social view point, manufacturing is evolving from being perceived as a production centred operation to a human centred business with a greater emphasis on workers, suppliers and customers involved in the loop. Human capability and machine intelligence will be integrated within production systems that can achieve maximum efficiency as well as worker satisfaction. This allows supporting the building up and securing of knowledge intensive jobs, and can contribute to a more geographically balanced wellbeing distribution [Tukker and Tischner 2006a]. In the following, the main expected societal impacts from European commission are described in deep:

- Increase human achievements. The balance between cost efficient automation and intelligent use of human capacities in manufacturing will determine the choice for future production and factory location. To achieve competitive and sustainable manufacturing here, performance must be radically increased by manufacturing systems. Future knowledge workers should interact dynamically and share tasks with smart manufacturing technology. Collaboration and allocation of tasks between humans and manufacturing technology should be done through appropriate and adjustable levels of physical and cognitive automation. Human capabilities should be enhanced to increase manufacturing flexibility and quality, while reducing complexity and process time, simultaneously enhancing economic sustainability;

- Creating sustainable, safe and attractive workplaces. It is vital that manufacturing workplaces are inclusive, thereby adapting work demands to the physical and cognitive capabilities of workers, especially for older workers and disabled people. The next generation workforce is being raised in an Internet society and is accustomed to a vast range of technical gadgets and rich interaction techniques. This will challenge present value systems of leading manufacturing industries and research will bring manufacturing to new forms of collaboration and business models;
- Creating sustainable care and responsibility for employees and citizens in global supply chains. Sustainable consideration of employees is reflected in company reputation and customer respect. Companies must also sustain control, safety, and well-being to attract new employees and customers.

Finally, from an environmental viewpoint, it is well-know that manufacturing today is able to address a constantly increasing demand for consumer goods. As a consequence, the consumption of raw materials and energy by the manufacturing industry keeps increasing. In 2005 the energy consumption of the manufacturing industry was about 297 Mtoe (million tonnes oil equivalent), which accounted for 27.9 % of the total energy consumption in Europe. Moreover, manufacturing is one of the primary sources of hazardous emissions and waste generation. In 2006, manufacturing industries accounted for 25.9 % of GHG emissions, 15.5 % of acidifying substances and 27.0% of ground ozone precursors. In 2008, more than half (54.6 %) of the waste generated in the Europe by businesses could be attributed to industrial activities. In the following, the main expected environmental impacts to reach according to the European commission directives are described:

- Reducing the consumption of energy, while increasing the usage of renewable resources. This requires considering energy efficiency from a more systematic point of view in the design phase of manufacturing equipment. Moreover, process monitoring and control can provide support for optimising the performance and resource consumption. Process monitoring should also support the consideration of resource efficiency in maintenance approaches;
- Reducing the consumption of water and other process resources. Reduction of resource consumption should not be limited to energy but also include water and any other material resource that does not end up in the final product, but instead ends up in the form of waste or low value added by product;
- Near to zero emissions, including noise and vibrations. Simulation and modelling methods and tools that consider resource consumption and emissions will have an impact both in the design and operational phase of manufacturing systems. It is important to use lifecycle analysis in order to avoid sub optimisation and to promote transparency;
- Optimising the exploitation of materials. Increasing the capability of manufacturing to process advanced or environment neutral materials that foresee materials recycling. The use of waste as a resource within the manufacturing process is to be considered here as well. Another aspect is the need for optimising the exploitation of manufacturing equipment at the end of life.
- Co-evolution of products-processes-production systems or ‘industrial symbiosis’ with minimum need of new resources. This involves engaging raw material suppliers and final transformation industries in developing new innovative combined processes which result in the elimination of overlapped manufacturing stages.

In order to have a qualitative measure of the sustainability in manufacturing industry, lifecycle approaches can be adopted. They allow quantifying product, service or process impacts and providing tangible commercial values in terms of efficiency and costs [Jeswiet, 2003]. They are based on the definition of several indicators to assess the lifecycle performances and support comparative analyses. Some techniques to support this described lifecycle approach are the LifeCycle Assessment (LCA) [ISO 14040:2006], in order to evaluate the environmental impacts, and the LifeCycle Cost Assessment (LCCA), in order to recognize all the economic impact during the product lifecycle. Recently, also the social impacts have been included in the lifecycle design approach by the so-called Social LifeCycle Assessment (SLCA).

The key technologies and enablers of the Factories of the Future to reach the sustainability are described below.

1. Advanced manufacturing processes. The efficiency and sustainability of the manufacturing is very much determined by the processes involved. Innovative products and advanced materials are emerging but are not yet developing to their full advantage since robust manufacturing methods to deliver these products and materials are not developed for large scale.
2. Mechatronics for advanced manufacturing systems. Manufacturing systems include machines, modules and components that integrate mechanics, materials processing technologies, electronics, and computing capabilities (ICT technologies) to perform desired tasks according to expectations. Mechatronic systems do not only interface with materials, parts and products, they also cooperate safely with factory workers and communicate with other systems in the factory. Also they connect to manufacturing execution and monitoring systems on a higher factory and management level. Hence manufacturing systems are becoming smarter in order to generate high value while consuming less energy and generating less waste. The needs for re-configurability and the

ability to produce smaller lot sizes of personalised products require not only smart mechatronics but also higher efficiency and effectiveness in the planning and engineering of such manufacturing systems. A major impact is expected above all in advanced machine interaction with humans, allowed by ICT infrastructures.

3. Information and communication technologies (ICT), which support a constant feedback loop without media breaks between product designers, engineers, state of the art production facilities and customers, creating a collaborative supply network. Remote service management helps to improve equipment uptime, reduce costs for servicing, increase service efficiency and accelerate innovation processes. The customer collaboration is very important and the gathering of customer and after sales information (such as the social networks) allow developing personalised and customised products. Connectivity is inherent to the development of the future workplace.
4. Manufacturing strategies are required for generating new approaches to operate supply chains and address markets. The most relevant ones are:
   - From delocalisation to Globalisation. This requires fostering the interaction between large enterprises and SMEs (Small-Medium Enterprises).
   - From product/services systems (product centred approach) to services through product (solution oriented approach). In such a context, there is a strong need to create distributed, adaptive and interoperable virtual enterprise environments supporting these ongoing processes. In order to do so, new tools must be provided for enabling and fostering the dynamic composition of enterprise networks. In particular, SMEs require tools and instruments which follow them in their continuously reshaping process, enabling collaboration and communication among the different actors of the product service value chains.

- From user centred design to user well-being design, according to the new paradigm of sustainability. The user is at the same time a customer, a citizen and a worker. The well-being of the user could therefore become a winning strategy both for business to business (B2B) as well as business to consumer (B2C) companies.
- Virtualisation and digitalisation of the interrelation between manufacturing and new business models. As products are today virtually designed and tested before being engineered for production, new business models need also to have tools to support the company to design and test them before they are implemented through products, services and manufacturing processes.

5. Modelling, simulation and forecasting methods and tools. Advances in ICT in terms of computing power, communication speed or multi modal visualisation are moreover enabling the further development of simulation and forecasting tools.
6. Knowledge workers. Future factory workers are therefore key resources for industrial competitiveness as well as important consumers. This includes the following important aspects of the human resources:

- New technology based approaches to accommodate age related limitations, through ICT and automation;
- New technical, educational, and organisational ways to increase the attractiveness of factory work;
- New approaches to skill and competence development, as well as skill and knowledge management, to increase competitiveness and be part of the global knowledge society;
- New ways to organise and compensate factory knowledge workers;
- New factory human centred work environments based on safety and comfort.

As saw in the lines above, manufacturing changes in Europe toward the creation of Factory of the Future is a priority both by political and economic level. Indeed, nation's economic prosperity is tied to the robustness of its manufacturing sector. Currently, one of the mean to generate and produce value in manufacturing is increasing the customisation of physical products, so that they could better meet the requirements of markets and the related customers' needs. In this context, one of the most promising innovation model is commonly perceived by most of the analysts as Servitization of manufacturing, which implies to equip the product with an ICT infrastructure able to deliver several services, until to make a new value proposition where the core business is not the product but the service propose on the market. From a business perspective, the so-called "SMILE" challenge (Figure 1) evidences the increasing relevance of manufacturing services in the European economy and the strong need for a holistic approach to joint product-service lifecycle engineering.

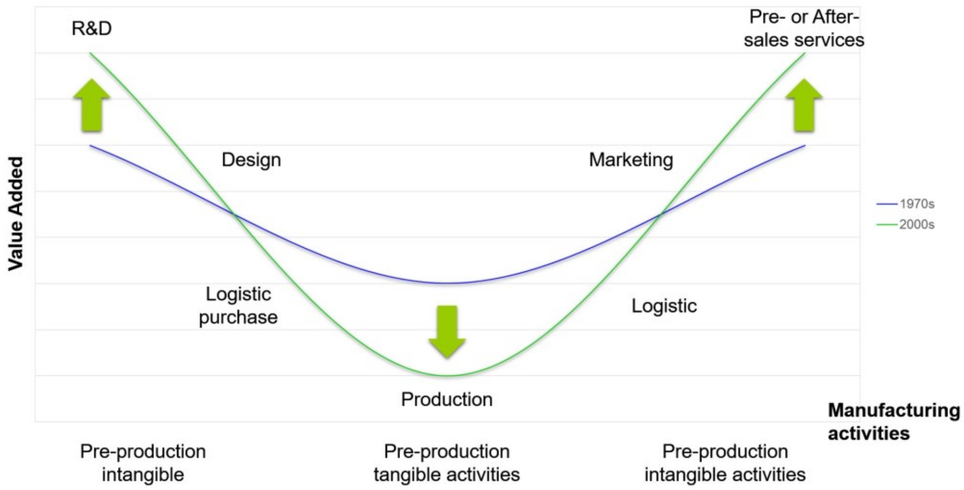


Figure 1. *Change of value creation in European Manufacturing companies*

1.2. Technical and Scientific research objectives

According to the discussion about the technologies able to reach sustainability of innovative solutions in Europe for manufacturing companies, the present thesis focuses on one particular manufacturing strategy, which is the adoption of product-services systems in manufacturing, providing new service functionalities on existing products. Generally, this approach aims to innovate products that are in the maturity phase of their lifecycles, and create new business opportunity for those products (Figure 2).

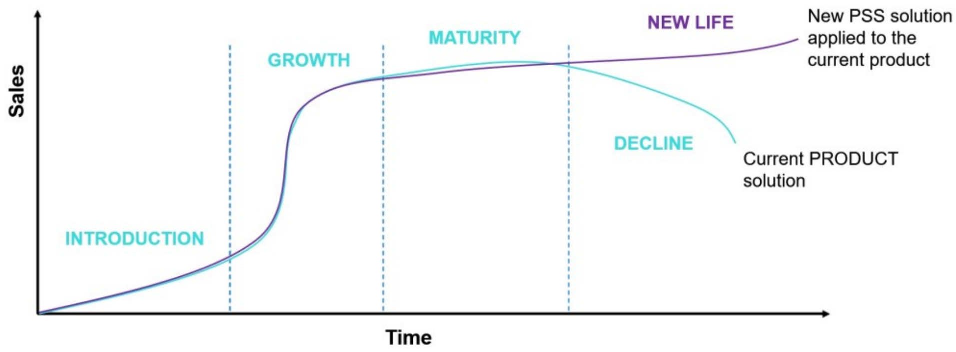


Figure 2. *Product lifecycle trend*

For example, the implementation of product-services system strategy can facilitate the development of circular economies that are able to create a close-loop along the product lifecycle. This behaviour foster also the application of sustainability principles described above.

Actually, along the last twenty years, the industrial trend consisting of adding services to the physical product in order to create an added value for customers [Thoben et al., 2001; Manzini and Vezzoli, 2002] has concretised, until to see Product Service System (PSS) as a mean to extend the current product lifecycle and therefore, to enhance the company market share. According to this vision, PSS represents a new challenge for manufacturing companies that would compete in a global market, but they should be able to extend their products, offering new usage experiences to the customers or even more, with the aim to sell not the ownership of the products but their usage. Indeed, for modern companies, offering product-service solution represents a widespread tendency to add value to existing products, create a new value proposition with low effort for the producing company, and better satisfy the market needs [Goedkoop et al., 1999]. Such a trend is becoming a real opportunity for manufacturing industry with the coming of pervasive Information and Communication Technologies (ICT) and Internet of Things (IoT) technologies.

However, designing PSSs represents a new challenge for manufacturing companies, because they are involved in the design of no more single products, but a set of integrated and complex systems, providing functions by combining physical devices and intangible assets as well as specific software tools and a proper supporting infrastructure. Indeed, currently the design process is still structured as for traditional products, where the design methodologies are mostly product-oriented, following the well-defined product design and development processes, even if recently several researchers have started to address also PSS design issue, proposing service-oriented approaches able to support the industrial companies, adding value to their products, developing the ad-hoc service functionalities according to customer needs. Therefore, companies are pushed to move from a product-oriented to an innovative service-oriented scenario, when a new interpretation of the basic design concepts is adopted and design involves both product and services [Manzini and Vezzoli, 2002].

Anyway, creating PSSs entails two important changes in manufacturing processes. Firstly, traditional Product Lifecycle Management (PLM) has to be enhanced by including also the Service Lifecycle Management (SLM), entailing the adoption of a Product-Service Lifecycle Management (P-SLM). Indeed, the strong interconnection between the tangible (physical product) and the intangible (service system) assets imply that they cannot be managed as independent entities, because if some commonalities exist between the two lifecycles, the main differences must be harmonized. This can be done adopting for example two main approaches. One based on the Open Innovation paradigm, which allows the management of information involved in the Ideation phase, collecting and filtering contributions from different stakeholders. The other one, based on the creation of a virtual environment inside the company to support the Design phase, where the involvement of all the required actors with their specific competences and skills is the key successful factor. The second change in manufacturing companies is about the extension of the product-oriented company model to realize a service-oriented ecosystem [Peruzzini et al. 2012a]. Actually, it is necessary not only a multi-disciplinary cooperation inside the company, but also at a strategic level, involving in the production network all the partners and stakeholders able to guarantee the development, delivery, exploitation and decommission of the PSS solution. This approach leads to the creation of extended partners' network, which can be defined as Global Production Network (GPN) or Virtual Manufacturing Enterprise (VME), according to the referred context. This supports the interrelations between physical products and intangible services, which are complex to model and manage: they require creating relationships with different stakeholders working in an operational network of business partners able to share skills, competencies and resources in order to exploit business opportunities on the market. For these reasons, Product-Service Lifecycle Management (P-SLM) represents the new challenge for the manufacturing domain, and the PSS design process must be properly supported, starting by the analysis of customers that will be the final user of the services delivered.

Several methodologies to design a PSS are explained in literature [Ducq et al., 2014]. However, industrial sector is still far from the adoption of PSS management solutions inside the companies, due to a scarce research, development and improvement of the reference processes that support all the PSS design phases. In fact, above all the early stages of lifecycle, such as PSS Ideation and PSS Design, are complex and multifaceted, requiring multiple competences and cross-functions cooperation within the manufacturing company. They manage a great amount of information that needs to be analysed and elaborated, in order to define the new PSS proposal and which requires multiple competences and cross-functions cooperation both within the manufacturing company and among the enterprises involves in the extended network. Moreover, the strong interconnection between product and service along the PSS design process implies that they cannot be managed as independent entities, adopting Product Lifecycle Management (PLM) and Service Lifecycle Management (SLM) approaches separately. Therefore, any tool or application that monitors the evolution and the change of PSS offer, must provide a holistic approach able to manage their concurrent evolution.

According to those issues, the present thesis would propose an innovative approach to support the design of Product-Service Systems in order to extend the current product lifecycle and apply the sustainability concept. In this way, new business models can be generated and defined, already during the PSS design phase. The approach proposed combines several methodologies already exist in literature into a unique and integrated flow able to support the collection and management of information on Product and relative Services along the PSS design process. Actually, such the innovative methodology goes from the early PSS lifecycle stages (Ideation and Design) until the definition of the production network, the business model and the assessment of correlative sustainability.

This innovative methodology provides a strongly user-centered approach during the early stages, to guarantee the satisfaction of the customer needs and the involvement of the most proper partners into the design process. At the same time, each methodology step is also business-centered since business modeling runs in parallel to traditional design activities and effectively supports feasibility analysis and comparison among alternative use scenarios.

Moreover, a set of web-applications developed along a European project are customized and then adopted for collecting and combining crowd and company knowledge in order to design and develop innovative PSSs.

1.3. Research questions

This research thesis has the aim to investigate the Product Service System engineering for supporting manufacturing companies to approach the Servitization process in order to extend and innovate their current business proposal.

According to this purpose, such the thesis investigates several research areas around the PSS topic, such as:

- *PSS concept and definition*, in order to contextualize the topic and the research field by a theoretical point of view. Thus, the main definitions and concepts needed to conduct the PSS engineering are defined in deep;
- the *main technologies* able to implement a PSS. In this context, the ICT and IoT technologies have been faced in order to understand how they can foster the PSS engineering and exploitation;
- the *product and service engineering* in terms of lifecycle management. In this context, the PLM and SLM have been studied in deep in order to investigate the main correlations along the lifecycles;
- the *business model* to adopt, because engineering a PSS instead a product involves a change for example in value proposition, activities, suppliers, customer relationship, which means a change compared to the current product business model;
- *Tools & Methods in PSS Engineering*, in order to analyse the current literature about the tools used to design a PSS or to support the

Servitization process in manufacturing. Involved in this research area there is also the study about Requirements Engineering because it is the main aspect when the design change from a product-oriented perspective to a user-centred ones;

- the *Sustainability aspects* coming from the adoption of PSS solutions, in order to understand how the business model changing is able to influence the Sustainability;
- *KPIs* for measuring the PSS impacts, in order to analyse what are the main rules to measure the PSS benefits for manufacturing companies during the Servitization process adoption.

According to these research areas, the following chapter (Chapter 2) faces each of them, showing a detailed literature analysis. The results of this literature review have allowed defining a methodological approach able to joint product and service lifecycles engineering. Such the approach tries to answer to the following research questions that are the foundation of this research thesis:

a. what are the main links between Product Lifecycle Management (PLM) and Service Lifecycle Management (SLM) during product and service engineering?
b. if in PSS engineering the tangible asset is represented by the product, how is it possible identify and thus design the intangible assets?
c. how ICT and IoT technologies are involved in PSS engineering?
d. how change the business model from product proposal to PSS value proposition? What are the main affected areas in the new business model?
e. how to support manufacturing companies in the approaching of Servitization process? What are the main challenges?

In order to address these research questions, the following chapters deals both the literature review derived from them and the proposed methodological approach with its main results, as summarised in the following.

1.4. Thesis general overview

This thesis is structured as in the following:

Chapter 2. Product-Service System: Literature point of view

Chapter 3. PSS main Issues & Challenges

Chapter 4. European platforms and tools for supporting Product-Service Systems

Chapter 5. Methodological approach to Design a Product-Service System

Chapter 6. PSS Design Method applied in Household appliance sector

Chapter 7. PSS Design Method exploitation discussion

Chapter 8. Future works & improvements

Chapters 2 analyses the State of the Art about PSS from different point of view, which respectively are the Academia and Industry viewpoint, and the existed methods and tools that are able to address at least one of the PSS lifecycle phases.

According to this analysis, Chapter 3 identify the main issues and challenges to face talking about PSS, which some European platforms described in Chapter 4 are able to answer for some aspects. At the same time, Chapter 5 proposes and describes in deep the new methodology approach resulted from this research thesis, which addresses others of the challenges identified in the previous chapter.

Chapter 6 gathers the description of the methodology application in a specific sector (white goods) and the main results derived, which are described and discussed in Chapter 7. Finally, Chapter 8 gives an overview about the future works that can be faced thanks to the results of this research thesis, and what are the main methodology improvements to implement in an industrial application.

Chapter 2. Product-Service System: Literature point of view

2.1. Product-Service System Concept and Definition

The concept of Product Service System (PSS) appears in a research publication at the end of ’90 years, in the Journal of Cleaner Production. The authors were Goedkoop et al. (1999) and they proposed a report about the sustainability, where PSS has been defined as “a marketable set of products and services capable of jointly fulfilling a user‘s needs”. This work can be considered a milestone in PSS literature, since it provided a clear evidence of a spreading trend in different industrial sectors. Furthermore, the authors also defined the PSS characterizing elements, which are:

- Product, that represents the tangible commodity manufactured to be sold and capable of fulfilling the users’ needs;
- Service, that is the “activity” delivered to generate an economic value by its exploitation and often done on a commercial basis;
- System, that contributes to realise the collection of the two elements after defined, including their relations.

After this first characterization of the PSS concept, in literature, several authors along the time have faced this innovative way to join the product and service offers. Some of them were mostly interesting in the definition of the PSS by its main components [Goedkoop et al. 1999, Mont 2004a], others in the identification of PSS typology according to what it is able to deliver to customers [Tukker 2004, Baines et al. 2007, Alix and Zacharewicz 2012]. Many others faced the definition of the concept of extended product [Thoben et al. 2001, Manzini and Vezzoli 2003, Brady et al. 2005, Wiesner et al. 2014a], while other ones investigated PSS as a mean to improve the sustainability [Brandstotter et al. 2003, Baines et al. 2007].

Finally, some research studies focused also in the models to integrate products and services in order to reach customers' needs [Mont 2002, Brandstotter et al. 2003, Aurich et al. 2010].

However, in literature PSS concepts and relative definitions are mainly centred on the keywords of integrated bundle of products and services, and concerns directly the customer, aiming at the achievement of sustainability [Baines et al. 2009]. This first literature review on PSS proves that even if several terms used to identify the integration between product and service exist (e.g. extended products, technical services, product-service systems (PSSs)), they represent the same concept: a mix of tangible products and intangible services designed and combined to increase the value for customers [Furrer 2007]. According to that, the value creations is realized through the extension of the current business network, involving different stakeholders having the knowledge and skills required to design, develop and deliver the new PSS offer.

The shift of both Industry and Academia towards an integrated offer of products and services starts from the idea of the Extended Product, where intangible services are integrated into a core product to add value for customers and improve company's profits and competitiveness. Moreover, such concept is illustrated by the Servitization process. Vandermerwe and Rada introduced a formal definition of Servitization. They referred not directly to the concept of PSS (which was not born yet, but it may be a consequence of this definition), but to several models specifically designed for those enterprises that would create a new value for their products, and having as a result the increase of their profitability and market shares [Vandermerwe and Rada 1988].

Some years later, this concept was conceptualised in a transition paradigm represented along a linear axis like four different steps. In particular, the common idea is moving from the traditional customer experience (i.e. consumers buying products) to a new customer experience (i.e. consumers buying solutions and benefits in respect to their needs). Figure 3 below shows the Servitization process as conceived by Thoben et al. (2001) and it involves the following four steps: 1) tangible product, 2) product and supporting services, 3) product and differentiating services, 4) product as a service. Steps 2 and 3 are defined also as Product+Service, and they mean the selling of product plus several services; while the fourth step Product2Service refers to selling only the service [Hippel 2005]. According to this view, PSS is defined like a combination and integration of product and services into a system to deliver required functionalities in order to satisfy the customer needs [Aurich et al. 2010] and it is able to produce synergies among profit, competitiveness, and environmental benefit.

The so defined PSS is composed by four main elements: the product, the related services, the ICT infrastructure required, and the partners' network to involve [Mont 2004a].

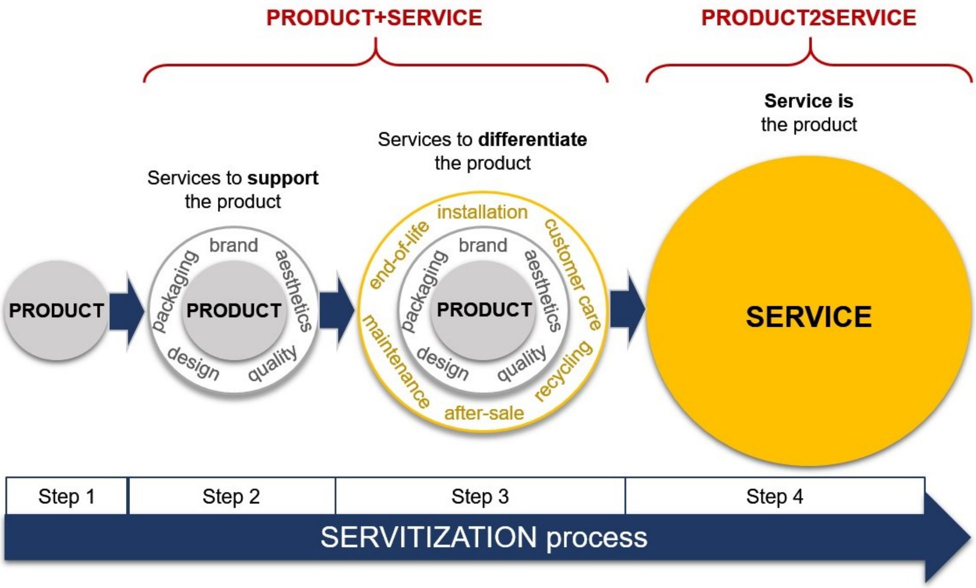


Figure 3. *Servitization process - adapted from Thoben et al. (2001)*

In recent years, clear evidence shows that service plays an increasingly important role in many manufacturing industries, especially in the companies that produce complex products. The concept of servitization drives the strategy transformation of manufacturers in high-value-manufacturing. As an immediate consequence, most of them have moved from selling products to delivering product-service systems. Indeed, the Servitization process is a fundamental mean for manufacturing companies that would find new business opportunities and involve new customer segments, increasing their market share [Spohrer and Maglio 2010, Weisner et al. 2014a]. Anyway, such the process not affects only the company business model, but also the whole enterprise, in terms of those internal processes and standard procedures that support the design, development and delivery of the new value proposition.

As reflected in previous definitions, PSS is a business mean that allows manufacturing companies creating a new value for those products become mature. Indeed, in the market, several mature products exist (e.g. household appliances, phones, cars, etc.); they represent products that, after a period of introduction into the market and the consequent growth in term of sales and market shares, are becoming old for technology, aesthetics or so on. For such the products, it is required to create a new business value, in order to extend and reinvent their lifecycle trend. The application of PSS concept to those products is a way to improve their business value and extend their lifecycle (see Figure 2).

In literature, several typologies of PSS have been defined from different authors. They aim to describe different options of product-service offer within a certain company or for a particular manufacturer. Moreover, they always identify the different kind of Business Model to implement. For example, Wise and Baumgartner (1999) identified four types of PSSs: those have embedded services, comprehensive services, integrated solutions and distribution control. This classification is very useful about the description of the service content but the authors not consider the relative product ownership. Instead, the concept of product ownership is one of the topics faced by Michelini and Razzoli (2004), which distinguish different provision forms: provision of tangibles with included lifecycle services, provision of tangibles under leasing arrangements, provision of shared products and function delivery. Roy (2000) proposed a categorization consisting of four types of PSS:

- Result services, where the service provider is responsible of all physical aspects of the system, providing a 'result' instead of a product;
- Shared utilization services, consist of sharing products among different users or a community of users in order to increase their utilization rate;
- Product-life extension services, where the service provider is responsible of the maintenance, repair, reuse and recycling activities related to products to increase their useful life;
- Demand side management (or integrated resource management), which was originated in the field of energy supply in US as an evolution of the idea that it was often more economical to reduce energy demand than build more generating capacity.

Mont (2002) stated that a PSS comprises products, services or their combinations and classified the services which forming a PSS from the product lifecycle perspective:

- Services at the point of sale;
- Services related to product use;
- Services prolonging product life cycle;
- Revalorization services, which refer to products end-of-life and consisting of reverse logistics, reuse or recycling of products or their parts.

Oliva and Kallenberg (2003) proposed the service space where different types of services can be considered according to two main drivers: whether the services are related to a product or to end user's process, and whether the service is based on transactions or on relationships.

Even if other authors proposed different examples, the Tukker PSS classification is the most widely accepted by Academia. Such the classification identifies the following three PSS models [Tukker 2004]:

- Product-oriented PSS. The physical product is sold to the customer in a combination with services such as maintenance, recycling and customer trainings, which guarantee the functionality and a long use-cycle. Main aspects in the development of this PSS type are the creation of a durable product to minimize service costs and optimize the product end-of-life through recycling and reusable parts.
- Use-oriented PSS. In this case the product is not owned by the customer anymore but is made available (e.g. through leasing) for customer-usage through the producer. High rates of usage as well as a long lifecycle of their products are the main goals for companies offering these product-service-systems.
- Result-oriented PSS. This is the most complex type of a PSS, selling a desired result in place of a product (e.g. the offering of washed clothes instead of selling washing machines). The ownership as well as the decision of technology, maintenance, disposal etc. stays with the producer. Thus, the development of this PSS has to focus on the changed business model for which the consumer only pays per obtained output.

Firms can move from one type of PSS offering to another by changing the relative share of product and service components according to user requirements. Figure 4 shows such the classification and how the author, according to the product and service concepts, conceives it.

Often, researchers used the Tukker's classification refining it and adding further elements in order to describe what should be the kind of business cooperation between customers and suppliers [Azarenko et al. 2009, Cook et al. 2006, Tukker and Tischner 2006b, Copani et al. 2010, Azevedo and Ribeiro 2013, Barquet et al. 2013]. Nevertheless, the Tukker's classification about PSS is not able to capture the complexity of PSS model itself; for this reason, these categories may be explored more in deep to facilitate the most appropriate categorization for manufacturing companies that should apply such theoretical models in practice.

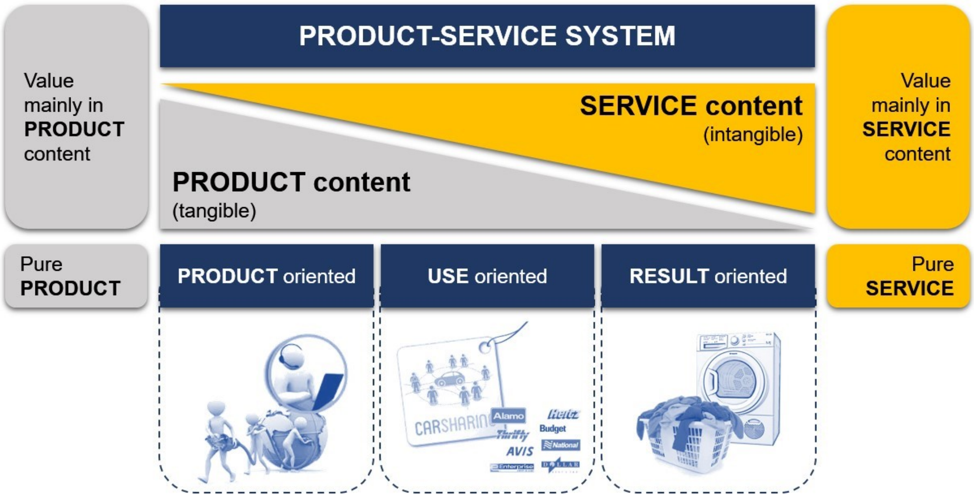


Figure 4. *Classification of PSS - adapted from Tukker (2004)*

According to this aim, Adrodegari et al. (2015) has proposed a new PSS classification according to the Tukker's model, where five PSS configurations are identified in two different groups:

- *Ownership-oriented* (Group A): the focus of this group is that the product sales are the main source of revenue and the services are sold as an add-on to the product, through a transactional (e.g. technical assistance without any contractual agreement) or relational approach (e.g. maintenance contracts). Inside such group, two main configurations are highlighted by the authors:

- Product-focused: the provider sells the product and separately it guarantee payment services during the product use phase (e.g. break-fix repair, maintenance contract, etc.). Companies have traditional ‘tangible’ production costs and the revenue is mainly generated from the product sale;
- Product and processes focused: the company offers services, both in the pre- and after-sale phases in order to optimize and increase efficiency and effectiveness of customer’s operations. Anyway, the main revenue stream still consists of product sales: in the product price is often included a pre-sales service component.

▪ *Service-oriented* (Group B): the focus of this group is the service, strictly linked to the usage of a product, which represent the main source of revenue. Indeed, in his category the ownership of the product is not transferred to the customer.
  - Access-focused PSS: customer does not buy the product but pays a fixed regular fee to gain access to it. The fee is not related only to the product usage but includes the guaranteed additional services. The company usually keeps the product property rights and has the responsibility for its utilization during a given period of time;
  - Use-focused: customer does not buy the product but pays a variable fee that depends on the usage of the product (pay- per-usage time, pay-per-usage unit). The manufacturing company is responsible for all life cycle costs, stimulating the company itself to optimize the product costs. Customers are focused on the value-in-use, rather than on the value- in-exchange. For this reason, the company should be able to predict the customer behaviour, since otherwise no clear cost calculation can be made. Such configuration allows defining a new revenue model, where the focus is the definition of new selling

parameters driven by customer perceived value instead of internal cost. The payback period of the value delivered is often longer than the payback period of traditional product sales.

- Outcome-focused business PSS: customer does not buy the product but pays a fee that depends on the achievement of a contractually set result in terms of product performance or outcome of its usage. Here the value for the customer is generated by the reduction of initial investment, the minimization of operational costs and risks to achieve an expected outcome with the product usage. An outcome-based contract could be contracted on a fixed payment basis tied to performance measures.

At the same time, Benedetti et al. (2015) proposed an alternative Energy Services' classification proposal based on the definition of three different dimensions:

- "intangibility", which basically corresponds to Tukker's PSS classification;
- "scope" as defined in Sorrell's classification (Sorrell 2007);
- "risk" accepted by both the client and the service provider.

Table 1 contains the main PSS classification defined in literature by several authors that have faced such the concept.

The results of this first literature analysis about PSS concept proved that it is a new emerging trend for manufacturing companies, where the focus is proposing a solution and selling no more a product (based on its ownership), but rather selling its usage (e.g. renting, pay-x-use, etc.) and performances (e.g. pay-x-performance). This phenomenon concerns the evolution from a traditional product-centred business model to a new service-oriented ones. According to this trend, several authors have conceptualized the shift from products to PSS through various concepts: "servitization" (Baines et al. 2009), "transition from products to services" (Oliva and Kallenberg 2003), "going downstream in the value chain" (Wise and Baumgartner 1999), "product-service systems" (Tukker 2004), "moving towards high-value solutions, integrated solutions and system integration" [Davies 2004, Windahl and Lakemond 2010], "manufacturing/service integration" [Schmenner 2009] and "service infusion in manufacturing" [Kowalkowski et al. 2011, Gustafsson et al. 2010, Ostrom et al. 2012]. All these authors converge into the concept of solutions defined as innovative combinations of products and services leading to high-value and unified responses to customers' needs.

Table 1. *PSS classifications in literature*

Reference	*PSS categories in literature*			
Tukker 2004	*Product-oriented*	*Use-oriented*	*Result-oriented*	
Adrodegari et al. 2015	*Ownership-oriented*	*Service-oriented*		
Benedetti et al. 2015	*"intangibility" (Tukker's categories)*	*"scope" (Sorrell's classes)*	*"risk" (from client and service provider)*	
Wise and Baumgartner 1999	*PSS through embedded services*	*PSS through comprehensive services*	*PSS through integrated solutions*	*PSS through distribution control*
Michelini and Razzoli 2004	*Provision of tangibles, included life cycle services*	*Provision of tangibles by leasing arrangements*	*Provision of shared products and function delivery*	
Roy 2000	*Result services*	*Shared utilization services*	*Product-life extension services*	*Demand side management*
Mont 2002	*Services at the point of sale*	*Services related to product use*	*Services prolonging product life cycle*	*Re-valorisation services*
Oliva and Kallenberg 2003	*Services related to a product or end user's process*	*Service is based on transactions or on relationships*		

2.2. ICT & IoT

The opportunity to develop PSS in order to move manufacturing companies towards the factories of the future is born with the arising and more diffusion of ICT technologies and IoT approached.

Indeed, the recent advances in Information and Communications Technologies (ICT) could give also to manufacturing industries the competences required to develop sustainable PSS. Indeed, recent studies demonstrated that ICT could validly support sustainable business by the development of smart products, improved stakeholder's communication, dematerialization, increased social inclusiveness, and consumer empowerment [Hernández Pardo et al. 2012]. However, despite the potential of ICT in developing sustainable PSS, little is known about how such technologies should be integrated into products to create a sustainable PSS and which opportunities can arise.

At the same, Internet of Things (IoT) is considered by the research community the paradigm with the highest economic impact [McKinsey Global Institute 2013] on PSS development. This technology is wide used by several manufacturing companies that approach the transition from product-centred production to the creation of a new value proposition through the development of PSSs. However, these companies need to investigate their current processes and technologies to create a collaborative environment, both internal and external to themselves.

Some manufacturing companies, approaching the IoT paradigms, have faced the Open Innovation model. In fact, it focuses on the idea and discussion about the use of both inflows and outflows of knowledge to improve internal innovation and expand the markets for external exploitation of innovation [Hartmann and Trott 2015, Cheng and Huizingh 2014]. Indeed, this paradigm assumes that firms can and should use external ideas as well as internal ones, internal and external paths to market, as the firms look to advance their technology [Chesbrough 2003]. This means that industrial company should innovate with external partners by sharing both risk and reward. Thus, the boundaries between a firm and its environment have become more permeable and innovations can easily transfer inward and outward. According to this trend, also the knowledge management acquires a key role in the development of a PSS.

2.3. Product Lifecycle Management (PLM) & Service Lifecycle Management (SLM)

According to the innovative trend to approach the PSS, a change in the development process thought manufacturing companies was realized. Indeed, the innovation concept has moved from the manufacturers' needs, complying the production costs and constrains, to the users' satisfaction. For a long time, the producers were considered to be the main beneficiaries of innovation and their motivation to innovate is driven by monetary profit expectations from selling products and services. Within the last decades, users were becoming an important complementary source of innovation, and their motivation to innovate is driven by their own needs and expected benefits from using the innovation themselves rather than monetary profit expectations. Moreover, also the sustainability aim is one of the drivers. In this context, the PSS has raised, addressing both the aims of manufacturers and users.

In this novel vision in manufacturing, the product development process must be revised according to the lifecycle thinking, in order to support not only the product manufacturing, use and end-of-life, but also the relative service that it is able to provide. Thus, Product Lifecycle Management (PLM) and Service Lifecycle Management (SLM) must be combined together. Currently Service development might not be identified as similar to Product development, due to the differences concerning product and service lifecycles. Therefore, the link between product and service activities is possible through the application of lifecycle management approach. Stark defines lifecycle of an offer (tangible or intangible offer), as following: Imagine, Define, Realize, Support/Service, Retire [Stark 2011], but it does not show up the interactions between PLM and SLM. For this reason, it is worth to analyse both PLM and SLM separately, in order to understand what the main intersections should exist to develop a PSS.

Product Lifecycle Management is defined in literature as a holistic approach to manage the product information along its lifecycle [Saaksvuori and Immonen 2008], supported by Product Data Management (PDM) applications, which focus on designing and engineering data [Eynard et al. 2006]. Moreover, PLM is able to exploit the interoperability with other informatics systems of an industrial company to manage the product information. Indeed, the final aim of a PLM is managing information in an integrated manner into a digital chain [Le Duigou et al. 2011, Bricogne et al. 2011]. Usually, PLM covers the whole lifecycle of a product, from the first idea and concept to its recycling and disposal. The majority lifecycle models disseminated in literature are based on three main lifecycle phases, shown in Figure 5: Beginning of Life (BoL), Middle of Life (MoL), End of Life (EoL).

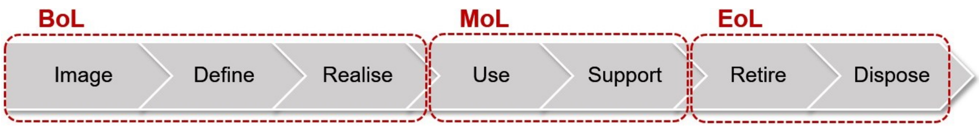


Figure 5. *PLM lifecycle phases according to Stark 2011*

The Service Lifecycle Management is involved in the Service Science, Management and Engineering (SSME) [Spohrer and Maglio 2010], which is a young research field that addresses the open questions and challenges coming from the servitization process. Indeed, service lifecycle concern appears in the literature often correlated to PLM. SLM aims to create a link between Management and Engineering. Despite this topic is quite new and innovative in literature, some approaches are arising to manage also the service information. According to Freitag et al. (2013), the SLM framework consists of four parts:

- Phases of Service Life Cycle Management;
- Role Model for Service Life Cycle Management;
- Methods and Tools for Service Life Cycle Management;
- Interactions between product and Service Life Cycle Management.

Anyway, the main model to compare PLM and SLM involves three Service lifecycle phases, as shown in Figure 6 [Wiesner et al. 2014b]:

- Service ideation;
- Service engineering, which involves service requirements, service design, service implementation and service testing;
- Service operations management, where the first task is to acquire customers. After this, the service needs to be delivered to the customers.

Figure 6. *SLM lifecycle phases according to Wiesner et al. 2014b*

In Figure 7 both PLM and SLM lifecycle phases are identified and displayed according to the most widespread idea that considers services and their lifecycles as aligned to the product, in order to be assessed and designed together.

Nevertheless, currently, with the increasing interest in PSS approaches and methodologies, there is the need to have a strong interaction between PLM and SLM, in a systematic way and in both the directions. In Figure 7, the detail per each PLM and SLM phase is represented in different colours: white, grey and yellow. White characterises the phases that are common for product and service, while grey and yellow respectively identify product and service phases.

In order to identify the interactions between PLM and SLM, different models have been developed by researchers. Mahut et al. (2015), starting from the definition given by Stark (2011), proposed two categories to identify the possible interconnections between product and services:

- Major links, which represent the substantial link between product and service activities. It reveals the necessity to construct products and services in a very strong collaboration;

- Minor links, which are necessary but not predominant interactions (they can identify a purpose).

Such the approach does not assume how PLM and SLM should be managed and what is the typology of their interconnection. Indeed, in literature four alternative typologies exist and have formalised [Wiesner et al. 2015]. Figure 8 shows them, which represent the possible kind of interactions between Product and Service Lifecycle Management. This analysis has borne inside the development of a European project, namely Manufacturing SErvice Ecosystem (MSEE), which had the scope to design and develop several tools able to support product-oriented manufacturing companies to design a new PSS.

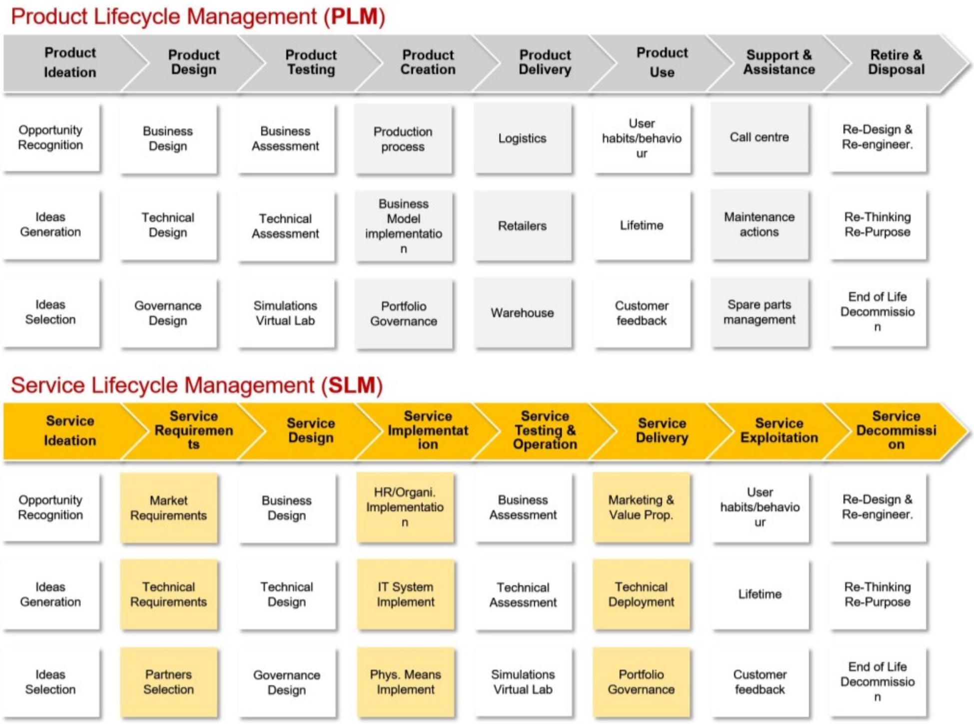


Figure 7. *PLM and SLM lifecycle phases*

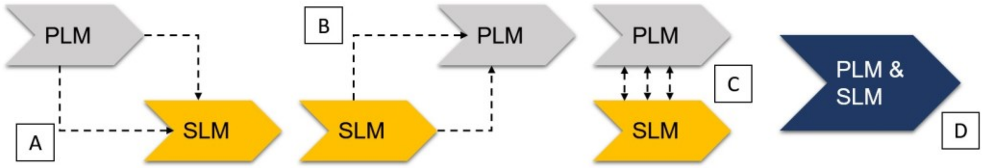


Figure 8. PLM and SLM interactions by MSEE European project

According to Figure 8, the possible configuration of PLM and SLM are defined in the following:

A. Direct interconnection, which is the most common situation in the manufacturing industry, where SLM is triggered by PLM and depends on it. The management of the service lifecycle is driven by changes of the PLM;
B. Indirect interconnection, which is completely opposite than the previous one, and PLM depends on SLM (the management of the product lifecycle is driven by SLM).
C. Parallel interconnection, where product and service lifecycle are managed at the same time. Mostly, the product and the according service lifecycle are the same length but the interactions take part only if they are necessary;
D. Coordination, where both lifecycles are managed in a highly integrative way and the managerial boundaries between PLM and SLM disappear. Decisions always have influence on both components of the integrated life cycle, until the highest degree of integration is reached, where products and services do not looked at separately anymore but treated as integrated PSS. This interconnection is the best desirable, thinking to a PSS offer.

According to this literature analysis, the need to define a model to manage the product and service lifecycles together emerges. Actually, Peruzzini et al. (2014a) proposed a first example of Product-Service Lifecycle Management, which is able to unify product and services under one common approach, managing Product and Service Lifecycles concurrently, and allowing also an effective collaboration of product and service actors. It provides both services information management through a service-centred approach (i.e. SLM), and product information management through a product-centred approach (i.e. PLM). At the same time, this model allows having a strong interaction between the two main entities (product and service) in both the directions. Indeed, its final scope is to provide and share to product and service stakeholders all the information required. Anyway, the management of products and services activities requires a transversal collaboration among partners that should be supported by a collaborative framework.

Figure 9 shows the comparison between the different PLM, SLM and P-SLM models proposed in literature.

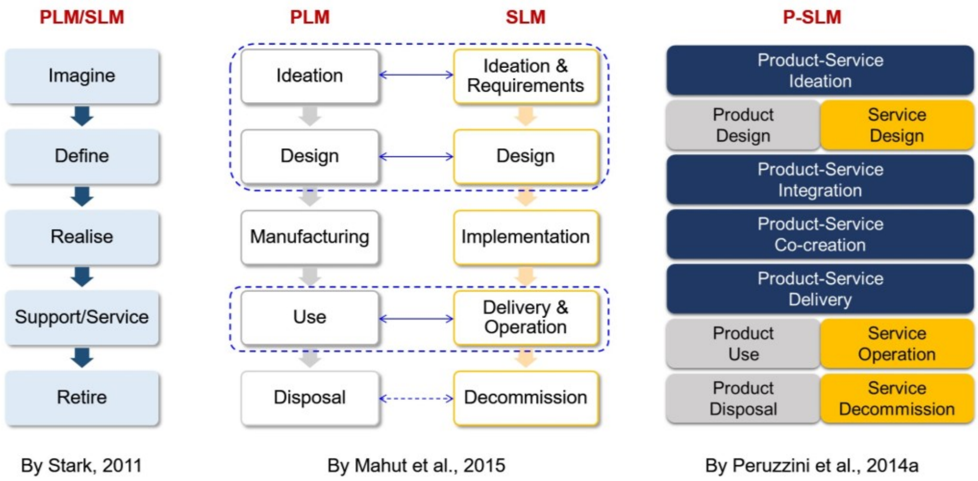


Figure 9. *PLM, SLM and P-SLM concepts*

Defining a new approach as P-SLM to manage the integration of PLM and SLM in the aim of proposing a PSS instead of traditional product, a new challenge is to identify the methods and tools able to support each phase inside the P-SLM.

2.4. Product Service System: a new Business Model

The shift from providing only physical products to integrated solutions able to increase market share and customer satisfaction expands the company role in the value chain by seeking to innovate and design new products and services in order to not compete only on the basis of cost [Porter and Ketels 2003]. Indeed, PSS leads to a new business model definition that aims to sell not only goods, but also value added service propositions like training, system integration and consulting.

A Business Model (BM) describes the rationale of how an organization creates, delivers, and captures value [Osterwalder and Pigneur 2013]. According to this definition, BMs in manufacturing have focused on fabrication or assembly of more or less customized products, which generate a revenue from their sales. Therefore, required machines, materials and qualified personnel cause high fix costs, implying that supply chain organization and its efficiency have a high influence on competitiveness.

The PSS business model, instead of traditional products, changes the manufacturer's perspective about the costs and revenues arising during the PSS lifecycle. This issue represents a challenge for industrial companies and offers opportunities of investigation [Mont 2004b].

The development of a PSS necessarily requires the creation of a structured network of partners and stakeholders, able to exploit the necessary tangible and intangible assets and create valuable solutions to share among all partners [Wiesner et al. 2013a]. This means moving from the traditional concept of manufacturing enterprise to a new idea of Global Production Network (GPN), which represents an aggregation of several partners with different knowledge and capabilities, focused on the realization of a specific PSS value proposition. Moreover, the GPN implies the definition of a proper Business Model in order to recognize the strategic factors for each partner as well as the key resources and activities and mechanisms for risk and profit sharing to involve in the new PSS scenario to develop [Ghaziani and Ventresca 2005].

According to the aim of designing, configuring and developing a new PSS, business modelling techniques are the most appropriate to analyse the scenario to develop. They can be considered as conceptual tools able to support industrial companies to identify, understand, design, analyse, and change their current Business Models (BM) [Osterwalder et al. 2005]. In literature, several research studies identified the same method to develop a new BM for a PSS; which involves four main research steps [Barquet et al. 2013]:

- Identification of PSS characteristics and typology;
- Investigation of business model concepts;
- Development of the framework;
- Application of the developed framework by means of a case study.

In this context, the Business Model Canvas [Osterwalder and Pigneur 2013] is a well-defined concept that allows the company easily describing and configuring business models to create new strategic alternatives. Such the model consists of nine elements or business areas, which are:

1) *Value* proposition. It represents the offer proposed to customers (what the manufacturing company would offer to market);
2) *Customer segments*. It represent the groups of expected people or organizations to reach through the defined value proposition (who the manufacturing company would reach). For a successful BM, it is important to identify and address potential customer segments outside the current boundaries of the manufacturing industry;
3) *Channels*, which are the company's interfaces with its customers (how the manufacturing company reach its customers). Pure physical delivery of the product has to be extended with new channels for service provision;

4) *Customer relationships*, which represent the types of relationships the manufacturing company establishes and maintains with specific customer segments. The selling transaction has to be replaced by a permanent relationship to the customer to generate constant streams of value and information;
5) *Key resources*, which are the assets required to offer and deliver the value proposed. Additional human, financial, physical and intellectual resources are required. This includes competencies in service development, product-service integration and collaboration;
6) *Key activities*, those involved in offering and delivering the value proposed have to change from manufacturing to service provision and the creation and management of a suitable network of partners for each customer demand;
7) *Key partners* (i.e. network of suppliers and partners that support the business model execution) must be complemented by service providers and other stakeholders of the PSS. An ecosystem has to be created, in order to be able select the appropriate network partners for the realization of each value proposition;
8) *Revenue streams*, which represent the revenue that the manufacturing company is able to generate from each customer segment. Revenue then will not be generated by a one-time sale of a product, but it should be concentrated on generating a constant revenue stream through service or usage fees;
9) *Cost structure*, which represents the costs incurred when operating a business model. PSS are value driven. The focus should not primarily lie on reducing the costs for manufacturing the product, but to combine products and services in a way to deliver the largest possible value to the customer.

Those areas are shown in Figure 10 below.

This business model has been applied in several organizations widespread around the world (e.g. IBM, Deloitte, Ericsson, etc.) and it is adopted both by industrial companies to identify, design, analyse, and change their current business models, and by researchers, as an empirical analysis.

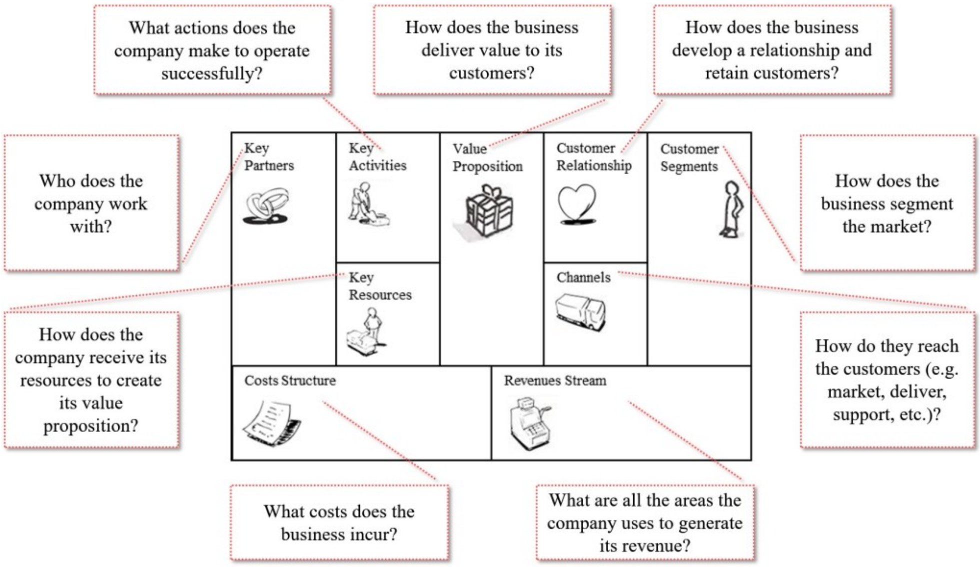


Figure 10. *Canvas Business Model adapted from Osterwalder and Pigneur (2013)*

The main challenge for manufacturing enterprises is to integrate the new and unknown value proposition of a PSS and the associated collaborative arrangements into their BM without experience in this field. Building networks with unconventional business partners is difficult and can bring incalculable risks [Gebauer et al. 2005]. New information and communication technologies (ICT) have to be used for service provision and to develop closer relationships to the customer. New stakeholders in the ecosystem affect the cost structure and require new kinds of revenue models, which are currently not elaborated in manufacturing industries.

Anyway, the Canvas model alone is not sufficient to understand the transition towards a more service-oriented business model. It is necessary to integrate this business approach together a technical approach able to design the value proposition. Indeed, the implementation of PSS BM requires disruptive changes in the existing organization. This includes the company structure, business processes and IT environment, as well as changing the mind-set from a product-centric to a more collaborative service-centric perspective. Thus, to overcome internal resistance to the implementation of a new PSS BM, a suitable change management approach is critical. It is necessary to analyse the changes required for the implementation of the new BM, define actions for servitization and collaboration and execute them in a structured process.

2.5. Product Service System Engineering

Engineering of PSS, in contrast to a centralized development process for simple products, requires the orchestration of distributed products, services and business processes for a common purpose. Therefore, organizational, technical and managerial interoperability is a prerequisite for the realization of the system.
In the following, the main PSS engineering issues will be faced and discussed in deep.

2.4.1. Tools & Methods in PSS Engineering

Usually manufacturing companies product-centred have well-defined and structured product development processes, but they lack a sufficiently in defining service development processes as found in traditional service companies. Therefore, they are poorly equipped with appropriate approaches, methodologies and tools for supporting in efficient way the design and thus the development of a PSS.
Despite in literature several methodologies have been proposed to drive the P-SLM along its lifecycle phases, some of them are very theoretical and hard to implement in practice, others are very specific and have a limited applicability range. These

main methods, which usually coming from the service design and engineering, are listed below.

- *Service Computer-Aided Design (CAD)*, able to support the decision-making evaluation through the concept design, prompting different alternatives scenarios. Moreover, the Integrating Service CAD with a lifecycle Simulation allows also a quantitative and probabilistic PSS designing [Komoto and Tomiyama 2008];
- *Software simulation tool* for designing service activity and products concurrently and in a collaborative way during the early phase of PSS design [Shimomura et al. 2009, Marilungo et al. 2016]. These tools enable also designers to predict service availability [Sakao et al. 2009];
- *UML (Unified Model Language) 2.0 model*, which allows conducting concurrently a systematic technical-services design and the corresponding product design process [Aurich et al. 2006];
- *Model-based approach* to allow Industrial PSS (IPSS) design modelling, fostering the functional behaviour of PSS artefacts [Welp et al. 2008];
- *Service Engineering* based on Structured Analysis and Design Technique (SADT) representations [Tomiyama 2005, Komoto and Tomiyama 2009, Sakao and Shimomura 2006, Sakao et al. 2009, Shimomura and Arai 2009]. It is able to provide technical specifications by fully describing the object-service system, considering the different combinations of the two main aspects of Total Care Products: architecture (hardware and service support system) and business (markets, risks, partnerships, business chains, agreements, sales and distribution);
- *Knowledge-sharing network* [Chirumalla et al. 2013];
- *Lifecycle oriented approaches* [Matzen et al. 2005, Matzen 2009, Tan 2010, Peruzzini at al. 2014b];
- *Layer-based Development Methodology* [Müller 2013];

- *Business Process Modeling (BPM) techniques*, which are the most appropriate to analyse the scenario to develop. In particular, Canvas model is based on the Business Model (BM) concept and it is one of the most used in manufacturing. It is based on building blocks and provides a more clear definition of company organization considering both product and services. Numerous techniques and tools exist but none of them is complete enough to model a complex PSS scenario. Thus, a combination of techniques is necessary to achieve a comprehensive analysis.

Requirement Elicitation (RE) is a crucial method within the Service Engineering approach to adopt during the design process of a PSS, in order to identify the main requirements according to the target market. Indeed, offering PSS instead traditional product requires additional competencies to identify the service functionalities to enhance the product, and a better understanding of the customer requirements to reach [Miller et al. 2002]. This implies a huge quantity of implicit knowledge to be elicited and a big variety of actors involved. As far as RE in PSS, recent studies proposed the following approaches:

- *Design Structure Matrix (DSM)*, which can be used to define the main PSS functions, combined with Business Use Case (BUC) analysis. The BUC defines the use-case model and a goal-oriented set of interactions between external actors and the involved system [Peruzzini et al. 2014c];
- *Serious Games*, able to elicit PSS requirements and investigate the PSS lifecycle [Wiesner et al. 2012];
- *Quality Functional Deployment (QFD) techniqu*e, which allows mapping the customer needs with the PSS functions in order to elicit the final PSS requirements for the solution to develop [Thompson 2005].

The combination of these techniques with a deep process analysis and related modelling allows achieving a comprehensive mapping of PSS tangible and intangible assets. Indeed, process analysis and modelling allow defining the main activities to achieve the process tasks, and identifying the enterprise's ability in capturing and sharing process knowledge and transferring it. The main common techniques for process modelling come from static models, focusing on the information flow (e.g. UML, Petri-Nets, flowcharting, IDEF0, etc.), till to dynamic models for process evaluation (i.e. Event-Process Chain). They are useful for process representation and performance evaluation, providing a high-technical view.

2.4.2. Roles in PSS Engineering

Pahl and Beitz (2007) defined a number of roles along the product lifecycle, from product origination to disposal or recycling. The following roles are relevant for the product engineering process:

- The Market/Customer delivers information about the requirements and constraints in order to generate and select product ideas and create a requirements specification. Furthermore, the customer is the direct user of the product and gives feedback about its perceived quality.
- The Product Planner defines the product portfolio of the manufacturer according to the information from the market and the available technology. The aim of the strategic product planning is the development contract, specified by requirements and justified by a promising business plan.
- The Product Designer is responsible for specifying the to-be product according to the customer requirements within the necessary documents for prototyping and production. This figure may also be responsible to create and review prototypes.
- The Production Planner allocates the necessary employees, materials and production capacity in order to realize the product portfolio created by the Product Planner and Designer.

- The Suppliers deliver the necessary materials, components and missing competencies to realize the product portfolio.
- The Product Development Team is representative from several of the roles defined above and deals with the coordination of the product development process. Therefore it is responsible for the project management for specific product lines and information exchange between the actors.

Moving to Service Engineering, additional actors for the service-lifecycle management must be necessary defined. They should address the following three roles:

- The Project Manager, which provides a regular communication with customers about Service Engineering results and monitors the project's economy about development efforts and added value for customer/revenues;
- The Project Team, which monitors the customer demands and can answer promptly and in flexible way to short-term changes on them;
- The Project Moderator, which controls the group members meeting and takes care of personal relations in an interdisciplinary team.

Therefore, it is possible to state that PSS Engineering process is characterized by the inclusion of various actors' competences during the development phases [Schweitzer et al. 2010]. During a PSS project, the involved actors are determined, development teams are established and assigned to several PSS specific roles that can be found in literature:

- The PSS Provider is the focal point of all involved stakeholders and is responsible for the whole PSS lifecycle. The tasks of the PSS provider include the coordination and execution of design, development and production of the product, as well as planning and development of complementary services [Müller et al. 2014];

- The Production Network comprises various PSS suppliers who are responsible for provision of materials, parts and components or system modules for the PSS Provider [Mont 2002];
- The Service Network contains distributors, subsidiaries and service partners, which are mainly material and service specialists. The main task of the Service Network represents is the PSS distribution, which includes the market-specific adaptation of the integrated service shares and the handling of client orders including the individual PSS configuration [Aurich et al. 2006];
- The Customer plays another key role next to the PSS Provider. Especially in the early stages of development, customer is considered as the initiating part, because demands towards the PSS will be drawn up and implemented based on the determined customer needs [Schweitzer et al. 2010];
- The PSS Project Manager acts in various phases of the PSS development process and performs management activities. The main tasks of the PSS Project Manager include the establishment of the connection between the PSS project management and the PSS development process. In addition, it is a task to coordinate the PSS actors and their communication and networking over the phases along the development process [Abramovici et al. 2012];
- The PSS Architect can be defined as another PSS specific role. The role is characterized by its PSS specific knowledge and the overarching effectiveness in the PSS development process. The duties of a PSS Architect include, among others, the PSS idea generation, documentation and management of PSS concepts and making the link to the PSS project management. Thus, the activities of the PSS Architect also span over several phases of the development process [Lindow et al. 2011].

Figure 11 below shows such the roles about product, service and PSS lifecycle.

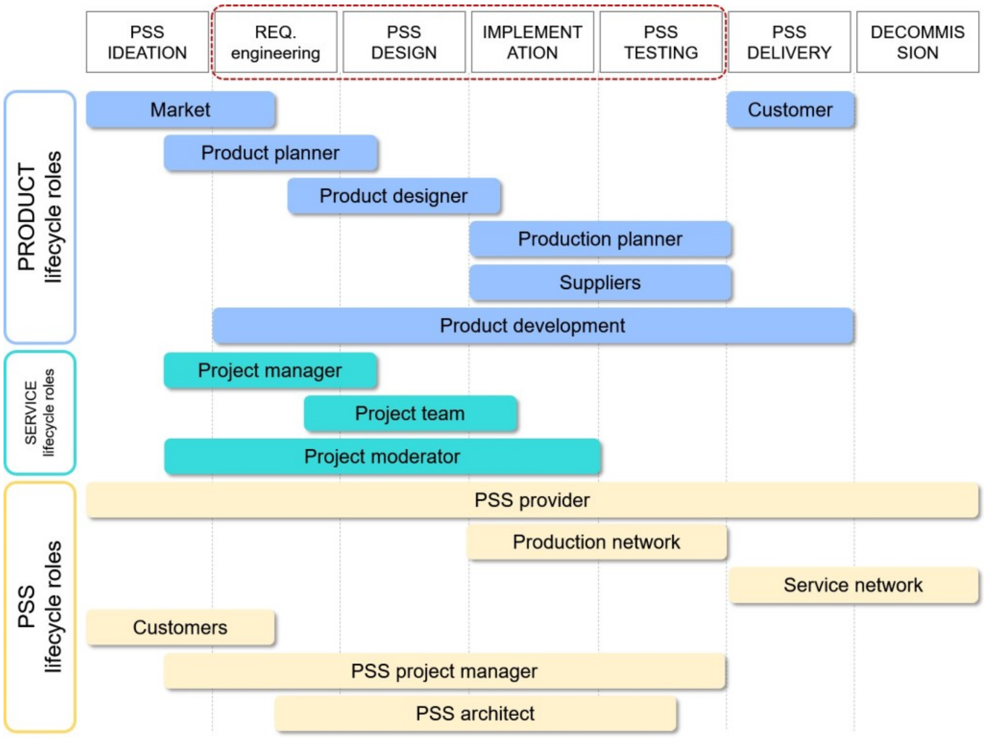


Figure 11. *Engineering roles in product, service and PSS lifecycle*

All those actors that are involved in the PSS development process need to communicate with each other in different phases and for different reasons. According to the respective phases, thus there is a different distribution of tasks, competencies and responsibilities as well as changing communication needs [Müller et al. 2014].

2.4.3. Requirement Engineering for PSS

Due to requirement Elicitation (RE) is a crucial method within the Service Engineering approach, it requires to be investigated more in deep.

To be successful RE needs to start from the analysis of users' requirements: they first have to be captured and then translated into more formal system requirements.

However, traditional approaches do not seem to be very suitable to elicit requirements for innovative PSS; they lack in understanding the tacit users' knowledge and formalizing user-centred processes [Peruzzini et al. 2012a]. Indeed, RE is particularly critical because of the huge quantity of implicit knowledge to be elicited and the variety of actors involved [Wiesner et al 2012]. As a consequence, RE needs to be faced in a structured and rigorous way.

During the engineering process, identify the customer and other stakeholder's expectations, and link the information obtained from all the phases of product or service lifecycle to the development process is the key factor to engine successful solutions [Nilsson and Fagerström 2006, Elgh 2007, Rouse and Sage 2009]. Indeed, it has been proved that an inadequate RE is a main source for failure of development projects and leads to exceeding budgets, missing functionalities or even the abortion of the project itself [Hauksdóttir et al. 2013]. For this reason, in PSS design, where the customer is the key actor for identify the referred demand, RE acquires the most predominant role in the P-SLM. Indeed, requirements are used to define the needs of stakeholders and specify which solution must provide to satisfy those needs. Moreover, the development of a PSS solution requires temporary collaboration of different stakeholders in several P-SLM phases, increasing the complexity of the RE process. Besides the customer and user of the system, actors as the project manager, product designers, software developers, service engineers, marketing experts, suppliers, quality assurance and many more have to be involved. This induces a change in RE from a well-defined and simple environment to a more complex and dynamic variation, making the RE process more challenging, due to both different cultural issues, but also organizational issues [Azadegan et al. 2013]. Indeed, RE for PSS has to be conducted for a growing number of tangible and intangible components from a variety of distributed, multi-disciplinary stakeholders. Due to the inherent complexity, the direct involvement of the end-user and information exchange between the different stakeholders has to be enabled during RE. Thus, the domain specific formalisms and tools have to be made interoperable or substitutable.

According to Berkovich et al. (2011), the literature about PSS development and design faces the development process only abstractly without going into detail. Moreover, concrete procedures for the translation of initial requirements to domain-specific requirements and procedures to capture the interdisciplinary relationship between requirements are not provided. Indeed, RE methodologies already exist in literature address the product, service and software disciplines only by the respective domain. This implies that the procedures and methods can be applicable only to the respective domain, making it impossible to apply them to other domains, let alone PSS as a whole.

The elicitation procedures in the product domain focus on technical requirements and aim to elicit such the requirements as checklist, which is not suited for the elicitation of service requirements. Anyway, as far as product development, RE approaches have already been implemented with a high degree of formalization. However, they focus almost exclusively on requirements development that is only conducted at the beginning of the development approach [Pahl and Beitz 2007]. Collaboration and integration of development processes with other business partners are not explicitly mentioned. In general, the lack of an interdisciplinary view and thus missing interfaces towards other domains, as well as the insufficient requirements documentation complicate the adoption of product engineering methodologies for RE of PSS solutions.

The elicitation process in service engineering comprises the tasks of identifying essential information (e.g. service ideas, possible customers and their expectations, and the sources of the requirements) and determining the goals, chances and risks. The procedures are service-domain specific and they are not detailed enough to be used as the basis for the PSS development. Indeed, a set of models for the systematic development of services have been proposed by Bullinger et al. (2006).

However, none systematic procedures for the implementation of RE have been established, due to the service characteristics that pose greater challenges. Thus, Service Engineering procedures do not integrate a holistic RE until now, but focus more on methods like "trial and error" [Spath and Demuß 2006].

About software engineering methodologies, standard procedures have been established and besides generic process models, specific methods for RE exist in literature. Requirements and their sources are identified in the elicitation phase and customer integration is emphasized. Anyway, software these methodologies do not involve interdisciplinary collaboration, because collaboration is strictly within the software domain, and the procedures described for the prioritization of requirements are not suitable for the development of new PSSs.

Finally, requirements validation, which is an important part of the RE process to check the requirements for ambiguity and falsity, is conducted against the initial requirements to define the stakeholder needs. Validation procedures are discussed in detail above all in the software engineering approaches [Berkovich et al. 2011], but it is clear that the customer integration is restricted to the requirements definition stage. Collaboration in software engineering is taking place in various ways during the whole lifecycle of the development (e.g. collaboration with stakeholders to elicit requirements, identification of errors and collaborative working on the software design) [Lanubile 2009, Whitehead 2007], but it referred only to the software domain.

It is clear that the adoption of existing requirements engineering methodologies from the product, software and service domain to develop a PSS seems to not be possible. This because the methodologies of the product domain do not cover all the lifecycle phases required to realize a PSS. Instead the requirements engineering methodologies of integrated products and services cover all phases of the PSS, they do not provide the required integration interfaces. Finally, the selection of collaborative business partners depending on the configuration of the PSS and the formalization of business networks is not described in any of the previous methodologies. In order to define integrated approaches for RE of PSSs, it is fundamental to guarantee a cross-domain knowledge, interfaces and interdisciplinary requirements. Currently, the RE methodologies of the integrated products and services are too vague and do not provide the procedures necessary in order to realize a PSS. Moreover, the necessity of requirements translation of initial stakeholder's requirements to design requirements is faced in the analysed approaches, but procedures for the concretization of requirements are not mentioned explicitly. Quality Function Deployment is applied in product engineering, but it cannot be used to derive design requirements from customer requirements [Berkovich et al. 2011].

2.5. PSS Sustainability

The transition of manufacturing companies from a product-oriented model to a new service-oriented one by adding service features to traditional products in order to increase the value perceived by the customers [Neely 2007] implies that PSSs are composed by physical items, which are usually produced by manufacturing firms, intangible goods and a proper system infrastructure [Aurich et al. 2006].

In literature, it has been proven that service-enhanced products can provide not only a higher customer satisfaction [Garetti et al. 2012], but also a great advantage on the sustainability [McAloone et al. 2010, Peruzzini et al. 2012b]. In particular, sustainability is assuming a relevant role in both customer choices as the people attention to energy saving and environmental issues are increasing on the markets [Xing et al. 2013]. As already faced in Introduction, the modern sustainability thinking considers three main dimensions: environment, economics and social wellbeing [Adams 2006]. From the economic viewpoint, services create new market potentials and higher profit margins, and can contribute to higher productivity by means of reduced investment costs along the lifetime as well as reduced operating costs for the final users [Baines et al. 2007]. From the environment viewpoint, PSS provides a more conscious product usage thanks to the service functionalities delivered, increasing resource productivity and a close loop-chain manufacturing as reported by some examples [Favi et al. 2012]. Moreover, because the PSS requires the involvement of different partners and stakeholders, they will deliver a solution able to create a sustainable supply chain, according to the service provided. Finally, services are able to support the building up and securing of knowledge intensive jobs, and can contribute to a more geographically balanced wellbeing distribution [Tukker and Tischner 2006a].

Moreover, the development of PSS forces product-centric firms to innovate their current business model and evolve their own processes. For instance, optimizing the delivery process as well as creating new customer interface and new buyer-seller relationship [De Jong and Vermeulen 2003] represents the core of service innovation. However, compared to product innovation, there is a limited understanding about service, especially in manufacturing industry [Yen et al. 2012], even if its introduction can bring numerous advantages as new business opportunities and new market shares.

The PSS and the relative Servitization process extend the responsibility of the PSS provider to the whole lifetime of the product [Aurich et al. 2010]. For this reason, it is required to bring the focus of the offer assessment to a lifecycle perspective. In those manufacturing industry that face the PSS, sustainability can be achieved by adopting lifecycle design approaches: they allow quantifying product impacts and providing tangible commercial values in terms of efficiency and costs [Jeswiet 2003]. They are based on the definition of several indicators to assess the lifecycle performance and support comparative analysis. Some techniques to support this described lifecycle design approach are the LifeCycle Assessment (LCA) [ISO 14040:2006], in order to evaluate the environmental impacts, and the LifeCycle

Cost Assessment (LCCA) [Woodward 1997], in order to recognize all the economic impact during the product lifecycle. Recently, also the social impacts have been included in the lifecycle design approach by the so-called Social LifeCycle Assessment (SLCA) [Weidema 2006].

All these methods have been defined for product assessment, but they could be "extended" and applied also to a PSS. However, the common indicators that assess economic, environmental or social domains separately will not approach and assess PSS sustainability in its complexity and wholeness. Indeed, the sustainability of a system cannot be assessed by the use of a single criterion mainly because of the intrinsic multidimensionality characteristic of sustainability. It is required to generate and assess a unique value that is the combination of all those. Along the time some researches faced the sustainability issue not only for products but also for PSSs [Mont 2002; Young 2010], but without adopting lifecycle approaches. While others, more recently, propose to translate a LifeCycle Design (LCD) approach to assess the PSS sustainability [Peruzzini et al. 2013a; Kwak et al. 2013]: they demonstrate how to calculate the sustainability impacts of an integrated PSS by considering not only the impacts related to the product realization, usage and dismissing, but involving also the ecosystem actors and the benefits due to the service implementation. In fact, PSS design implies the development of a new set of relationships among the stakeholders involved in the PSS network [SUSPRONET]. It means to involve for example organizations, public bodies, tertiary service providers and also the customers to create a new business framework that is organized to support both product and service lifecycles [Wiesner et al. 2013b]. Indeed, providing PSS entails moving from a vertical supply-chain to an extended enterprise collaborative network able to support it. It is a new situation where product and service lifecycles are integrated to establish an extended value creation network, which is defined as Virtual Manufacturing Enterprise (VME). It contemporarily involves manufacturing agents producing and supplying products and services, and sales agents negotiating with customer agents [Nishioka et al. 2001]. In this context, considering the PSS sustainability in the VME by understanding the impacts on the three sustainability dimensions can be particularly interesting and represent a novelty in research and in industry.

Figure 12 below tries to give an overview about the PSS sustainability concept into a VME, while

Table 2 shows how researchers addressed the PSS sustainability and what kind of indicators they used to assess the three main dimensions and the total sustainable index. In the columns, the three main lifecycle indicators are identified (i.e. Environmental Impact, Economic Impact, and Social Impact) and also the integrated indicator to calculate the entire Sustainable impact, while in the lines the main representative authors are identified.

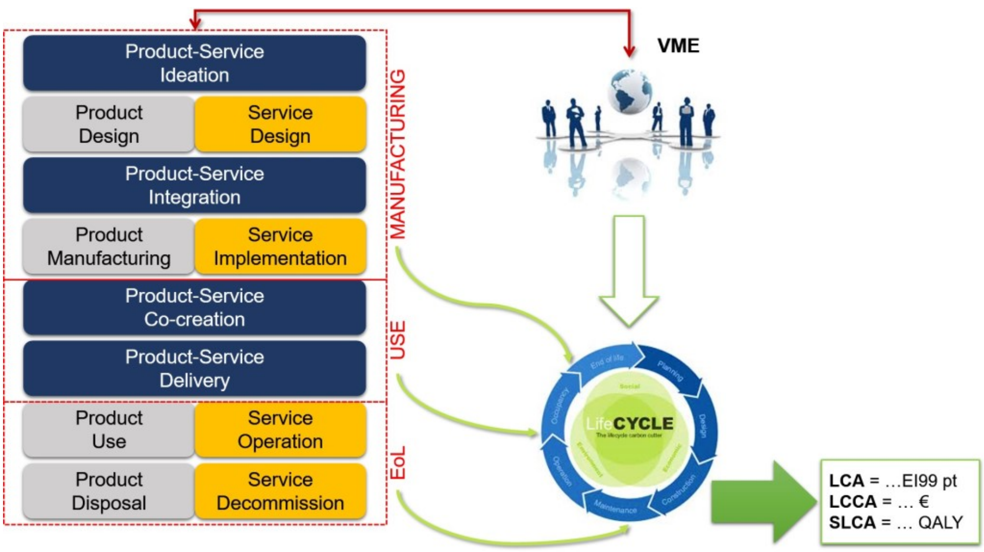


Figure 12. *PSS sustainability in the VME*

Table 2. *Lifecycle indicators to calculate the PSS sustainability*

References	*Environmental Impact indicator*	*Economic Impact indicator*	*Social Impact indicator*	*Sustainable impact indicator*
Peruzzini et al. 2013a,	ENI (ENvironmental Indicator) measured by Eco-Indicator99 point (EI-99)	ECI (EConomic Indicator) refers to all the lifecycle costs through the Equivalent Annual Cash Flow technique (EA)	SOI (SOcial Impact) considers separately Human Health contributions according to EI-99 methodology	SI = ENI + ECI + SOI (Each indicator is normalized to obtained a monetary value (€), that is SI)
Kwak and Kim 2013	Total environmental impact along lifetime	Total lifecycle cost	None	None
Weidema 2006	Global Warming Potential	Lifecycle costs	QALY (measure of well-being)	QALY as a single-score alternative to direct monetarisation
Mont 2002	Life span, efficiency of resource consumption, closed cycle efficiency, and potentials for improvement	None	None	None

2.6. KPIs for measuring PSS impacts

For manufacturing companies, the measurement of PSS performances is a crucial aspect to identify the greatest solution to provide on the market and able to satisfy the customer needs, improving the product value proposition. Moreover, identifying the best PSS offer allows improving the company business model, its business performances, and thus its revenues. In order to promote the PSS offer performances measurement, two main principles must be taken into account: "what cannot be measured cannot be improved" [Gries and Restrepo 2011] and the Plan-

Do-Check-Act (PDCA) approach [Deming 1992], since a continuous monitoring is required during the entire P-S lifecycle that it is measured.

In literature, four different kind of performance measures can be identified:

- Result indicators (RIs),
- Performance indicators (PIs),
- Key performance indicators (KPIs),
- Key result indicators (KRIs).

KPIs are not financial indicators; they are measures of a current or future situation able to encourage the stakeholders to adopt any strategy in order to face up the scenario that arises. Anyway, so that manufacturing companies are able to have a wide vision over their businesses, it is necessary that they use and implement a mix of different types of indicators. Such a mix is called a performance measurement system and it has the scope to focalise the company attention on what is important to measure and not only on what is easily measureable [Cedergren et al. 2012].

According to the aim to measure the PSS offer performances, the KPIs are able to provide the guidelines to drive the company in the right business direction. Indeed, KPIs measuring the company performances about a certain business, they give information to company stakeholders during the decision-making process. Moreover, they are involved to discover what are the non-adding value activities (that approximately represent the 60% of a company's activities) inside a specific business [Dombrowski et al. 2013]. Therefore, in order to identify the right KPIs to adopt for evaluating a certain business, literature proposes the adoption of the SMART principles, which are Specific, Measurable, Attainable, Realistic, and Time sensitive [Abramovici et al. 2013]. KPIs that comply with these five criteria allow companies assessing their real time performances, defining measure early enough before problems occur, and collecting the appropriate KPI for PSS evaluation during the Design phase. This last one is a crucial aspect in PSS assessment, because the evaluation and validation of a new PSS offer during the design phase allows both reducing the time to market and reaching successfully the customers' needs.

Currently in literature, few works about performance assessment in PSS exist; thus, it is an open issue yet. Anyway, an interesting research was conducted by Mourtzis et al. (2015) that has classified KPIs in the respect to the main PSS Design methods. Those classes are three: Customers (C), Business (B), and Sustainability (S). Figure 13 shows how the KPIs classes refer to the PSS design methods explained in the previous chapter.

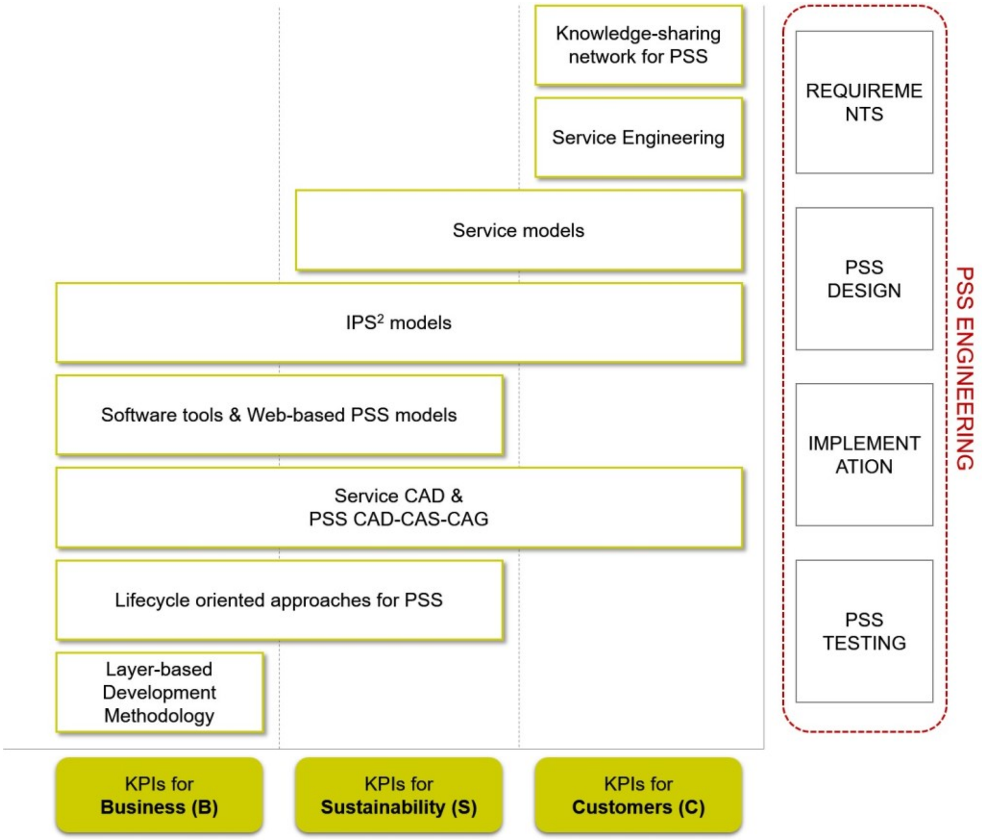


Figure 13. *Mapping of KPIs in PSS design*

Here, B referring to Business aspects, S relating to Sustainability, and C relating to the Customers. The main KPIs involved and the relative class are listed in Table 3. Beyond the advantages that KPIs measurement offer to assess a PSS offer during the Design phase, some weaknesses exist yet. Indeed, the KPIs measurement demands lot of effort due to a frequent evaluation. For this reason, a critical aspect in the performance measurement system is to compare the value of an indicator with the effort required for its evaluation [Kerzner 2013]. Furthermore, the number of indicators should be limited to ensure a meaningful overview of the current situation. In this context, Parmenter (2010) suggests the 10/80/10 rule: it stands for 10 KPIs, 80 PIs and RIs, and 10 KRIs.

Table 3. *KPIs list for each class*

KPIs	*Class*	*KPIs*	*Class*
Customer Satisfaction	*C*	*Overall Equipment Effectiveness*	*B*
Acceptability	*C*	*Technical availability*	*B*
Acceptance rate	*C*	*Flexibility*	*B*
Availability for production plan	*C*	*Stability*	*B*
Number of customer needs	*C*	*Machine Reliability*	*B*
On-time delivery	*C*	*Service Reliability*	*B*
Efficiency	*C*	*Service Assurance*	*B*
Quality	*B, C*	*Team Qualification*	*B, C*
Customer Needs rate	*C*	*Knowledge Management*	*B*
Requirement Inconsistency	*C*	*PS Maintenance Efficiency*	*B*
Efficiency of collaboration	*C*	*Development cost*	*B*
Privacy	*C*	*Service delivery costs*	*B*
Product flexibility	*C, B*	*Environmental quality cost function*	*S, B*
Expansion flexibility	*C, B*	*Energy Efficiency*	*S*
Sustainable product-service efficiency	*S*	*Lease/ Reuse*	*S*

Chapter 3. PSS main Issues & Challenges

Applying the servitization process to an existing product enables the definition of a novel business model that allows a new product life, extending the current product lifecycle. The result is the Product Service System (PSS), which is composed by physical goods, usually produced by manufacturing firms, intangible items and a proper system infrastructure [Aurich et al. 2006].

Numerous manufacturing enterprises are moving from a product-oriented model to a new service-oriented one by adding service features to traditional products in order to increase the value perceived by the customers [Neely 2007] and moreover, to improve the company market share [Aurich et al. 2006] for those products that are positioned in the maturity phase of their lifecycles, and for which any other innovation action has not more possible in order to satisfy the customers' expectations. Moreover, for these products, ICT allows the creation of a new sustainable business model (e.g. circular economy, social well-being monitoring), which is not possible to reach through the exploitation and usage of the lonely product.

The introduction of PSS in manufacturing firms can bring numerous advantages, but for all those companies that face this novel opportunity is not so simply change their vision and their configuration in terms of engineering processes, supply chain and delivery channels. Indeed, along the Servitization process, manufacturing companies deal with several challenges, such as:

- extension of the company boundaries, involving other actors rather than those already involved in the current supply chain, in order to design, develop and deliver the new PSS value proposition. This entails the creation of a global production network, according to the value proposition defined in the business model;

- knowledge sharing among all the actors involved in the novel network, and thus, knowledge management in order to have the sensitive information when they need, to make the actors' chain more promptly and efficient, and to avoid the information sharing outside the GPN boundaries;
- business model changing and thus, change also the way to produce value for manufacturing companies in order to obtain a win-to-win business model (both customer and companies);
- sustainability improvement (i.e. economic, environmental, social well-being) for the involved product, developing new sustainable business models (e.g. circular economy) able to address the sustainability issue and extend the current product lifecycle;
- ICT and IoT technologies and frameworks adoption, in order to equip the product with the required hardware and software infrastructure able to deliver the service functionalities expected by customers;
- customers and market monitoring, to understand when these two entities are ready to adopt PSS solutions instead traditional products.

These challenges can represent an issue for some manufacturing companies, because this implies that they must completely change above all their current manufacturing processes and the methodologies, and also tools already adopted during the engineering phase of the product lifecycle. It is true that novel technologies and frameworks exist to support in a proper manner the development and the adoption of PSS (e.g. ICT, IoT), even if they should be integrated more and more in manufacturing industry.

For these reasons, in this chapter through the following paragraphs the main PSS challenges are explained in detail, in order to highlight what are the key areas where innovation is needed.

1.1. Knowledge Management

In the PSS context, where tangible product and intangible services are integrated together to provide a new solution for customers, the PSS value creation depends on the close cooperation among all the actors involved in the PSS dedicated cluster (e.g. VME, GPN, etc.). Therefore, all the stakeholders (e.g. customers, suppliers, research partners, etc.) participate in PSS value creation process, where there is the customer’s willingness to pay for service, unlike the traditional product value realization, based on its delivery [Wang et al. 2015]. In this novel vision, the PSS design aims to define and highlight the technical interactions and connections between the product and service, according to all the stakeholder requirements elicited [Lützenberger et al. 2013]. For this reason the PSS design process needs of a strong cooperation and collaboration of different companies’ teams and departments in order to set-up a PSS co-design, where tangible goods and intangible components are strongly linked and dependent on each other [Larsson et al. 2010, Chirumalla 2013, Nemoto et al. 2015], and they are characterized by an intense exchange of technical information and engineering knowledge [Clarkson and Eckert 2005].

In literature, different authors discussed about the concept of product and service co-design. For example, Ordanini and Pasini (2008) investigated the role of customers as value creator, while Baxter et al. (2009) approached such the topic identifying the main requirements involved in the PSS co-design. Moreover, Annamalai et al. (2011) defined an approach to help the PSS designer to manage the activities along the process in an efficient and effective way, in order to reach a better value creation and customer satisfaction. Other authors [Nergard and Ericson 2012, Cedergren et al. 2012] faced also the knowledge exchange issue in PSS, seeing the PSS co-design phase like a dynamic process able to involve several actors and where the individual knowledge needs to be combined for creating the value proposition expected by the customers.

Anyway, to identify the knowledge exchanged in PSS co-design, all the stakeholders involved in such the process must be identified, what kind of resource they represent and what kind of target knowledge they are able to produce. According to this scope, a role model should be applied to describe the set of roles involved, which can be identified as the owners, which can be internal or external stakeholders, and so on. The role model is completely aligned to the company PSS co-design process, to the organizational structure, and the stakeholder's competences; indeed these roles assigned define the division of work between all the company stakeholders.

Talking about the knowledge exchange during the PSS co-design phase, among all the stakeholders identified until now, external environment and market (to identify the market needs) and customers (to satisfy the customer' requirements) must to be involved. Indeed, they give the guidelines to the product specifications and PSS concept, which are the key information to start the PSS design [Zhang et al. 2012]. Currently, as regards the product design, this knowledge can be formalized in text documents, spreadsheets, diagrams, CAD drawings and other tools, but the formalised knowledge is only about 4% of the entire organisational knowledge that is always shared during the product design phase [Bell 2006]. For this reason, the Knowledge Management (KM) discipline is investigated a lot in literature about the product design. Considering that in the PSS design more and more information are shared rather than product design, it is possible to understand how the KM represents a key aspect in PSS co-design and a challenge for both researchers, which are engaged to find novel tools and approaches to guarantee the appropriate KM, and manufacturing companies, which should apply in their reality such the tools to improve the collaboration among all the actors involved along the PSS engineering.

Currently, some approaches and frameworks exist in literature able to address the knowledge formalization issue in PSS design. For instance, Nemoto et al. (2015) described a framework to manage PSS design knowledge through by five elements (i.e. core product, need, function, entity and actor). Zhu et al. (2015) and Zhang et al. (2012) formalized knowledge from previous PSS cases in a physical and a service model. Furthermore Baxter et al. (2009) defined a KM framework for PSS design process knowledge, manufacturing knowledge, service design and service operations knowledge. Other authors have defined some conceptual approaches to manage the unstructured knowledge. For example, Bertoni (2010) emphasized the importance of "bottom-up" knowledge sharing in PSS design and suggested Web 2.0 tools such as blogs, wikis or social networks to capture tacit knowledge and tap into the "wisdom of crowds". Larsson et al. (2010) have extended this idea into the concept of "Engineering 2.0", applying easy to use technologies for knowledge sharing, while Chirumalla (2013) explored the use of Web 2.0 tools for knowledge sharing in a PSS case study.
This brief review has highlighted as the KM disciplines in PSS design implies two main aspects: need to formalise the engineering knowledge and exchange it in a flexible way among the stakeholders involved, also sharing the tacit knowledge. Anyway, the balance between this two aspects is not so simple if it is necessary apply it into a manufacturing company, due to the tools already used, the established standards or the corporate mentality. Indeed, some barriers for knowledge sharing in PSS design currently exist [Bertoni and Larsson 2010], thus to foster knowledge sharing during the PSS design phase, cross-functional teams need to be created. Leadership of the teams can be rotating, according to the current issues and problems of the project. This means that stakeholders from product, service, or system integration, can lead the team at specific points of time. It is important that all members of the development team have access to the same knowledge in the right form [Nonaka et al. 2000].

To model and exchange PSS design knowledge, a meta-model layer is provided by default in the specification of UML. Anyway, because it is not feasible for all involved stakeholders to use a common standard for knowledge representation or work with models from other domains, ontologies can be used as an efficient mean to share knowledge, even if they are very complex.

Recent studies on open innovation, e.g. in the form of application of crowdsourcing techniques [van den Ende et al. 2015] or implicit feedback leveraging from social media [Budak et al. 2011], have established the important role of open, crowd-oriented opinion and sentiment in enhancing products and services. This knowledge is mostly informal and unstructured, consisting of individual posts and discussions, ideas, comments and other interactions. Thus, it is difficult to codify and share, as it requires individual interaction to transfer. It is however equally important as knowledge for PSS engineering.

1.2. PSS methods & tools

According to the literature review faced in chapter 2, different authors have dealt diverse aspect of PSS engineering, proposing and developing methods and tools able to satisfy that specific area. Figure 14 shows such the methods disseminated in literature in order to understand which kind of engineering phase they are able to support. As is clear, some of them focus on the product and service co-design, others support the product and service integration, and finally more ones are involved in the product and service co-creation. However, an integrated method or approach able to support the entire PSS engineering from Ideation to co-creation does not exist.

A recent study [Vargo and Lusch 2004] stated that PSSs are perceived by customers thought their “value in use”. Therefore, for the realization of value in a PSS, designers need to focus more on customers and their requirements instead of pursuing a benchmarking strategy determined by a competitor analysis. It is true more for PSS than for traditional products. Müller et al. (2010) composed a checklist of clustered criteria to enable designers to retrieve and describe PSS requirements systematically. In this checklist, users requirements are extracted from both object-oriented (i.e. structure, technical artefact, contract, and so on) and process-oriented (i.e. behaviour, service, lifecycle activities, and so on) aspects. Differently, Ota et al. (2013) proposed a method for requirement analysis that considers the environmental factors (i.e. political, social, and technological). In such context, Favi et al. (2012) offered a preliminary approach about the adoption of lifecycle design methods. Furthermore, for requirements evaluation Akasaka et al. (2010) proposed a method that uses the SWOT analysis. Another important aspect is represented by the evaluation of the PSS value proposition. In a recent study [Kimita and Shimomura 2014] proposed a review of such the approaches from different viewpoints: from value to cost, functions, qualities, or performances. A new trend about PSS design is the configuration of a tailored set of partners or stakeholders able to guarantee the right design, development, delivery and knowledge sharing of the PSS involved. According to this new aspect, Wang and Durugbo (2013) showed a methodology to evaluate the uncertainty of service networks that deliver a PSS. Following the same issue, Krucken and Meroni (2006) presented an approach to design communication material in the aim to develop strategic alliance in order to deliver a complex product service system. Diversely, Gebauer et al. (2013) focused more on the service network design phase, identifying four different service networks and the capabilities needed to use such networks, while Peruzzini et al. (2013b) provided an assessment of a PSS in the virtual manufacturing context. Finally, in the last years also business aspects assumed more and more attention to support PSS design. Barquet et al. (2013) proposed a framework to support PSS adoption by using the Business Model (BM) concept. Armstrong et al. (2014) was interested to define an innovative business model for clothing industry with the final aim to reduce its environmental footprint; in such context, the authors found that PSS may provide many opportunities to identify positive or negative perceptions in the clothing sector. Guidat et al. (2014) gave a set of guidelines to define innovative business models for remanufacturing by exploiting both remanufacturing and PSS characteristics.

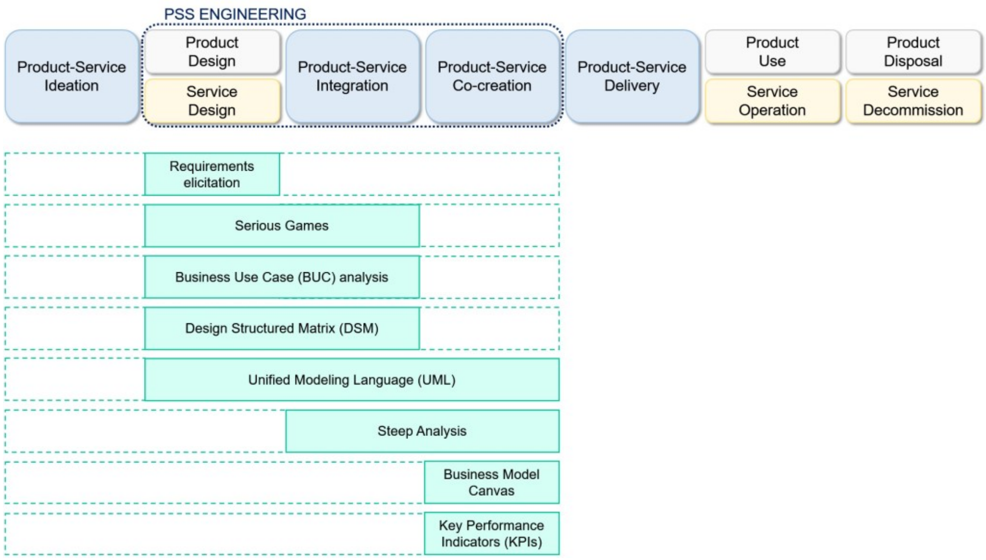


Figure 14. *How the main PSS methods & tools address P-SLM*

Moreover, by literature analysis it can be stated that, while many researchers have developed design methods and evaluation tools for PSSs and validated their effectiveness, guidelines for how to use these methods and tools concretely in the design process are rare. In fact, previous researches in literature tend to assess only one PSS issue at a time, without considering the entire design process and the specific context of application. This means that researchers have investigated in deep only one of the following themes:

- PSS business aspects, in order to identify the customer requirements or the business model to apply;

- PSS value proposition, to satisfy the customer requirements according to the product to extend;
- Ecosystem creation, in order to design, develop and deliver the PSS.

1.3. User-centred Design

Design decisions are not technology driven nor manufacturing related, but the customer problem is in focus. In this context, user centred design (UCD) has become a driving force [Hazenberg 2011].

UCD is a design philosophy that aims to extensively address needs, demands and expectations of users at each stage of the design process. A traditional UCD process starts from the identification of users' needs and establishment of requirements, and proceeds with the development of alternative design solutions to meet such the needs, the building of interactive prototypes which can be assessed, and finally the evaluation of what is being built by involving final users [ISO 13407:1997]. In this context, ergonomics and usability historically assumed a central role [ISO 9241-210:2009]. The combination of this two aspects has been defined as User Experience (UX).

In the context of PSS, the investigation of UX is not common yet. On one hand, there is a lack of literature about the adoption of UCD approaches to PSS design. On the other hand, in order to investigate such the response by UCD application, interactive prototypes able to support a proper behavioural and cognitive evaluation in shorter time are needed [Bullinger et al. 2010], but creating a realistic prototype for PSS is hard to realize. In fact, it requires a functional and interactive prototype able to reproduce the integrated functioning of both product and services with high fidelity in order to reproduce both physical and cognitive responses in the final users. These aspects are strongly interrelated and difficult to divide, so that the UX of a PSS is a mix of behavioural feedback, which refers to the way in which users behave in front of the PSS and how they act and reach, and cognitive feedback, which refers to the judgment that user makes about the PSS as a whole, on the basis of the information perceived through the sensorial modalities and experiences lived.

As far as PSS, traditional low-fidelity prototyping techniques (e.g. paper sketches, cardboard mock-up) can be applied only for some aspects of product or service interfaces, such as the layout of controls and displays [Hall 2001], but they are not suitable for the evaluation of the effects of visual, motion, tactile, and auditory feedback, that usually a PSS has. In this context, high-fidelity prototypes (e.g. software and physical mock-up) can make users realistically appraise product aesthetic attributes and functionalities [Sauer and Sonderegger 2009], but they are costly and are usually built up in an advanced design stages, when the majority of features are already defined.

Virtual Reality (VR) technologies have been demonstrated to successfully create virtual interactive mock-ups within immersive environments to simulate product functions; furthermore, using virtual mock-ups allows rapidly carrying out usability testing from the earliest design stages involving users substituting costly physical mock-ups [Park et al. 2008]. The level of interaction can be improved mainly thanks mixed prototypes and virtual interactive mock-ups. The former combined physical objects with virtual objects, but integration is usually hard due to the complexity of systems' interfaces, the unnatural manipulation, the non-intuitiveness and intrusiveness of the adopted devices, especially for non-expert users. The latter is based on virtual interactive virtual prototypes (IVP) and allows the user to interact with the prototype into an immersive environment in a more natural way, creating a realistic interaction [Bordegoni and Ferrise 2013]. IVP has been recently adopted to evaluate ergonomics and user experiences on products in numerous cases and different industrial sectors (from household appliances to automotive, from interior design to furniture), but they are not applied for services.

Chapter 4. European platforms and tools for supporting Product Service Systems development

The European Factories of the Future (FoF) have identified along the last years the "ICT-enabled intelligent manufacturing" as one of the four pillars to support European manufacturing industry in the challenging transition from post-crisis recovery to a European sustainability and regain competitive advantage in the global market competition. According to this perspective, three main priority areas have been identified, involved into the smart European factories:

- agile manufacturing and Virtual Factories;
- global networked manufacturing and logistics and Digital Factories;
- manufacturing design and product and service lifecycle management.

The latest developments on "ICT-enabled intelligent manufacturing" has led to the current definition of Industry 4.0, where all these three areas are strongly linked together in order to make the future factories smarter, more efficient and more sustainable by the three dimensions commonly defined (i.e. environmental, economic, social well-being).

According to this European industrial trend, it implies the implementation of Service-orientation and Open Innovation grand challenges into European virtual and digital factories (i.e. implementing Service Innovation). This requires the capillary dissemination of the related concepts and methodologies, the exploitation of the tools and IT systems, as well as the training and formation of a new generation of managers and knowledge workers who will be able to transform European enterprises into service-oriented, collaborative entities. Awareness, involvement and education of citizens and consumers is also necessary, in order to make them understand and perceive properly the new benefits deriving from the implementation of Service Innovation to develop Product Service Systems. For example, in the product2service scenario, are customers available to renounce to the ownership of the physical good, in change of a plethora of services? In the automotive sector, perhaps taxis, trucks, buses, ambulances, electric cars are more suitable to be rented and not sold to customers, but perhaps private cars aren't yet. Moreover, in the product+service scenario, are consumers available to spend more money for intangibles or for the certification of Made in Europe, social sustainability, environmental protection and low carbon footprint?

In order to address the Service Innovation challenge, the European commission has identified several project calls inside both European Union's Research and Innovation funding programme for 2007-2013 [FP7] and the "Horizon 2020" [HORIZON 2020] program. Some of these calls gave rise interesting research projects focused on different PSS issues, such as MSEE (Manufacturing SErvice Ecosystem) [MSEE 2012-2014], FLEXINET (Intelligent system configuration services for FLEXIble dynamic global production NETwork) [FLEXINET 2013-2016], Manutelligence (Product Service Design and Manufacturing Intelligence Engineering Platform) [Manutelligence 2014-2017] and PSYMBIOSYS (Product-Service sYMBIOtic SYStems) [PSYMBIOSYS 2015-2018]. These projects are only an example of how much the European research is so thrives about PSS.

Among these projects, MSEE and FLEXINET will be involved in this research thesis, because they are actually attended by the Italian company involved in the exploitation of the proposed methodology.

According to Figure 15, the two European platform, through their tools and methodologies delivered along the projects, cover different phases along the Product-Service Lifecycle Management. Indeed, currently a methodology able to cover the entire P-SLM does not exist; instead, several European platforms that address more P-SLM phases have been developed.

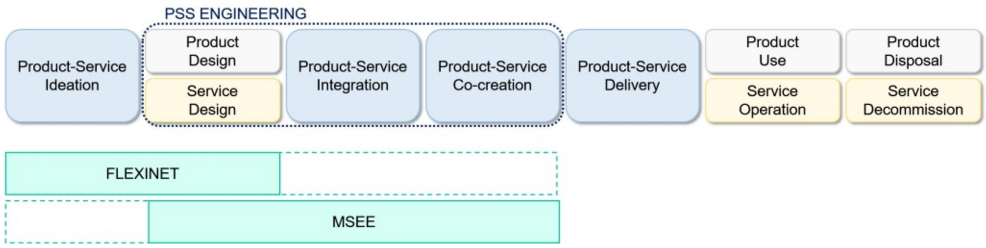


Figure 15. *How European platforms address the P-SLM*

In the following, the details of both the projects are presented and discussed, in order to identify which kind of tools and methodologies have been developed in Europe and what are their main scope. Moreover, the aim of this chapter is to identify the methodologies and tools that are useful to develop the integrated approach shown and discussed inside this thesis.

4.1. FLEXINET

The FLEXINET project is born to support manufacturing companies in decision-making process during the early design phases of global production network configuration, based on the implementation of new complex technologies. Indeed, FLEXINET applies advanced solution techniques to the provision of a set of Intelligent Production Network Configuration Services that can support the design of high quality manufacturing networks, understanding the costs and risks involved in network re-configuration, and then mitigating the impact of system incompatibilities as networks change over time. These are fundamental requirements for high quality decision-making in the early design of intelligent manufacturing system networks. These innovative concepts will enable a fast and efficient response to market variations and be easily adaptable across industrial sectors. Moreover, FLEXINET thanks to its ICT solutions developed along the project can support also the early stages of PSS design through tools able to manage the information shared among the company departments. Indeed, according to the challenges discussed in the previous chapter (chapter 3), FLEXINET is able to face the knowledge management issue, adopting both an Open Innovation approach to support the PSS Ideation process and the Ontologies to manage all the manufacturing company knowledge inside the tools developed.

FLEXINET project has provided three main tools involved in the same platform (i.e. ERAS, PNES, PSCoMS), as shown in Figure 16. Each of them can deliver a set of applications, as described in Figure 17.

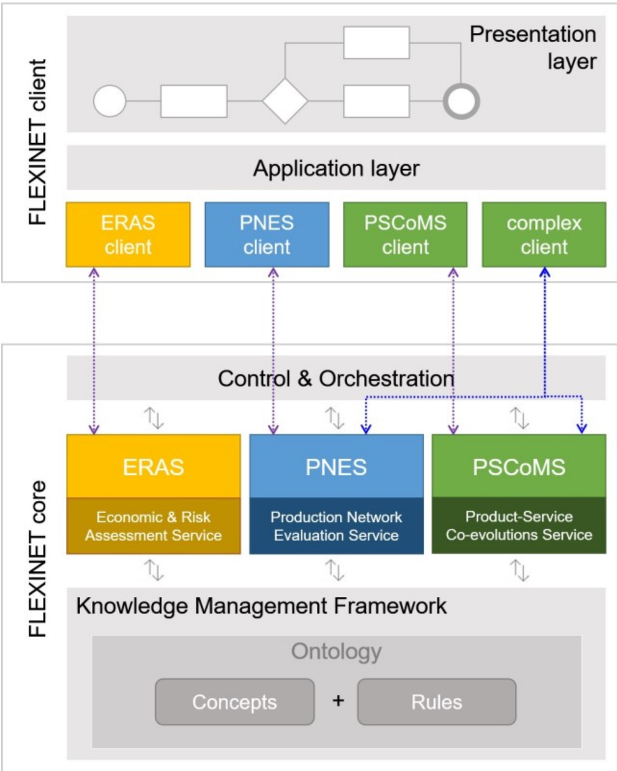


Figure 16. *FLEXINET platform*

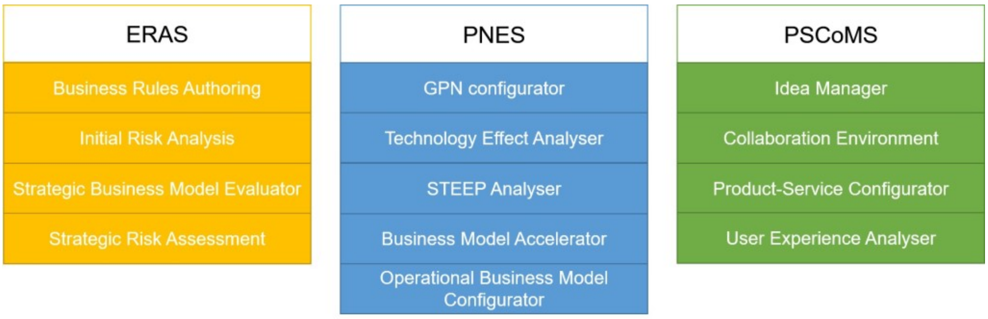


Figure 17. *FLEXINET applications*

The *ERAS* (*Economic & Risk Assessment Service*) tool focuses on the economic and risk assessment of product and services, providing a set of applications able to define the main risk factors on the GPN, discover risk associated with change, which is the ability to present a scenario and calculate the overall inoperability of the user's production output, and finally compare historical scenarios for risk assessment giving the user rational data for making an informed decision on risk avoidance or mitigation.

The *PNES* (*Production Network Evaluation Service*) tool focuses on the assessment of the GPN providing a set of applications able to support the decision making in evaluation of new business models or opportunities, and the design or update of the current GPN model.

The *PSCoMS* (*Product-Service Co-evolutions Service*) tool focuses on the Product-Service Lifecycle Management (P-SLM) providing a set of applications able to support the Product-Service ideas knowledge management, the Product-Service compliancy, and the decision support system, based on the KPIs evaluation according to the User Experience.

According to this thesis scope, FLEXINET has provided a set of applications belonged to the PSCoMS tool that are able to support the early stage of P-SLM, like the Ideation phase and Product and Service Design (Figure 15), through the Open innovation approach. For this reason, in the following, a deeply detail on

PSCoMS applications is given, in order to understand how the related applications are integrated inside the methodology proposed by this research work.

4.1.1. FLEXINET tools: PSCoMS involvement

The PSCoMS tool mainly aims to support manufacturing companies willing to move from product-oriented manufacturing model to PSS-oriented business model, providing support especially during the early stages of PSS development, which were found the more critical and difficult for manufacturing firms.

Indeed, PSCoMS is a collaborative design environment that support the collection, analysis and reuse of the information required to evaluate, refine and design a new PSS concept. This kind of information is usually poorly structured within the manufacturing companies, not shared and scattered into a number of different systems and formats. This fact makes difficult to recover and properly analyse such the data with the support of IT technologies.

The PSCoMS tool aims at structuring the knowledge collected and facilitating knowledge sharing and cooperation among all the actors involved within the company and not only inside the design team, in order to support brainstorming and decision-making activities. Thanks to virtual environments where information are shared among people placed in different physical locations and at different timing, it is possible to communicate and proceed with multi-disciplinary design actions.

The main PSCoMS functionalities are described in the following:

- *PSS new idea generation*, which drives different actors (internal or external to the company) in the creation of a proper information structure to describe a new idea, in order to be further evaluated and completed in the next steps of the PSS design process. The idea generation process allows voting and commenting already generated ideas and transforming one or more ideas into a new PSS concept, which is then go through the PSS design process;

- *PSS preliminary configuration*, which provides a workflow-like approach for the collection of all the knowledge and documentation required along the different steps of the PSS design process;
- *PSS preliminary technical viability check*, which supports designers by analysing the technical dependencies between the given product (existing) and the services to be provided to complement it in the new PSS offer. It also allows detection of possible incompatibilities between a product and a service, leveraging on the product-service relations formalised in the company knowledge base;
- *Feedback assessment*, which allows realising the feedback analysis, describing the user experience on the product prototypes, to check if and how the servitization of the project has been accepted by the market and how the PSS will be used.

All these functionalities are structured into four web-service applications (i.e., Idea Manager, Collaboration Environment, Product-Service Configurator, User Experience Analyser), which allow covering different P-SLM phases, as depicted in Figure 18.

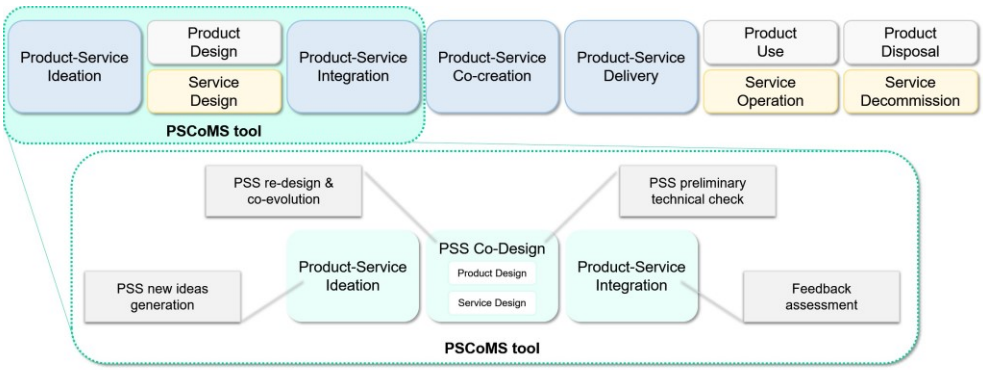


Figure 18. *How PSCoMS applications support the P-SLM process*

The overall knowledge generated along the PSCoMS tool is merged with knowledge extracted from the company legacy systems and properly structured thanks to an ontology-based approach. It also allows performing advanced queries and providing a common layer where different applications supporting the decision making within the PSS design and production planning process can contribute to the creation of "what-if" scenarios.

Figure 19 shows the PSCoMS tool architecture. It involves three main units:

- End User application;
- PSCoMS tool, including the four above-mentioned applications;
- Knowledge Management framework.

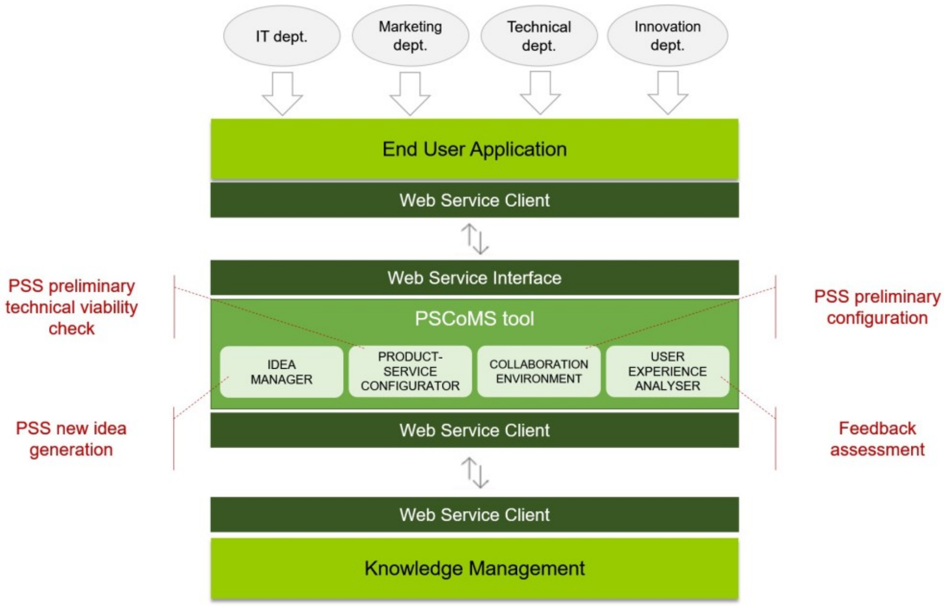


Figure 19. *PSCoMS tool architecture*

The web-service applications are used to synchronize the PSCoMS tool with the End User application, which allows having for each user their own interfaces, and can also be used as widgets within virtual rooms of the remote collaboration environment. The Knowledge Management framework consists of a repository of data and information generated by a set of ontologies and rules, containing the information extracted from legacy systems (e.g., product data, suppliers descriptions etc.), as well as the definition of PSS concepts, business models, production networks, risk factors, rules and facts. Such information supports decision-making during the different PSS lifecycle stages, and creates the knowledge required during the first phases of the P-SLM.

In order to understand how the PSCoMS tool works and what is the role of Knowledge Management framework, a brief ideation process description is given. Firstly, the Idea Manager application creates new instances of "Idea" in the Knowledge Management system. Such instances are elaborated and used to create new "concepts", which are evaluated within the Collaboration Environment and promoted to become "Prototypes", if they are not rejected along the decisional steps. After that, the Product-Service Configurator application extracts descriptions of Prototypes from the Knowledge repository and sets up a workflow where different stakeholders can contribute to the complete definition of a PSS prototype, completing different types of "what-if" analysis (e.g., risk assessment, business models evaluation, technology maturity assessment, etc.). Results are returned and combined in the Product-Service Configurator interface, where all the accumulated knowledge is traced and shared. All applications are accessed by members of the design team by the End User application, along the entire process.

Such the tool has been involved at the beginning of the methodology proposed by this research thesis, in order to identify and collect all the ideas generated. Moreover, such the FLEXINET tool can be used also to collect and manage all the design information and results derived by the different methodology steps that will be described in deep in chapter 5.

4.2. MSEE

The MSEE project vision stems upon two complementary pillars, which have characterized the last ten years of research about Virtual Organizations, Factories and Enterprises: Service Oriented Architectures (SOA) and Digital Business Ecosystems (DBE). Indeed the implementation and full adoption of both principles contribute to make European Factories and Enterprises smarter, more virtual, and more digital.

According to this vision, the grand challenge of MSEE project is to transform current manufacturing hierarchical supply chains into manufacturing open ecosystems, able to, on the one side, define and implement business processes and policies to support collaborative innovation in a secure industrial environment, and on the other side, define a new collaborative architecture to support business-IT interaction and distributed decision making in virtual factories and enterprises. In this way, manufacturing companies can go toward Virtual Factory industrial models, where service orientation and collaborative innovation will support a new renaissance of European business model in the global manufacturing context. More in particular, MSEE sees two main generic classes of scenarios for synthesizing service-orientation and open collaboration:

- *Product2Service scenario*, characterising by a sharply decoupling between manufacturing of goods and selling of services, and where physical goods remains the property of the manufacturer and are considered as investment, while revenues come uniquely from the services. Sometimes, physical products are not able to convey the right marketing and selling messages to customers, mostly those related to intangible values like reliability, accuracy, innovation, security, energy, environmental and social responsibility. In this way, selling services instead of physical goods could help Europe to beat the low-wages countries competition and to promote the new European values. This model represents a challenge for manufacturing industry, which needs, on the one hand, to self-organise in order to support the overall service lifecycle in connection with the existing product lifecycle; on the other hand, to develop and implement new market and business models, based on global collaboration and deep knowledge of the customers and their perceived value.

- *Product+Service scenario*, characterising by the simultaneous offering of physical products extended with proper tailored services. In this case, both physical products and services contribute to the revenues, and continuous innovation of services assumes a key competitive advantage. The need for an ecosystem of partners is in this case even more urgent, as manufacturing industry has in general nothing to do with innovation in social well-being or innovation in virtual services and IoT. This is usually really a revolution for European traditional manufacturing industries. Enterprises need to develop new competencies and processes in order to support the overall service lifecycle, while collaboration with research centres and participation of customers to the whole service ideation and development processes needs to be carefully planned and governed.

According to the described context and the European need for a holistic approach to joint product-service lifecycle engineering, MSEE has provided several methods and tools that are able to support the design and development of PSS solutions, both in Product2Service and Product+Service scenarios. MSEE proposes a 3D reference framework for Servitization: M dimension (Manufacturing extended products), where services and products are increasingly entangled towards new ways of business; S dimension (Service driven Engineering), which identifies the degree of knowledge necessary to implement the services; E dimension (Ecosystem collaborative innovation), regarding the different levels of collaboration among enterprises to implement the service innovation strategy (Figure 20).

The main areas covered by MSEE methods and tools along the PSS Design process are highlighted in the following:

- *Maturity, Positioning and Change Management*. This approach helps companies to identify their current positioning and the positioning of their ecosystem with respect to the ability to implement service innovation and to be collaborative in the creation of an ecosystem. It also suggests what are the weak Process Areas within the company that should be improved in order to increase the maturity level of the respective maturity index.
- *Service Strategy and Business Models*. This approach supports companies to identify opportunities for new and innovative combinations of products and services Due to limited resources, it focuses on promising search areas. The Method to define Search Areas should help manufacturing enterprises to look beyond well know domains that are already served and do this in an efficient way. An enterprise can choose different strategies to search for Servitization opportunities that depend by the link between the potential "distance" from the own existing product and the "home market" that is served (i.e. same business area, other business area, comparable physical products, different physical products or no direct product relation).
- *Service Ecosystem Solutions*. A Conceptual Model has been defined in MSEE place, involving different dimensions and components, as organisational dimension (it addresses the structure and composition of a MSE, its participants and roles performed by them), componential dimension (it focuses on the tangible and intangible assets that a MSE needs in order to fulfil its objectives), functional dimension (it addresses the activities and processes available at the MSE and the execution of time-sequenced flows of operations related to the different lifecycle phases), governance & Behaviour dimension (it addresses the principles, policies and governance rules that drives or constrain the behaviour of the MSE and

its members), ICT dimension (it involves the technical information infrastructure supporting the MSE and underlying IT and IoT paradigms).

- *Service Engineering Solutions*. A complete methodology was developed in order to engineer the service system related to the manufacturing product. The approach provides the assets used in the 'Requirement' and 'Design' phases of the SLM. In order to better define and implement the service system, it is necessary to separate the preoccupations, from the user point of view to the technical point of view. The user point of view is more focused on the definition of the service product and service system, in particular from the business process, the decision and the information system modeling points of view, while the technical point of view is more focused on the progressive implementation of the service product and service system taking progressively into account the technical constraints. This approach defines a framework for service system modeling based on three abstraction levels: BSM (Business Service Model), TIM (Technology Independent Model) and TSM (Technology Specific Model) as well as the dedicated modeling languages at each level.

According to the MSEE general overview and the challenges discussed in chapter 3, such the project is able to face the PSS design tool issue, proposing a set of methods and tools that foresee the manufacturing transition towards the development of service solution. Two of these tools have been involved in the methodology proposed by this research thesis and their details and description will be produce in the next paragraph.

4.2.1. MSEE methods & tools: SLMToolBox

The Service Lifecycle Modelling tool (SLMToolBox) is a software tool which supports the phases related to service engineering. The tool has been used in the frame of enterprise projects which aim developing a new service or an improvement on a service, within an organization. It can be used at the stage of "requirement elicitation" and "PSS design" of the product-service engineering process.

The foundation of the SLMToolBox is based on the modeling architecture namely "Model Driven Service Engineering Architecture", and it provides the appropriate structure for elaborating service requirements and design, thanks to a set of specific meta-models dedicated to the domain of manufacturing services.

The SLMToolBox supports the service system modeling activities by providing "template" editors for domain specific models and related modeling languages to enhance the description of the models. Additionally, such the tool provides service simulation features on the basis of "Business Process" models formalized with Extended Actigram Star language. The simulation will be based on two complementary criteria:

- Time (estimation of the time needed for a process execution, and of tasks within this process);
- Cost (represented by the cost of resources allocated for the process's execution).

It also supports the definition of the governance of the service system, which will be then implemented by the organization to continuously assess the performance of the service, according to the three decision levels of the organization (Strategic; Tactic; Operational), its functions and its detailed objectives. Finally, the tool proposes a reference list of performance indicators, categorized by domain and aggregation level (i.e. enterprise or virtual enterprise) according to the service governance method defined in the MSEE project.

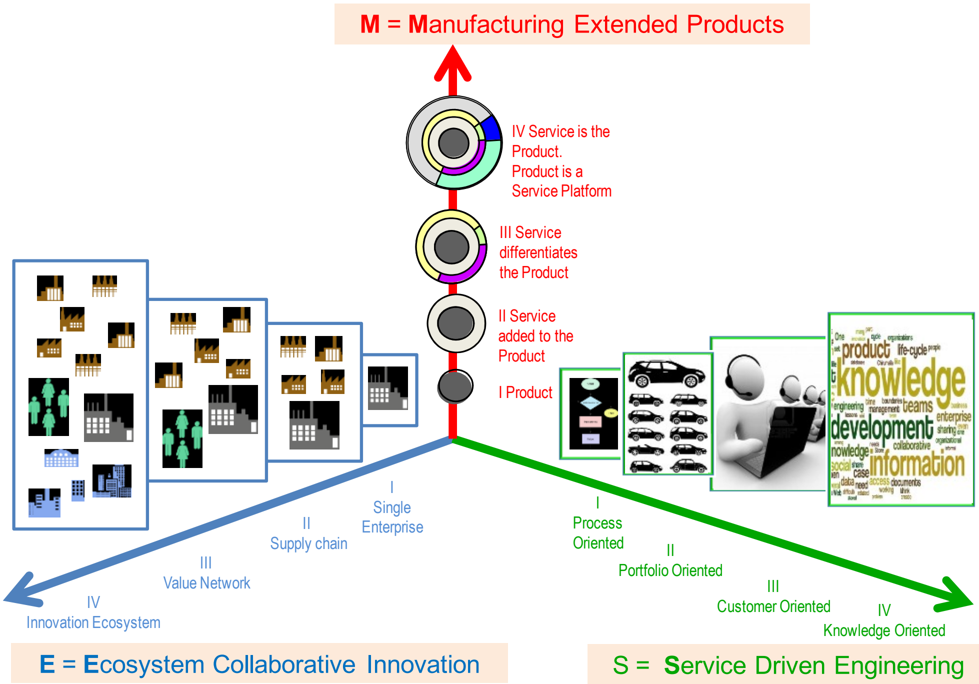


Figure 20. *MSEE 3D reference framework for Servitization*

4.2.2. MSEE methods & tools: Business Model development

The Business Model development is supported by MSEE in a workshop concept, outlining the different steps of the approach. The methods and tools involved during the workshop are based on each step of the Approach for Business Model Development, according to the diagram flow in Figure 21.

The participants of the workshop needed to start a discussion of the explicit competitive strategy according to the approach of Porters strategy framework. Following competitors analysis, the company’s strategy and Business Model are analysed, starting with the strategy if the company is in awareness of its own strategy and starting with the Business Model if not. By using STEEP-Analysis and the Six-Paths-Framework, two methods to analyse the ecosystem overall are applied. By using the Four Actions Framework, the old strategy is questioned and edited by new factors. Finally the result should be a new strategy canvas and a Business Model Canvas. The results of every method and framework were documented continuously in digital tables or on printed papers by notes. For visual support, a set of slides that supports the moderation and the application of the workshop were created.

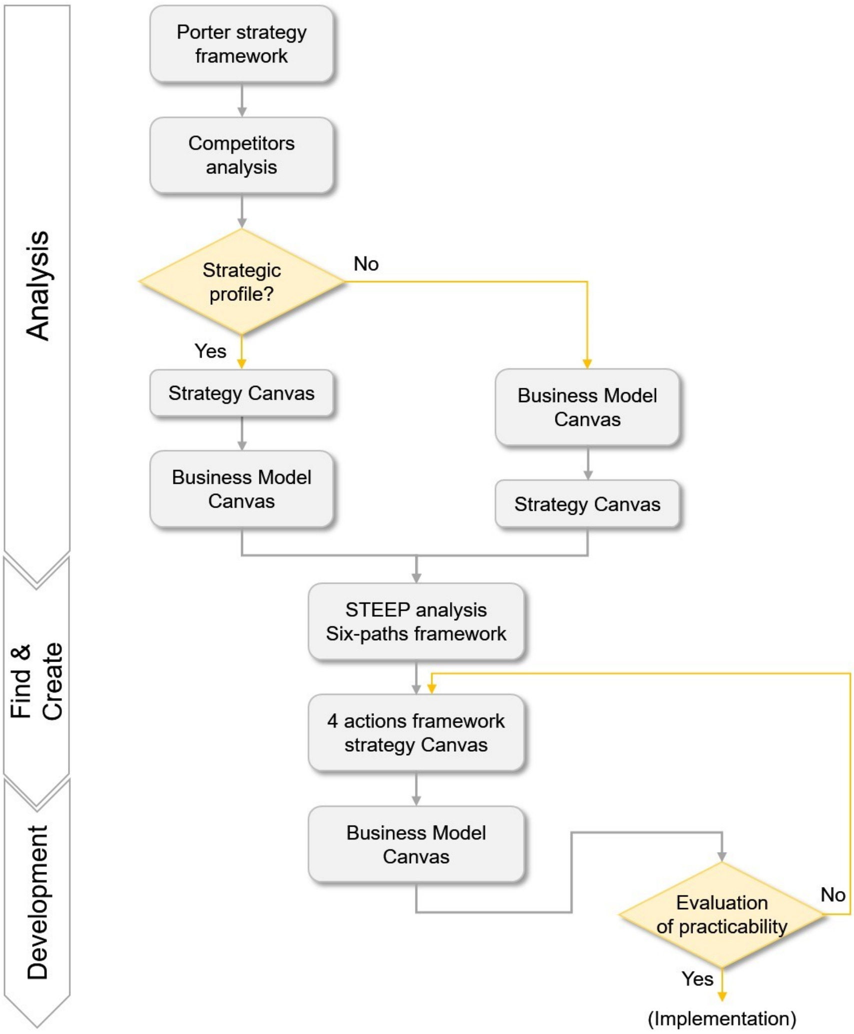


Figure 21. *Business Model development diagram flow*

4.3. Conclusions

This entire chapter (chapter 4) has showed how two European projects were able to address some of the main challenges identified in PSS field, and what are their main tools that can be involved inside the integrated methodology proposed by this research thesis. In the following, in order to have a clear overview, Table 4 shows which PSS challenges MSEE and FLEXNET address, and also which will be that addressed by this thesis work.

Table 4. *Correlation between challenges, European platforms and thesis aim*

PSS challenges	*Project*
Knowledge management *(Ontologies & open innovation approaches)*	*FLEXINET platform*
Design tools to support PSS development at different stages *(SLMToolBox, Business model development)*	*MSEE platform*
Integrated design method based on UCD approach *(QFD, role playing, serious game, etc.)*	*Method proposed by this thesis*

Chapter 5. Methodological approach to Design a Product-Service System

According to both the research questions identified in Chapter 2 and the challenges and issues discussed in Chapter 3, this thesis would propose a novel methodology to adopt for PSS engineering, by integrating different methods and tools already existed in literature, in order to overcome the main limitations emerged and achieve a successful PSS design process focused on the satisfaction of the customer needs.

Indeed, the limitations and gaps that such the research thesis aims to address are summarised in the following:

- currently, a structured design approach for PSS does not exist, thus manufacturing companies that would approach the Servitization process instead the traditional product-oriented proposal have several difficulties to configure the right solution to offer on the market;
- generally, the design of a novel solution is always set according to a product-oriented vision and not as a user-centred one. In this way, only the technical aspects are involved in the design phase, leaving out the component linked to the user needs and requirements;
- the business evaluation is generally conducted at the end of the technical design, where the economic aspects of the proposal are assessed according to the technical configuration designed. This means that if the economic assessment needs to have some changes at technical level for improving the business model, the timing to have the industrialization of the novel solution is very long.

According to the description of the main gaps that such the research would address, this thesis defines a structured method to correlate the different design steps, from the analysis of the customers' needs to the global production network definition. It considers the reference model proposed by Pahl et al. (1994) for product design, but enhances the current product vision including also the service design along the P-SLM. The methodology flow is based on a set of correlation matrices to map the relationships between input and output data that are faced at each P-SLM stage. It has been adopted a Quality Functional Deployment (QFD) approach [Cohen 1995] to drive designers along the technical and business evaluation, using the output of each matrix as the input of the following one. Moreover, the proposed methodology combines the User-Centred Design (UCD) principles and business modelling practices, in order to configure a tailored business model while designers and the other actors (Figure 11) are involved in the PSS engineering. In this way, designers can have at the end of the design phase not only the technical configuration of the PSS, but also the information about costs, revenues, delivery channels and partners' network, allowing also the reduction of time to market for innovative value propositions. Moreover, according to Figure 14 where different methods and tools support the PSS engineering in single phases, and Figure 15 where the two European platforms showed in Chapter 4 are able to face different steps along the P-SLM but not the entire engineering phase, Figure 22 highlights how the methodology proposed by this research work is able to support and cover all the P-SLM phases, from Ideation to Co-Creation.

According to the PSS challenges discussed in Chapter 3 and the general overview presented in Table 4, the proposed methodology aims to address the user centred design issue. Indeed, such the methodology proposes a UCD approach to involve the users into the definition of the PSS features and the early validation during the design stage. Firstly, techniques as interviews, questionnaires and role-playing allow company team identifying the PSS users' needs and the main tasks, by directly considering a set of "personas" representing sample users [Simsarian 2003]. Role-playing is performed by experts in the specific PSS domain, who play as characters into the real context of use, simulating the actions and moods of the consumers. Personas are wider used in the investigation of user experience as fictional characters representing different user types and experiences. The following step is the technical analysis of PSS tasks in order to define the PSS functions. In this context, Business Use Case (BUC) analysis provides a user-centred investigation and defines a PSS model where the most significant items are schematically represented and the goal-oriented interactions between external actors and the PSS are depicted. In this way, it supports the definition of the stakeholders involved and the main PSS features, the key business features, the necessary sub-systems, and the infrastructure capabilities [Wallin et al. 2013]. Finally, PSS validation is based on the creation of a PSS prototype able to concretize the PSS features and exploit the human-system interaction to support its evaluation and testing.

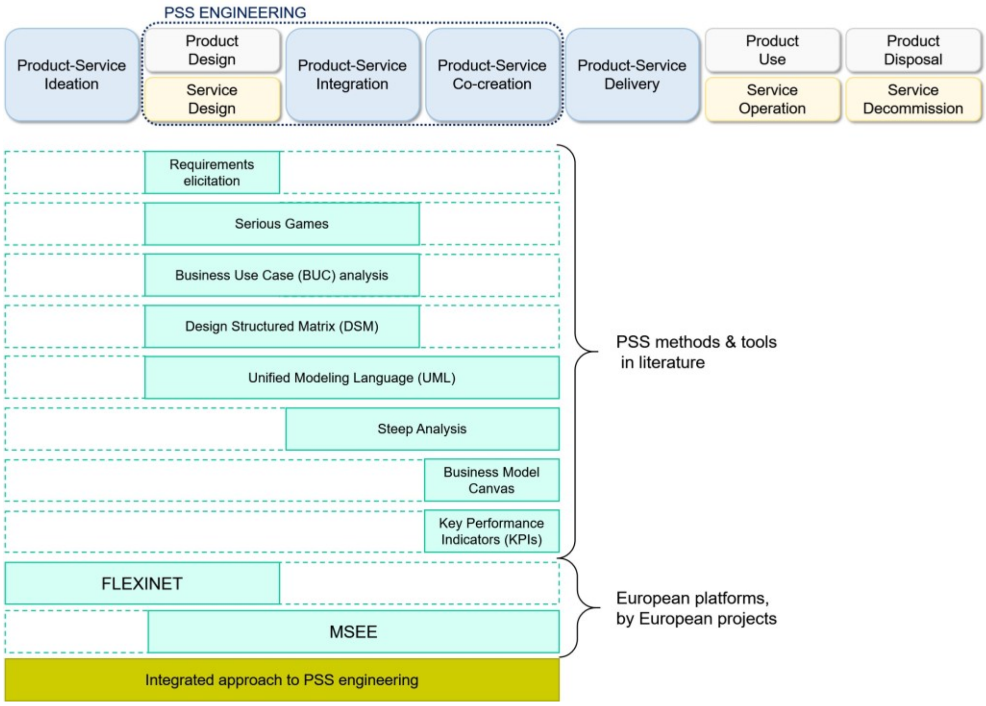


Figure 22. *How the Integrated Approach proposed address the P-SLM*

The next section (paragraph 5.1) provides a detailed description of the methods and tools involved by the proposed approach, while the paragraph 5.2 shows in detail the structured methodology steps to design a PSS and define at the same time also the business model.

5.1. Methods & Tools involved in the methodological approach

5.1.1. Quality Functional Deployment (QFD) approach

When companies face the product or service design, the dedicated design team needs to know what the object of the design activity and what the end-users will expect from it. Quality Function Deployment (QFD) is a systematic approach to design a product or a service, based on a close awareness of customer desires, coupled with the integration of corporate functional groups. It consists in translating the customer needs into engineering characteristics for a product or service, for each stage of the product development [Rosenthal 1992]. Indeed, it helps create operational definitions of the requirements, which may be vague when first expressed, translating often subjective quality criteria into objective ones that can be quantified and measured and which can then be used to design and manufacture the product. It is a complimentary method for determining how and where priorities are to be assigned in product development. The intent is to employ objective procedures in increasing detail throughout the development of the product [Reilly 1999].

As described by Dr. Yoji Akao (1990), who originally developed QFD, it is a "method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process." By 1972, the power of the approach had been well demonstrated at the Mitsubishi Heavy Industries Kobe Shipyard [Sullivan 1986]. Indeed, and when it is appropriately applied, QFD has demonstrated the reduction of development time by one-half to one-third [Akao 1990].

QFD is applied not also in product or service engineering, but also in marketing science, to help planners focus on characteristics of a new or existing product or service from the viewpoints of market segments, company, or technology-development needs.

The technique yields charts and matrices. Each phase, or matrix, represents a more specific aspect of the product's requirements. Relationships between elements are evaluated for each phase. Only the most important aspects from each phase are deployed into the next matrix.

- Phase 1, Product Planning: Building the House of Quality. Led by the marketing department, Phase 1, or product planning, is also called The House of Quality. Many organizations only get through this phase of a QFD process. Phase 1 documents customer requirements, warranty data, competitive opportunities, product measurements, competing product measures, and the technical ability of the organization to meet each customer requirement. Getting good data from the customer in Phase 1 is critical to the success of the entire QFD process.
- Phase 2, Product Design: This phase 2 is led by the engineering department. Product design requires creativity and innovative team ideas. Product concepts are created during this phase and part specifications are documented. Parts that are determined to be most important to meeting customer needs are then deployed into process planning, or Phase 3.
- Phase 3, Process Planning: Process planning comes next and is led by manufacturing engineering. During process planning, manufacturing

processes are flowcharted and process parameters (or target values) are documented.

- Phase 4, Process Control: And finally, in production planning, performance indicators are created to monitor the production process, maintenance schedules, and skills training for operators. Also, in this phase decisions are made as to which process poses the most risk and controls are put in place to prevent failures. The quality assurance department in concert with manufacturing leads Phase 4.

QFD is applied in a wide variety of services, consumer products, military needs and emerging technology products. The technique is also included in the new ISO 9000:2000 standard which focuses on customer satisfaction and it involves a set of matrixes that are able to manage and analyse a great amount of product and service information.

5.1.2. Unified Modeling Language (UML)

The Unified Modeling Language (UML) is a general-purpose, developmental, modeling language in the field of software engineering, which is intended to provide a standard way to visualize the design of a system, indeed its acronyms means unifying language enabling IT professionals to model computer applications. UML was originally motivated by the desire to standardize the disparate notational systems and approaches to software design developed by Grady Booch, Ivar Jacobson and James Rumbaugh at Rational Software in 1994–1995, with further development led by them through 1996.

One reason UML has become a standard modeling language is that it is programming-language independent. Moreover, the UML notation set is a language and not a methodology. This is important, because a language, as opposed to a methodology, can easily fit into any company's way of conducting business without requiring change. Since UML is not a methodology, it does not require any formal work products (i.e., "artifacts" in IBM Rational Unified Process® lingo). Yet it does provide several types of diagrams that, when used within a given methodology, increase the ease of understanding an application under development.

The most useful, standard UML diagrams are: use case diagram, class diagram, sequence diagram, state chart diagram, activity diagram, component diagram, and deployment diagram.

UML has been evolving since the second half of the 1990s and has its roots in the object-oriented methods developed in the late 1980s and early 1990s. It is originally based on the notations of the Booch method, the object-modeling technique (OMT) and object-oriented software engineering (OOSE), which it has integrated into a single language. Several evolution of this first version has been done along the time, until the definition of UML 2.0 revision replaced version 1.5 in 2005, which was developed with an enlarged consortium to improve the language further to reflect new experience on usage of its features. Other improved version of UML 2.0 have been developed until now

However, it is important to distinguish between the UML model and the set of diagrams of a system. A diagram is a partial graphic representation of a system's model. The set of diagrams need not completely cover the model and deleting a diagram does not change the model. The model may also contain documentation that drives the model elements and diagrams.

UML diagrams represent two different views of a system model (Figure 23):

- Static (or structural) view: emphasizes the static structure of the system using objects, attributes, operations and relationships. It includes class diagrams and composite structure diagrams.
- Dynamic (or behavioural) view: emphasizes the dynamic behaviour of the system by showing collaborations among objects and changes to the

internal states of objects. This view includes sequence diagrams, activity diagrams and state machine diagrams.

UML 2.0 has many types of diagrams, which are divided into these two categories.

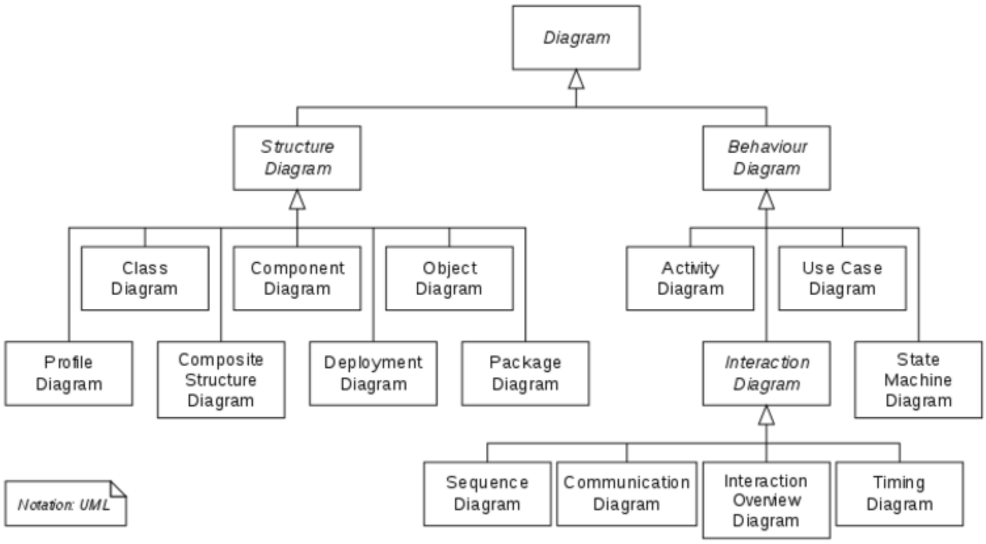


Figure 23. *UML 2.0 model: structure and behaviour views*

Structural model represents the framework for the system and this framework is the place where all other components exist. So the class diagram, component diagram and deployment diagrams are the part of structural modeling. They all represent the elements and the mechanism to assemble them. But the structural model never describes the dynamic behaviour of the system. Class diagram is the most widely used structural diagram. Behavioural model describes the interaction in the system. It represents the interaction among the structural diagrams. Behavioural modeling shows the dynamic nature of the system.

5.1.3. UCD role playing and the Business Use Case (BUC)

The user centred design is the main approach that can support the PSS design and it can be realised through the application of different methodologies that are listed in

Table 5. Here the main UCD role playing methods have been highlighted and discriminated by costs, outputs, size and application.

Table 5. *UCD role playing main methods*

Method	*Cost*	*Output*	*Sample size*	*When to use*
Focus groups	*Low*	*Non-statistical*	*Low*	*Requirements gathering*
Usability testing	*High*	*Statistical & Non-statistical*	*Low*	*Design & Evaluation*
Card sorting	*High*	*Statistical*	*High*	*Design*
Participatory design	*Low*	*Non-statistical*	*Low*	*Design*
Questionnaires	*Low*	*Statistical*	*High*	*Requirements gathering & Evaluation*
Interviews	*High*	*Non-statistical*	*Low*	*Requirements gathering & Evaluation*

Also the BUC is a UCD approach, but it is not involved as a role playing method. Indeed, Business Use-Case is a way in which a customer or some other actors involved or interested can make use of the business to get the result they want. An important point is that a single execution of a Business Use-Case should encompass all the activities necessary to do, what the customer (or other actors) wants, and also any activities that the business needs to do before the process is complete from its point of view. Thus, the duration of a BUC execution can vary greatly, depending on its nature. Some BUCs, like withdrawing cash from an ATM, can be done in less than a minute; others, like ordering goods for delivery, or getting a new phone line installed, can take days, weeks or even longer.

A primary purpose of the model of business use cases and actors is to describe how the business is used by its customers and partners. Activities that directly concern the customer, or partner, as well as supporting or managerial tasks that indirectly concern the external party can be presented. The model describes the business in terms of business use cases, which correspond to what are generally called "processes".

When looking at the activities in a business, it is necessary to identify at least three categories of work corresponding to three categories of business use cases:

- First, there are the commercially important activities, often called business processes.
- Second, there are a lot of activities that are not that commercially important, but have to be performed anyhow to make the business work. Systems administration, cleaning and security are typical examples. The business use cases are of a supporting character.
- Third, there is management work. Business use cases of management character shows the type of work that affects how the other business use cases are managed and the business' relationships to its owners.

Usually a business requires the involvement of many business use cases. Instances of several different business use cases, as well as several instances of a single business use case, will normally execute in parallel. There may be an almost unlimited number of paths a use-case instance can follow. These different paths represent the choices open to the use-case instance in the workflow description. Depending on specific events or facts, a use-case instance can proceed along one of several possible paths.

Every core business use case should have a communicates-relationship to or from a business actor. This rule enforces the goal that businesses be built around the services their users request. Even these business use cases have business actors that originally initiated them, and expect different services from them. Otherwise they would not be part of the business. Other business use cases will produce results for a business actor, although they are not explicitly initiated by the business actor.

Management and supporting business use cases do not necessarily need to connect to a business actor, although they normally have some kind of external contact. Abstract business use cases do not need a business actor, because they are never instantiated ("started") on their own.

There are three main reasons for structuring the business use-case model:

- To make the business use cases easier to understand;
- To reuse parts of workflows that are shared among many business use cases;
- To make the business use-case model easier to maintain.

Because a BUC is a good model, it requires to ollowing characteristics:

- conform to the business it describs;
- all use cases are found. Taken together, use cases perform all activities within the business;
- every activity within the business should be included in at least one use case;
- there should be a balance between the number of use cases and the size of the use cases: few use cases make the model easier to understand, many use cases may make the model difficult to understand, large use cases may be complex and difficult to understand, and finally small use cases are often easy to understand. However, make sure that the use case describes a complete workflow that produces something of value for a customer;

- each use case must be unique. If the workflow is the same as or similar to another use case, it will be difficult to keep them synchronized later. Consider merging them into a single use case
- the survey of the use-case model should give a good comprehensive picture of the organization.

5.1.4. Serious Game

This approach has been adopted in this research thesis to conduct the Requirements Engineering. It involves three main phases: preparation phase, gaming phase, and review phase.

The preparation phase deals with the preliminary identification of needs during early meetings with the end users and the creation of current business use cases and the accompanied scenario descriptions. Also, the Serious Games are adapted during the preparation phase and the scenarios are implemented.

The review phase consists of the analysis and documentation of the requirements from Serious Gaming. On this basis, new industrial models are developed and KPI's can be selected for the validation of the industrial model impact.

The gaming phase comprises the gaming workshop and the after workshop gaming sessions. In this phase, the desired changes in process parameters are defined by the end-users and the requirements are derived. After the first requirements workshop, the current Indesit product offer has been analyzed and compared to the Product+Service solution, in order to identify the innovative requirements. The specific use cases have been discussed in a second requirements workshop. Here, the business scenarios created from the use cases will be implemented into the Serious Games

The gaming is based on the results from the preparation phase. It can be divided into the gaming workshop and online-playing sessions that will take place after the workshop. The main objective during the gaming phase is the collection of detailed requirements.

The conceptual model of the gaming approach used for the collection of user requirements is described by the following:

- Definition of the business use cases;
- Analysis of needs;
- Refinement of needs into requirements;

- Specification of requirements.

In the first step, a dedicated tool simulates the business scenarios defined in the preparation phase. In the second step, a game for supporting the first phase in an innovation process will be used, which allows defining and playing different scenarios. Each scenario needs to be played three times, in order to develop requirements taking three different perspectives into consideration. The review phase starts after the gaming workshop has been conducted and is used to analyze and document the data generated during gaming. The outcome of the Serious Games sessions will be checked. Finally, the specific requirements of the players that have been elicited for servitization, and the innovation ecosystem in the second step, will be analyzed and used for the further enhancement of the requirements specification.

5.2. Methodology description: the integration of different design tools and methods

The Integrated methodology aims at supporting manufacturing companies in the early stages of P-SLM, from Ideation to Co-Creation, according to the above-mentioned workflow (Figure 22).

Such the method is based on QFD approach and offers an easy-to-use tool to overcome the main criticalities of PSS design, in particular subjectivity, poor sustainability, and involvement of the right partners according to the business model configured. Indeed, in general applying QFD can bring benefits during the design process such as:

- better structuring of the design process;
- shortening of design cycle;

- correlation among all data managed by the companies involved and their internal departments, especially facilitation of communication between marketing and engineering;
- objectification of the analyses by the translation of vague and immeasurable customer wishes into that tangible features;
- elicitation of robust requirements and identification of the product features that mostly contribute quality attributes.

As far as PSS is concerned, there are four reasons why it would be possible to justify the use of QFD in the development of PSS [Shen and Wang, 2008]: firstly, the application of QFD requires careful analysis of the consumer during the development process, which agrees with the definition of customer-oriented PSS and user-centred design approach; secondly, QFD can be used not only for products but also for processes and services design; thirdly, QFD brings cross-functional teams together and fosters communication and cooperation among multidisciplinary development teams as required for PSS; finally, QFD is a structured method with a great deal of flexibility and can be easily extended and adapted to different contexts of use.

In our case, the adoption of a QFD approach guarantees a careful selection of the consumer needs, a severe investigation of the PSS ideas coming from different actors, both internal (i.e. internal company departments) and external (e.g. actors involved in the network, customers) to the manufacturing company, and a controlled elicitation of functional and ecosystem requirements for identifying the PSS solutions. Moreover, the rigorous data structuring allows the PSS tangible and intangible assets to be easily selected by designers. Indeed, thanks to the sequential correlation mechanism based on a set of matrixes, data outputs at one stage are related to data inputs in the following stages, and results can be easily objectified. The methodology approach overview and all the involved steps are represented in Figure 24, where each step contributes to fulfil a matrix by using data and resources as indicated. Numbers in circles indicate the exact step number they refer to.

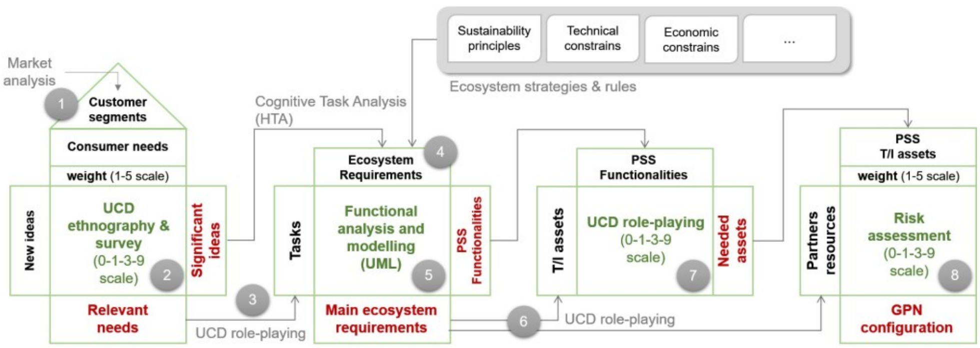


Figure 24. *Methodology steps for designing a PSS*

The process starts from the correlation between customer needs and the new ideas, and moves on, by exploiting the obtained results in the next houses in order to select both the main ecosystem requirements and the PSS technical functionalities. The ecosystem requirements are used to derive both the tangible and intangible (T/I) assets and the main partners' resources. Indeed, the third matrix aims to correlate the PSS functionalities resulted by the second one to the T/I assets derived. Finally, the last matrix puts in correlation the needed assets resulted by the third matrix with the partners' resources derived by the results of the second one. Thanks to its structured approach, the methodology supports companies in facing service innovation and designing PSS, involving different methods and tools already existed in literature in each matrix, in order to analyse the correlation between the values along the lines and columns. Moreover, such the method is able to integrate the sustainability principles beside from technological and economic constrains; they are involved in the second matrix, during the requirements elicitation, in order to identify all the ecosystem requirements, not only by technical point of view.

According to the application of this methodology, the PSS technical design can be developed. Contemporarily, the proposed methodology has a direct correlation with the definition of the PSS Business Model (BM). In fact, the results obtained by the various matrixes are linked to a specific business model area of the Canvas Model [Osterwalder and Pigneur 2009]. Figure 25 shows such the connection between each step of the design methodology proposed and the BM Canvas areas.

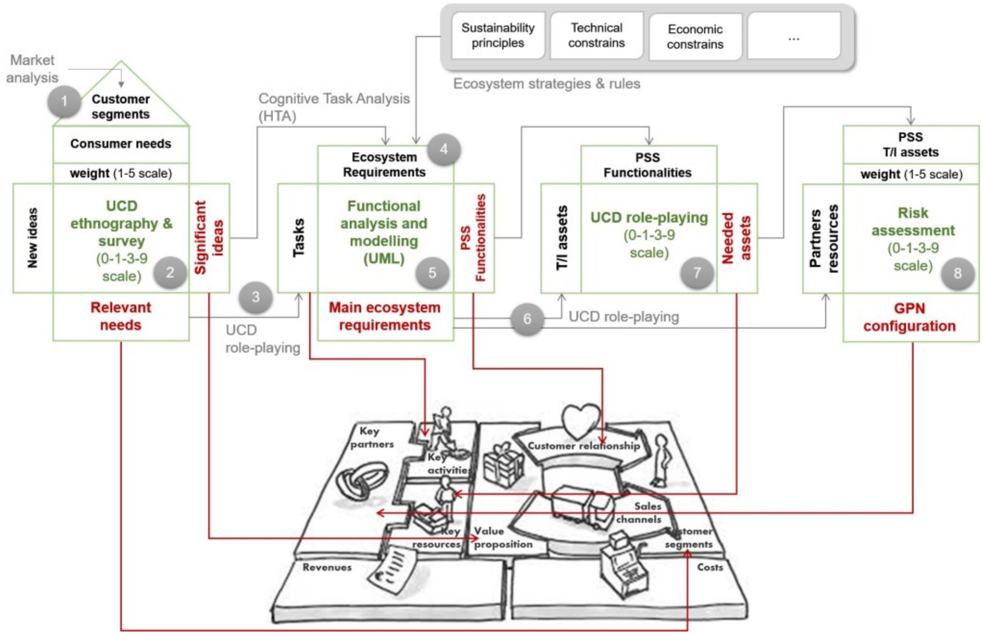


Figure 25. *Technical and Business evaluation in PSS engineering*

In this way the proposed method is useful not only by technical point of view to support the design of a PSS, but it also allows covering the main business areas (i.e. Value Proposition, Key Partners, Key Resources, Key activities, Customer Relationship, Customer Segments) together with the PSS design. This correlation represents the main innovation of this methodology, besides to have integrate several methods already existed in literature but facing a specific issue along the PSS engineering. Moreover, such the integrated approach represents a great advantage for PSS designers, because the BM definition can be anticipated at the early design stage to support feasibility analysis in easy and fast way. For this reason, the method allows simplifying the connection between PSS technical design phase and BM definition, which can be carried out concurrently.

The methodology steps highlighted in Figure 24 will be described more in deep in the following.

Step 1: Market analysis. It analyses the target market to define the customer needs as well as the demands for the new PSS solution. It can be carry out in different manners according to the specific sector and the market typology, adopting UCD techniques (e.g. focus group, involvement of sample users, desk research, interviews and questionnaires, ethnography, personas). Above all, ethnography and surveys [Sharp 2007] are used for eliciting the customer needs. Ethnography consists of providing a qualitative description of the human social condition based on fieldwork and users' observation in their natural setting. Survey is added to make the user study more interactive and also collect directly the users' feedback.

Usually, market analysis is carried out mainly by the Company Marketing department and allows identifying first of all the customer segments for the involved sector and the relative products, and then defining a set of needs and their relative weights (usually expressed according to a 5-point Likert scale). At the same time, new ideas are collected by different actors (both internal to the company and external to it, as customers) thank to the adoption of the Idea Manager tool (developed within FLEXINET project).

Step 2: Matching between customer needs and PSS ideas. This step produces the results of the first methodology matrix. It elicits the correlation between the collected ideas and the customer needs, which is a key activity to reach a high perceived value. This correlation has been defined by the direct involvement of the company technical staff (e.g. R&D department, Service department, Marketing department, designers), which expresses the link between ideas and customers' needs by a 0-1-3-9 scale, where 0 represents no correlation, 1 means low correlation, 3 is medium correlation and 9 represents high correlation. Through the result calculated by this first matrix, it is possible to identify the most relevant ideas and the most significant needs. Contemporarily, from a business viewpoint, the results obtained can be used to define two areas of the BM, according to CANVAS model; they are the customers segments and the value proposition.

Step 3: Definition of the user tasks. It adopts UCD techniques (i.e. role-playing) to highlight the tasks to be executed in order to satisfy the selected user needs. Role-playing is performed by experts who play as characters into the real context of use, simulating the actions and moods of the consumers, according to the customer segments identified in the previous matrix. Such the technique allows a vivid and focused exploration of different scenarios and generation of ideas in order to "being in the moment" and share with the customers their experiences [Simsarian 2003]. From a technical viewpoint, tasks are necessary to deal with PSS functions, while from a business viewpoint, tasks are connected to PSS customer relationship since they express how the users interact with PSS, how they communicate with PSS providers, under which circumstances and how frequently, how they access to both product and services, and so on. Moreover, tasks are used to define the Key Activities to realize and develop the value proposition.

Step 4: Requirements elicitation. It uses Cognitive Task Analysis (CTA) and in particular Hierarchical Task Analysis (HTA) [Kirwan and Ainsworth 1992] to define a list of basic, technical and attractive requirements. The elicitation inputs are the most significant ideas resulted by the step 2. Moreover, also the ecosystem strategies and rules are put into account, in order to identify those requirements that better address both all the PSS ideas and company strategic actions. These strategies and rules involve the sustainability principles (e.g. reduce transportations, energy and other resources efficiency, low emissions, foster the circular economy, etc.), the technical and economic issues and other company constrains (e.g. external factors, national policies, etc.). Such the method addresses the underlying mental processes that give rise to errors during task execution and it is strongly connected with the higher-level mental functions. HTA specifically allows addressing functional requirements as well as the specific actions that are required to satisfy these requirements. In order to elicit the requirements that will be correlated in matrix 2 with the tasks, the Serious Game activities have applied by the Company team involved in the PSS design.

Step 5: Functional analysis. It correlates the elicited requirements and the tasks identified through the application of the functional analysis, which allows analysing both functions and relationship among the two correlation entities (i.e. requirements and tasks). The research refers to the Kano's model to model the customer satisfaction by QFD [Matzler and Hinterhuberb 1998]. This step is carried out by the combined contributions of the marketing staff as well as the technical staff and the service personnel. The result of this second matrix is the definition of the main PSS functionalities that should be developed and delivered in order to satisfy the previous customers' needs. Indeed, during this step, also the UML 2.0 model of the PSS functionalities identified can be conducted. At the same time, according to the simultaneously business analysis, these PSS functionalities are useful to define the best Customer Relationship inside the Canvas BM.

Step 6: Main assets and resources definition. It focuses on the definition of both tangible and intangible (T/I) assets needed to realize the PSS in order to satisfy the value proposition and the customers' needs, and the ecosystem resources required to identify the GPN. To reach this scope, the main ecosystem requirements derived by the previous step (step 5), which is the result of the second correlation matrix, are properly managed through the adoption of the UCD role-playing. This approach is conducted by the PSS design team that involves people from different company departments (e.g. R&D department, Service department, Marketing department, designers, etc.) in order to have a multifunctional group able to face the specific challenge by different point of view. The ecosystem resources starts from the ecosystem analysis and maps all the potential partners and their features (e.g. skills, competences, services, products, response time, cost, regulation respect). Once partners are fully described, functional modelling is used to relate functions and T/I assets (step 7).

Step 7: Correlation between T/I assets and PSS functionalities. In this step, designers, thanks to the UML model conducted at step 5 after the PSS functionalities definition, are able to put in correlation the detailed functional structure of the PSS and the identified T/I assets. Also in this case, the correlation can be done through the adoption of the 0-1-3-9 scale. The result is the list and description of the tangible and intangible assets needed, which will be used in the next step to finally identify the GPN. From a technical viewpoint, the result is the list and description of the T/I assets strictly needed. This result is used by a business point of view to recognize the Key Resources required to realise the value proposition.

Step 8: GPN definition. This last step is based on the matching between the assets identified in the previous step and the specific partners' resources derived by the step 6, according to the risk assessment. Risk assessment focuses on the supply chain due to the distributed character of PSS, so that Supply Chain Risk Management (SCRM) methods are used: they consider risks within the supply chain in terms of supply costs, delivery time, supplier reliability, supply quality, and risks external to the supply chain according to a coordinated approach amongst the chain members to reduce the supply chain vulnerability as a whole [Jüttner et al. 2003]. In this second case, the so-called Social, Technological, Economical, Environmental and Political (STEEP) analysis is applied. At this stage the main company actors that are able to conduct this analysis are the Marketing, R&D and Purchasing staffs. Finally, the ecosystem partners selected during this correlation step are used to identify the Key Partners involved in the PSS network, which will be generate the GPN required to develop the value proposition.

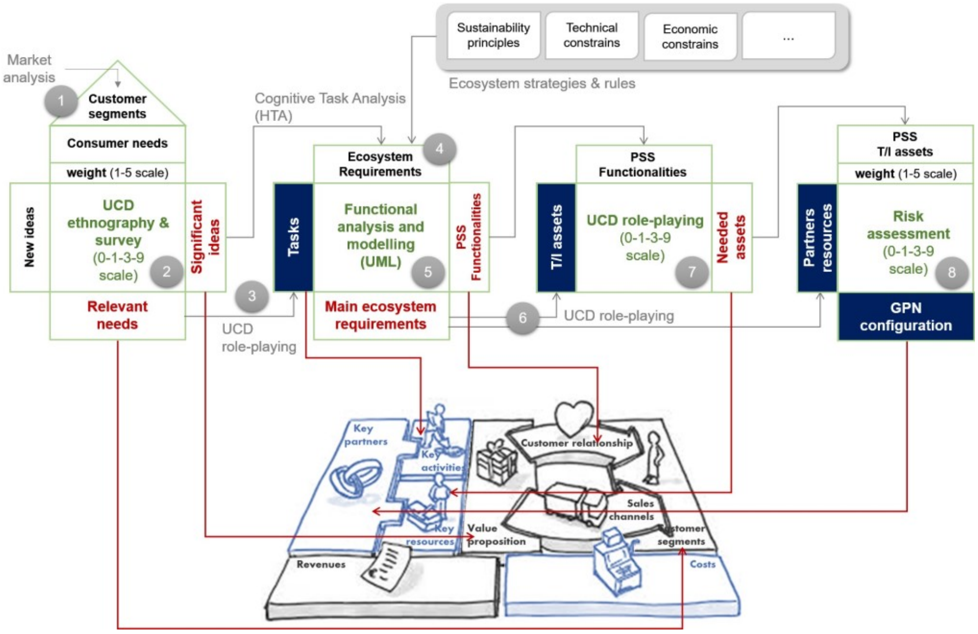


Figure 26. *Methodology affected costs*

As shown until now, the methodology allows conducting technical and business analysis at the same time, deriving the main aspects by the same data. The only two business areas that are outside of the flow already described are the cost structure and revenues. Anyway, also this two information can be derived according to the analyses conducted. Indeed, as shown in Figure 26, the main items involved in the costs generation are the tasks, the T/I assets and the resources, which by a business point of view they respectively are: key activities, key resources, key partners. While the revenues depend directly by the value proposition and the way it is sold or offer to customer (i.e. customer relationship).

5.3. PSS Sustainability Assessment

Inside this thesis, the Sustainability Assessment is a design tool that allows evaluating a solution in order to generate some strategic drivers able to guide the entire PSS design. Indeed, it is involved in step 5 to select and discriminate the different ecosystem requirements; however, such the kind of assessment can be also used as decision-making tool for identifying the best PSS solution after the application of the entire methodology proposed by this research work. For instance, the same value proposition can generate different BMs, which can assessed by sustainability point of view. Despite the different scope, the Sustainability Assessment conducted in this research thesis is in line with the overview presented in Figure 27.

It involves the following steps:

1. Apply a lifecycle modelling approach to the specific case and carry out a detailed functional analysis to assess the lifecycle stages and the systems / subsystems involved. The lifecycle functional model is organized into three main phases:
    a. Manufacturing: all manufacturing processes to realize the global system components and assemblies. It generally adopts the company viewpoint;
    b. Use: all contributions related to the Product or PPS use. It generally adopts the user viewpoint;
    c. End-of-Life: all data related to the Product or PPS recycling, disposal and eventually re-use. It adopts both the company and user viewpoints;
2. Define the use scenarios to be investigated for the specific case;
3. Develop a LifeCycle Assessment (LCA) that is fully consistent with the analysed model and covers all the lifecycle stages to assess its environmental impact;

4. Develop a LifeCycle Cost Assessment (LCCA) that is fully consistent with the analysed model as well to assess its lifecycle cost;
5. Normalize the LCA results by estimating the corresponding economic impact to obtain an monetary value for each use scenario;
6. Couple LCA and LCCA results to obtain a SI (Sustainability Indicator) for each analysed scenario.

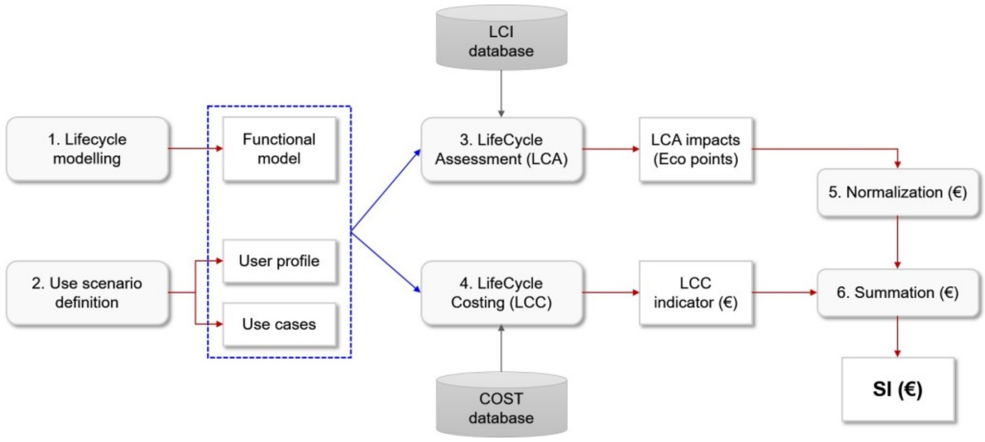


Figure 27. *Integrated LCA - LCC method for sustainability assessment*

In order to simulate the whole lifecycle environmental impact, all significant data referring to raw materials extraction, processing, assembling and transportation as well as the use phase data and the end-of-life information need to be collected. The LCA data need to be multiplied for a set of proper weights in order to have significant results. The Eco-Indicator99 (EI-99) methodology is adopted. EI-99 defines a set of "number" that considers the impact of each material or process according to three categories: Human Health, Ecosystem Quality, and Resources. The measurement unit of Eco-indicators is point (Pt).

LCCA analysis aims to assess and compare costs associated to the whole lifecycle, according to the same model adopted for the LCA analysis. A standardized methodology for LCC has not been defined yet and in literature many different viewpoints are adopted (supplier, manufacturer, user, society). While Net Present Value (NPV) is typically used as a decision making tool for business decisions, LCC takes into account a wide range of technical data which can occur during the whole product lifecycle (e.g. energy or fuel consumption in use, maintenance operations, end-of-life costs), to provide a more technical analysis. The final aim is to highlight the economic impact along the lifecycle by considering a certain lifetime. As a consequence, a proper calculation method needs to be used. In this research, the Equivalent Annual Cash Flow technique (EA) is adopted. It allows to transform a generic cash flow distribution into an equivalent annual distribution having the same actual value, by cost actualization. For cost estimation, the Equation 1 is adopted, where “n” is the lifetime years’, “i” is the generic discount rate (for example i =3%), and “P” is the value during the all lifetime. The values refer to the three analysed stages as well as for LCA investigation (Manufacturing, Using and End-of-Life). LCC results are the sum of the three main contributions after being actualized.

$$EA = P\,\frac{(i+1)^n * i}{(i+1)^n - 1}$$

Equation 1. *Equivalent Annual Cash Flow technique*

In order to combine LCA and LCCA analyses, a Sustainability Indicator (SI) is defined. It provides a monetary index representing both the environmental and economic impacts for the whole lifecycle and along a certain lifetime. It considers the LCA EI-99 results for each of the three safeguard subjects (humans, ecosystems, and resources), expressed by their own measurement units (DALYs and MJ), and redefines them in terms of Quality Adjusted Life Years (QALYs) for impacts on human health, Biodiversity Adjusted Hectare Years (BAHYs) for impacts on ecosystems, and monetary units (EUROs) for impacts on resource productivity. Finally, these three LCA contributions can be translated into monetary values representing the total cost of the environmental impact (Normalized impact). It can be added to the LCCA final result, which expresses the global economic impact, to obtain the global SI. Such a method can be repeated for each analysed systems (Product or PPS) or scenarios, and solutions can be compared by SI.

Chapter 6. PSS Design Method applied in White goods sector

The methodological approach proposed and described in deep in the previous chapter (chapter 5) and that aims to integrate several methods and tools disseminated in literature in order to provide a well-structured and integrated approach to support the PSS engineering, has been applied and validated in this chapter (chapter 6) inside the white goods sector, at Indesit Company, which is a world leader company designing and producing household appliances.

6.1. White goods sector: context, aims and main challenges

The white good sector is one of the most traditional manufacturing industries in Europe. It realizes machines enabling common activities within a domestic environment (i.e. washing dirty clothes, drying wet garments, freezing or cooking food) and it is characterized by high human-product interaction. Furthermore, in this field companies usually collaborates with numerous partners due to the multidisciplinary activities to be carried out. As a consequence, generally main companies have a huge ecosystem, which is one of the most strategic elements of success, and founded their knowledge on the experience and contribution of technological and business partners with peculiar skills.

In this industrial sector, innovation mainly refers to aesthetical and technological aspects and do not include service, indeed products are still sold in traditional manner. This is mainly due to the lack of experience and methodologies to drive companies in the shifting from products to services.

Anyway, these constrains have not limited the white good sector to investigate the PSS as a mean to create new business opportunities and to innovate a product that is almost mature on the market. Indeed, even if real solutions are not still shown on the market to be sold, several big manufacturers in white goods sector are studying and approaching the provision of services instead products, and the related technology that should be implemented.

In particular, household appliances are very good candidates to be enhanced with services because:

1) they usually support a lot of common activities within a domestic environment;
2) they are characterized by a strong human interaction;
3) they usually carry out a "function" more than being a product, so the most important thing for users is not their ownership but the service offered;
4) they are designed and arranged to be equipped with sensors, smart components and ICT systems (mainly to guarantee technical assistance and report back of problems) so they can easily retrieve data also for services (pay attention to the application of IoT and the implementation of Smart Home concept);
5) they have advanced user interfaces.

Moreover, considering that according to a research conducted by European community, by the 2020 the connected devices per person should be about 6, it is evident as the adoption of IoT paradigms and ICT technology have a key role.

This change is always more evident, starting from the home environment, where different appliances are connected to be controlled remotely by smartphone or computer (Smart Home), to make industrial factories and cities smarter and more sustainable (Smart Factories – Industry 4.0 – and Smart Cities), until to be any appliance around the world connected or able to be connected (Figure 28).

According to this trend and focalising the attention on the Smart Home, all the facts listed above state because white goods are a good example to be enhanced with service, and how they can facilitate the introduction of services as an add-on of traditional products, making this sector the perfect candidate to be investigated by a PSS point of view.

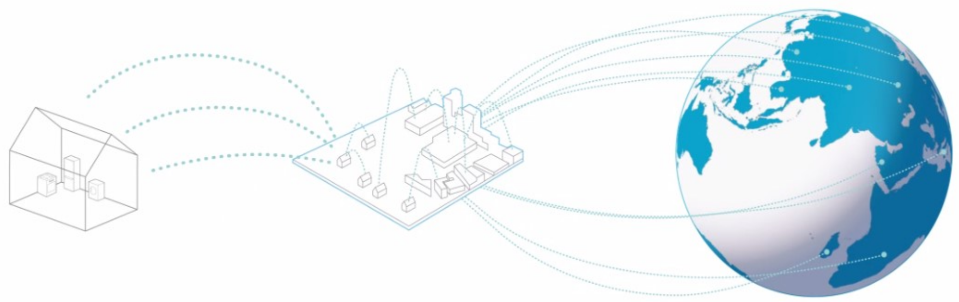


Figure 28. *From smart home, to smart city, until smart world*

The following use case has been conducted at Indesit Company, which is an Italian manufacturer world leader in household appliances production. Currently, such the company has been acquired by Whirlpool, one of its main competitors, but it was able to maintain its identity in terms of products portfolio and research activities.
Indesit Company is a product-centred manufacturer, which has the industrial processes structured as in traditional manufacturing firms, and a worldwide network of suppliers and branches organised in a vertical supply-chain, where there is one leader (i.e. Indesit Company) and limited cooperation with partners. Indeed, the company ecosystem is guided by the manufacturer and is driven by a product-oriented development process. Collaboration between the manufacturer and its partners and suppliers is limited to design stages and components' supply.
However, the company is moving from developing traditional products to designing integrated product-service solutions, with the aim to evolve its business portfolio, increase its market share and create new business opportunities. Actually, it is working on connectivity since several years and it is proposing a set of connected devices (e.g. washing machines, dryers, fridges, ovens) addressing the smart home concept (Figure 29 and Figure 30). Moreover, such the Company from 2012 to 2015 joined at MSEE European project (already explained in chapter 4) to

promote the shift from products to PSSs into a structured manner. The project supported the company to better understand the servitization process and to organize its resources in order to create a novel PSS solution [Peruzzini and Marilungo 2014].

Figure 29. *Indesit evolution, from products to PSS solutions_A*

Figure 30. *Indesit evolution, from products to PSS solutions_B*

Actually, the company still producing and selling products, while services are almost commercial add-ons, so that the real benefits for final users are still hidden, also due the lack of business aspects analysis. Indeed, technical aspects are faced at the beginning of the design activities, while business aspects are defined later on, during the implementation stage. But the company purpose is to innovate the current product offers through the creation of an appealing PSS solution, in order to really innovate the company commercial offer and provide tangible benefits for its customers. In particular, the company aims to integrate both technical and business aspects along the design phase, developing a set of services oriented to support final users in their everyday life and within their homes, by making the use of the new smart devices easier, safer and more comfortable. The main challenge is designing a novel PSS value proposition able to satisfy the real market needs and identify the right business model able to satisfy the customers' expectations. In fact, such the conditions represent the main drivers to foresee a PSS instead of a traditional product.

6.2. Use case description

According to the Company aim discussed in the previous paragraph (i.e. support final users in their everyday life and within their homes by making the devices' use easier, safer and more comfortable), the novel solution that addresses the PSS concept has been developed on a specific white good, which is the washing machine (WM), because Indesit know-how on WMs is wide and robust and a lot of innovative and advanced solutions have been recently applied on it (e.g. energy-saving, high-performance Smart Technology, silent motion control, auto-dose of soaps and cleaners, etc.). The involvement of WM in the experimentation of PSS concept has been started from the following considerations: the widespread of WMs inside domestic houses, the worldwide distribution and the underused potential of actual WM electronics. These factors make the WM as the ideal candidate to become an example of the Servitization process applied in manufacturing, and to be further developed. Such the WM has been involved in the definition of a tailored scenario that consists to connect a device (i.e. WM) through the development of an ICT infrastructure that can exploit IoT technologies to provide customer-oriented services, such as:

- Monitoring the devices parameters;
- Informing the users about the device status and consumptions;
- Providing messages and alarms to support the correct device use to improve the user lifestyle;
- Providing personalized advices and best practices about users' care according to the users' habits;
- Providing alerts to manage the maintenance actions.

This scenario implies the design and development of a Product+Service solution, where the product is represented by the household appliance involved (i.e. WM), the service is composed by a set of functionalities that users can exploit, and finally the infrastructure is the hardware and software architecture that equips the product and that is able to provide the service.

Actually, the PSS idea combines device monitoring functions with washing-supporting features and maintenance-related aspects. Product monitoring consists of energy consumption and product behaviours (e.g. programs, temperature control, water and soap control, etc.). Washing-supporting features consists of providing best practices to improve the product use as a sort of mentoring service, and maintenance-related features concerns the detection of dangerous situations and remote maintenance capabilities.

Currently, the traditional WM use consists in a set of common actions, like insert clothes, insert the cleaner soap, select the washing program, start the machine, etc., exploited by the user on the machine, in order to obtain a specific result (clean clothes). Instead, the WM offer is limited to sell the product, providing a restricted set of after-sell supporting services, as 5 years warranty, call-centre assistance, spare parts and accessories, product on-line registration, product manuals and documentation, positioning the Company in the first level of Servitization process defined by [Thoben et al. 2001]. However, considering the maintenance service by warranty contracts and the 24hours assistance service offered by call-centre and website, also the second Servitization level is partially achieved. Through the novel Product+Service scenario the Company wants moving to another step along the Servitization process.

Such the Product+Service scenario that the Company would develop has been called “Carefree Washing Service”, because the WM should be redesigned to integrate a set of services that make the customer not to care about additional actions (e.g. maintenance, machine control, soap recharge, spare parts, etc.). These services will be offered mutually with the product and will be used to support and differentiate the product itself (e.g. personalized contract, multiple options to choose about cleaner soap furniture, spare parts or disposal and recycling), because the Indesit core business is still represented by selling the physical product.

More in detail, providing the “Carefree Washing Service” (Figure 31) on the WM means reach the following objectives, through the implementation of tailored service functionalities which reflect the user’s habits, in terms of commercial offers, sales promotions, vouchers for detergents, ad-hoc product line for specific use, etc.

- WM easy to use, thanks to recommendations and best practices about users’ washing ways, foreseeing the on-line purchase of detergents and related products;
- WM safe, by monitoring the appliance status and delivering all data an information online, in order to have available and consult such the data both on mobile phones and web;
- Sustainable washing cycles, by controlling of energy-water-detergent consumptions, promoting their optimal use and offering ecological and low impacts detergents.

Figure 31. *"Carefree Washing Service" offer*

In order to realize this scenario, devices must include connectivity components and the monitoring of some specific data as well as the users' habits during the use phase. They must communicate and exchange data, and they must able to elaborate data for further scopes and extract information about devices' status and users' habits. Such the data are monitored by specific sensors and collected in a dedicated database; a set of elaboration algorithms analyse data to recognize the specific use scenario and support the user with personalized and tailored suggestions and advices. A web/mobile application provides personalized messages directly on their mobile phones or web account. Figure 32 shows this scenario infrastructure.

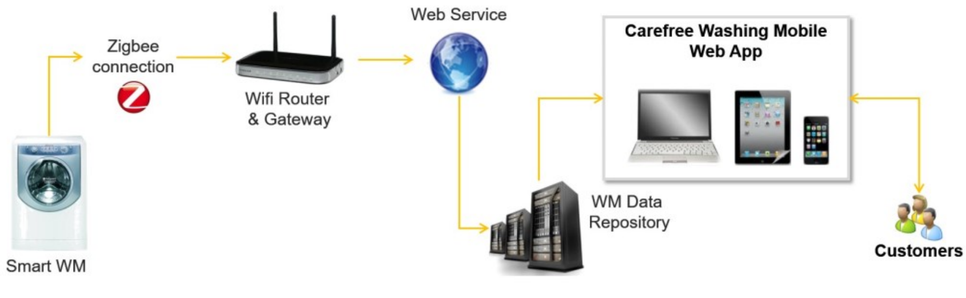


Figure 32. *Product+Service scenario infrastructure*

Moreover, the Produc+Service scenario is able to provide another service functionality, called “Smart Maintenance Service”.

It consists of providing ad-hoc maintenance service in order to prevent some WM faults and to manage the main appliance maintenance actions. Indeed, such the service provides personalized messages for coaching purposes and helping the final users in case of appliances’ faults. Figure 33 expresses idea of the “Smart Maintenance Service” and shows the main workflow. Data related to the WM are monitored by specific sensors, and then, they are collected in a database for data storage; here, a set of algorithms analyse these data according to two policies, which are coaching and fault management, in order to recognize the specific use scenario and support the user with personalized and tailored suggestions and advices. For the coaching function, the application gives best practices according to the product usage; for the fault management function, the system controls the appliances’ parameters, detects dangerous situations and supports the user when some critical values occur in order to carry out the recommended actions or some specific checking actions.

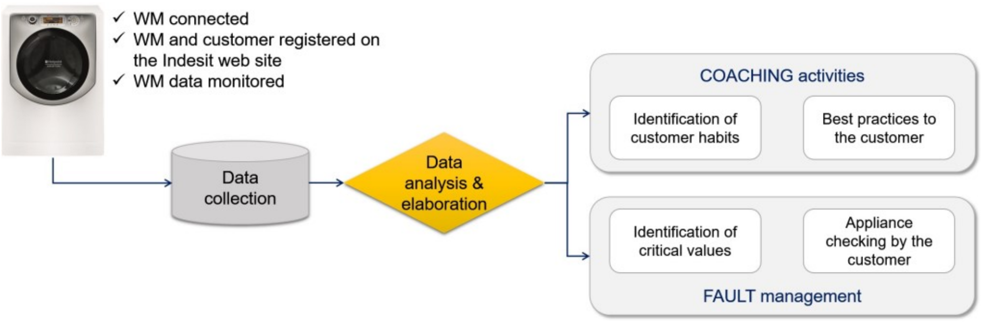


Figure 33. *Smart maintenance service workflow*

The development of the described Product+Service scenario at Indesit Company, which involves both the Carefree Washing and Smart Maintenance services, implies also a change of the current company ecosystem, which is composed mainly by internal actors and few external entities involved only in R&D phases. Contrariwise, the Product+Service scenario implies that some external partners will be involved after sales to support new service functionalities as service providers. It forces to define a novel robust and successful business model to make the ecosystem work. Innovation in the ecosystem is represented by the presence of so many partners and suppliers who must be coordinated in their actions and driven by common rules. It will be complex and challenging. Furthermore, the adoption of an external platform to deliver some services and to analyse data collected by the machines is a novelty. It implies two contrasting aspects: on one hand, data security and privacy issues must be faced and properly managed; on the other hand, such the platform (web-based, shared among numerous partners, etc.) can open new sales channels and can create marketing perspectives.

Appling the method studied and developed inside this research work, it has been possible design a structured idea of PSS that has been concretised into some prototypes (Figure 34), which have allowed the testing of the two services through a panel of real users.

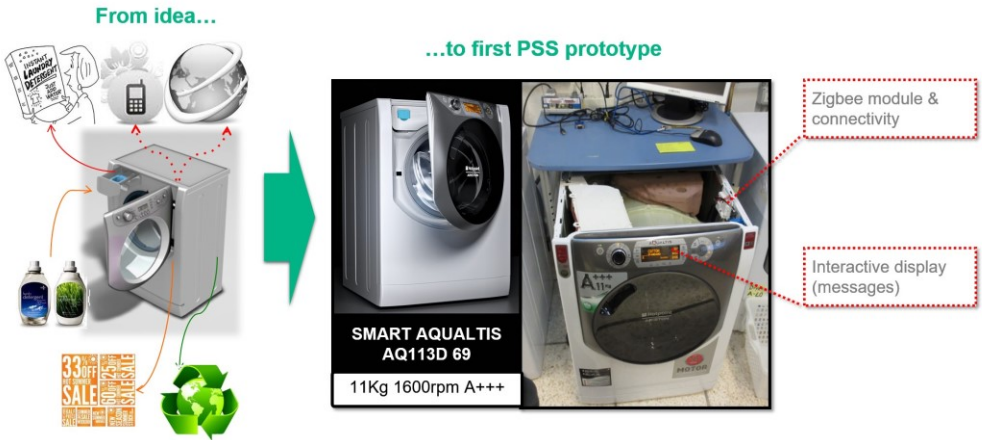


Figure 34. *INDESIT PSS – first prototype*

In the following paragraphs, all the steps of the method proposed by this research work to design a novel PSS solution will be described. More in detail: paragraph 6.3 and 6.4 show the tools exploited during MSEE and FLEXINET projects and that are also involved along the methodological approach object of this thesis; paragraph 6.5 collects the results of the sustainability assessment of both current Indesit value proposition and the new Product+Service solution; finally, paragraph 6.6 describes in detail all the steps of the methodological approach applied to this described use case scenario.

6.3. MSEE tools exploited

As highlighted in the previous lines, MSEE project has helped Indesit Company to analyse its current status in order to make the company ready to implement a new PSS scenario. According to this aim, the methods and tools exploited by the Company and that are relevant for the implementation of the integrated approach proposed by this thesis have allowed conducting the Business process analysis, the product lifecycle model, and the analysis of internal and external factors. The results obtained applying them are able to lay the foundation for a preliminary analysis of the company and to conduct some steps of the integrated approach proposed.

6.3.1 Business process analysis

According to the above-mentioned smart home PSS scenario, the most affected processes are the PSS Ideation and PSS Design, because decisions taken during these two processes involve the following steps. Indeed, starting from these phases, the main actors can be identified in terms of their competences and skills required in each activity involved in the process.

Figure 35 and Figure 36 show an example of data collected by interviews with the company management about the analysis of its current partner's network and Product-Service relationships.

These information will be used to define the T/I assets and also to identify the main ecosystem resources (step 6 of the proposed methodology).

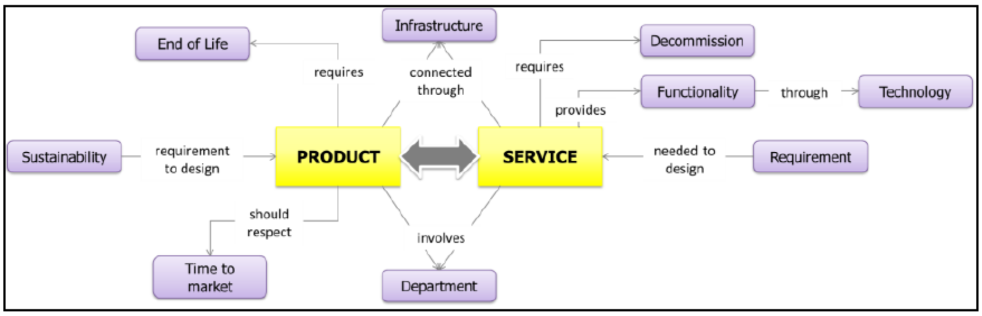


Figure 35. *Extract of interviews questions for business process analysis – Product&Service*

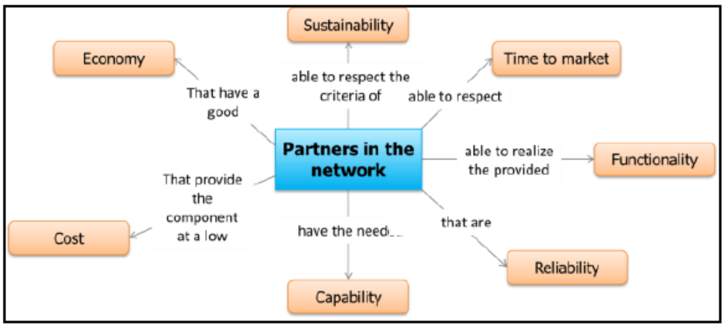


Figure 36. *Extract of interviews questions for business process analysis – Company current network*

6.3.2 Process modeling

The SLMToolBox provided by MSEE project will be used by the proposed methodology to model the PSS functionalities.

Figure 37and Figure 38 represent respectively the P-S Ideation process and the P-S Design process to realize the desired PSS solution; they are two example of the tool application. Indeed, the PSS infrastructure composed by the products, data collection and elaboration, and service provisioning is almost the same for all services and almost independent from their specific functions.

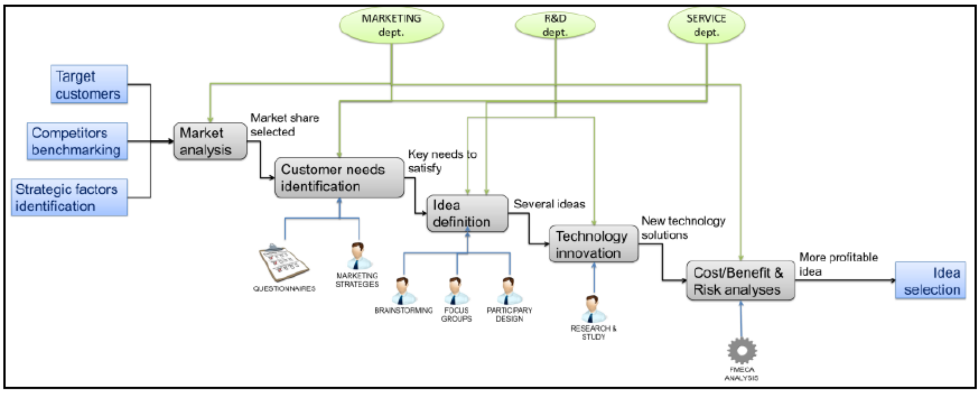


Figure 37. *PSS Ideation process modelling by SLMToolBox*

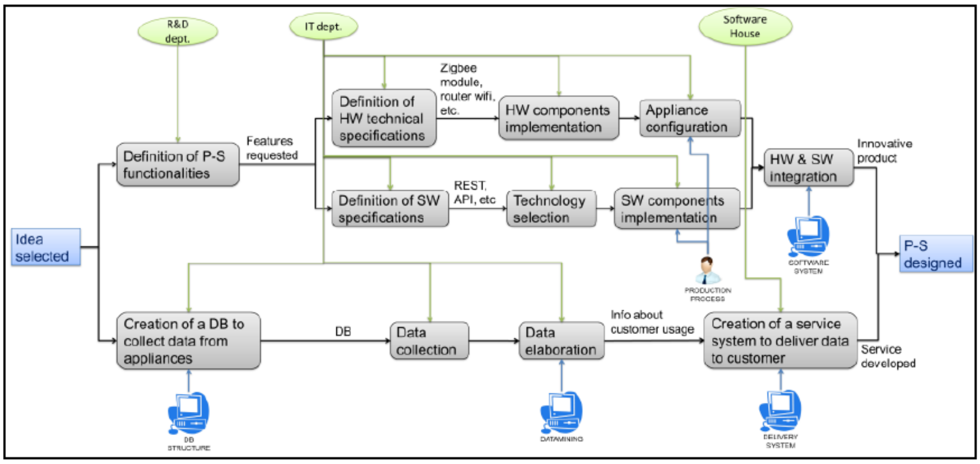


Figure 38. *PSS Design process modelling by SLMToolBox*

Each process has been modelled through a representation of input, output, resources needed (e.g. tools, detailed knowledge, specific technologies, etc.) and controllers (i.e. the internal department or an external company which is directly involved in such activity). The first activity is market analysis in order to highlight

the customers' needs and expectation, the idea definition and the technology definition; finally the cost/benefits analysis allows selecting the most promising P-S solution.
This representation is useful to identify not only the activity to develop along the process, but also to recognize all the competences needed to develop the P-S solution, and to highlight especially which one are missing within the company.

6.3.3 Internal and External factors analysis

The aim of this analysis is to identify the main external and internal trends to be considered during the PSS development. Indeed, a deep analysis of the company internal factors allows understanding the strengths and weakness of the company itself, but also external factors must be considered as they define limits and constraints that strongly affect intra-company processes and heavily condition the inter-company processes, that are fundamental in P-S development.
The internal factors' impact was identified by directly involving company internal people through a detailed questionnaire that investigates several issues: from the company's cost model, to the strategic risks evaluation, the value-network configuration, the suppliers choice factors, the importance of the external factors on the company's business model, etc. The scope is to identify the main factors to be considered in the PSS development process. Such analysis interested each company of the network; the strategic factors emerged during the analysis are also comparatively analyzed considering the main competitors. Next step referred to understand the influence of each factor on the process activities and on the network configuration. The most important factors refer to five trends: political, environmental, sociological, technological, and economic, according to the STEEP approach. Also in this case, an ad-hoc questionnaire is used for the analysis involving all the partners.

Table 6 shows an extract of the questionnaire, which collects the main questions focused on the company's factors analysis. Such the analysis allows evaluating the company's strategic factors and compares them with its competitors. Figure 39 shows an example of the internal and external factors analysis.

Table 6. *Extract of the questionnaire's questions for external and internal factors analysis*

Questions about: **Company's General contents**	**Questions about:** **Strategic factors definition**
Definition of: company's products	What factors affect the change in your supply network?
Definition of main: suppliers, target customers, services offered, company responsibilities	What factors influence the company's cost model?
Description of the design / production process	What factors influence strategic risk in your supply network?
P-S Quality	What factors affect the choice of suppliers or any other partners?
Definition of the key indicators (focus on: product development process and business evaluation)	How does your information flow look like and how is it modeled?
Product Cost impact	How does your material flow look like and how is it modeled?
Change management analysis (from only Product to P-S)	Which external environmental factors are influencing your design / production?
Management of rules and regulations (at company level)	How do you forecast such factors trends?
Current business model evaluation	How do you test your new business models?
Method to evaluate new business opportunities	What are the strategic objectives of your company?
Methods of assessing and mitigating risks	What are the guiding KPIs on a strategic level?

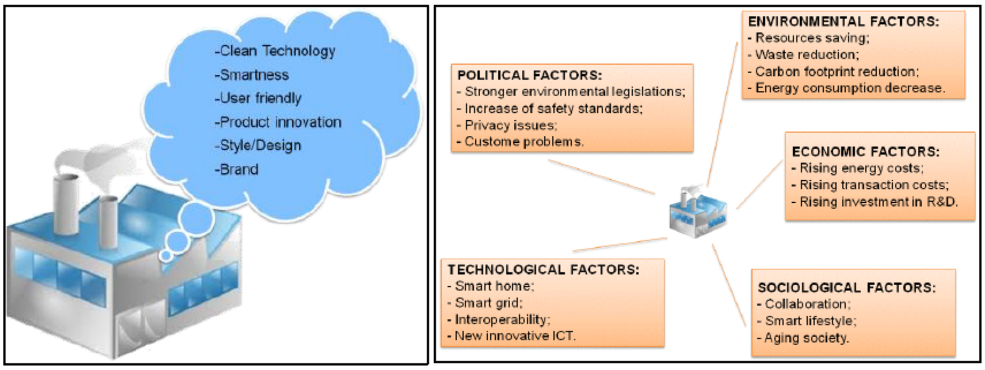


Figure 39. *Example of the analysis of internal (on the left) and external factors (on the right)*

In this way, the main affected processes by the PSS development have been modelled, and the company internal and external factors have been analysed in details with the focus on the network data flows and interactions among all the actors involved. The results obtained will be used in the ecosystem requirements elicitation (step 4 of the proposed methodology). Instead, the internal and external factros analysis will be useful to correlate T/I assets and ecosystem resources during the last step of the proposed methodology.

6.4. FLEXINET tools exploited

FLEXINET project has helped Indesit Company to analyse the preliminary phases of the product development process in order to understand what were the main criticalities, and how to improve such the process in order to manage the PSS design and development.

According to this aim, the tools exploited by the Company and that are relevant for the implementation of the integrated approach proposed by this thesis have allowed the management of both the ideation phase and the design phase, structuring an approach to manage the company knowledge. The results obtained are used as inputs of the proposed approach.

Indeed, the PSCoMS tool presented in chapter 4 consists of different applications with different aims. Those have been involved in this research thesis are mainly two: Idea Manager application and Product-Service Configurator application.

6.4.1 Idea Manager application

The Idea Manager (IM) application has been developed to support the Open Innovation approach, where new ideas come from different actors. It supports the Ideation process from the preliminary collection of roughly ideas provided by the design team, including both internal and external actors, until the complete definition of the first PSS virtual concept, which is used as the starting point for the detailed PSS co-design. IM is able to manage several company roles, having different visibilities and rights of modifications of the PSS ideas created. It is a web application that uses the Open Innovation approach following the scheme proposed in Figure 40: new ideas can be submitted on the application by the user account, filling in a simple online form; then, the approved ideas by the moderator account can be shared with other users that can comment, vote and/or give their "like" upon them. Ideas should pass different evaluation steps and refinement phases, where the initial description is enriched with technical, economic and marketing details, before being promoted to become a new PSS in the company's portfolio. When several ideas describe a similar concept, they can be grouped together defining a "concept". However, it is important to explain that to fully support the Open Innovation approach, the IM should be used in tight connection with the Collaboration Environment and the Product-Service Configurator.

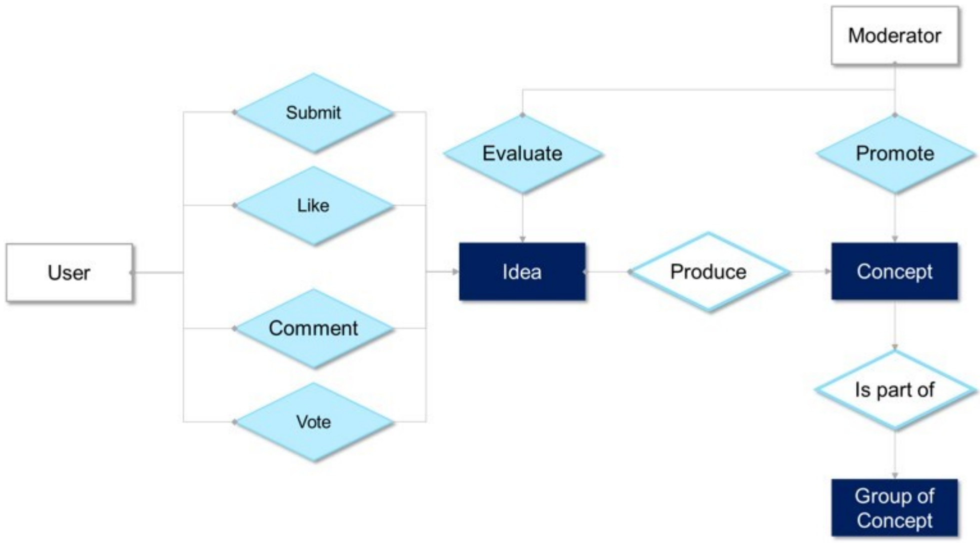


Figure 40. *The Idea Manager workflow*

However, it is important to explain that to fully support the Open Innovation approach, the Idea Manager application should be used in tight connection with the other company tools.
According to the proposed methodology, the IM has been used by Indesit company to collect all the ideas coming from the different actors and analyse them to be used inside the first matrix of the method.

6.4.2 Product-Service Configurator application

The Product-Service Configurator application offers a set of functionalities to support the evolution of the initial concept of a PSS and its transition from the innovation phase to the Design phase, along the P-SLM. People with different roles inside the company can contribute to the definition of the different information that contributes to the complete Design of PSS. Indeed, once the PSS virtual concept has been detailed through IM web-application, PSC supports the technical team (composed by several people belonging to different company departments) in the definition of Bill-Of-Material (BOM), the ICT architecture configuration (including the hardware and software components), the Business Model configuration, the Global Production Network description, the aesthetical model delineation, and so on. These elements are defined through the integration of the PSC with other tools already existed inside the company to conduct the technical and business evaluation (e.g., sustainability assessment, risk assessment, technical and economic evaluation) and for the production network configuration.
A process driven approach guides the usage of Product-Service Configurator along the main steps that have to be accomplished to provide a complete configuration of the PSS generated by innovative ideas. The application generates a warning in case any step is not properly completed.

Figure 41 shows the close link between Idea Manager application and Product-Service Configurator application, highlighting the main actions and functionalities of each tool and what is the main step to move from IM to PSC.

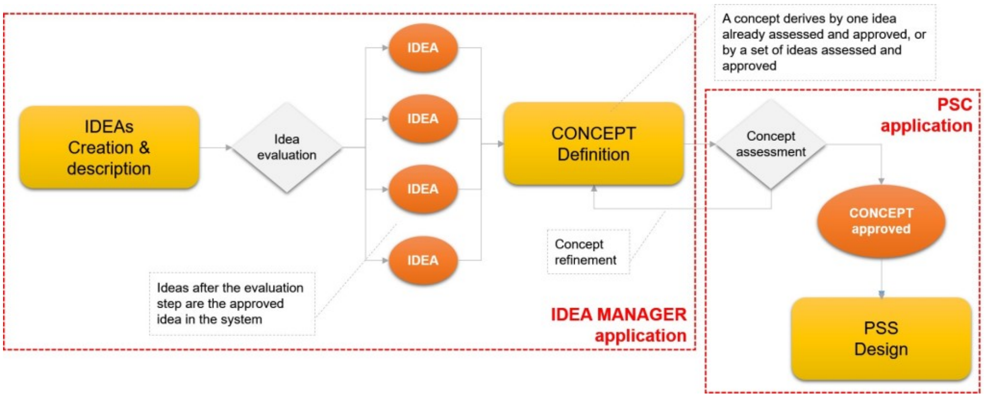


Figure 41. *The interconnection between IM and PSC applications*

According to the proposed methodology, the PSC has supported Indesit company in the collection of all the design information that will be generated by the proposed methodology along all its steps. Moreover, thanks to its link with the IM application, it is able to correlate the derived information from the method with the initialy ideas proposed and collected in IM.

6.5. Sustainability Assessment

The sustainability assessment has been conducted to evaluate the impacts on both the current washing machine, sold as a mere product, and its evolution, represented by the Product+Service scenario described above (paragraph 6.2).

The product scenario considers the tangible good as an assembly of numerous components, which enables washing clothes. The consumer pays the product at the beginning (about 460 €), and then pays for the consumed resources (i.e. clean water, electric energy and detergents) according to a traditional model.

Instead, in the Product+Service solution, the customer pays for the service while the WM is given for free. The user pays a service rate consisting of two parts: a "payXuse" fee at each washing cycle effectively done (0,60 €/cycle) and a discounted rate for the consumed resources (water and energy) fixed in collaboration with the energy suppliers. The washing cycle costs involve also the maintenance actions that should be exploited along the PSS lifecycle. Compared to the traditional case, the product involved in the PSS is enhanced with some additional components able to connect the WM to Internet and allow remote monitoring. The ecosystem is more complex as it is made up of the producer company, the energy supplier, the water supplier, a service provider who is responsible for service activation and delivery, some local technical partners who take care to deliver the WM at home and control its status, and the technical service that provide the Smart maintenance service.

For both Product and PSS cases, three different scenarios have been investigated. They considers the most representative European lifestyle according to a recent market analysis belonged to the Indesit marketing department. For each case, lifetime varies from 1 to 10 years. The identified user profiles are:

- *House Manager (HM)*: expert user, generally a woman, housewife or retired, taking care to house management and family issues in a special way. They usually have 4,3 cycles/week;
- *Efficiency Seeker (ES)*: user, generally a man, with an active social life and an efficient, fast and pragmatic house management. They usually have 5,8 cycles/week;
- *Delegator (D)*: young user that pay a limited attention to the house care in general and has an intense workload. They usually have 3,9 cycles/week.

These three users' profiles have been selected to have different use-phase scenarios.

According to the sustainability assessment model described in the previous chapter and schematised by Figure 27, the SI of both traditional product scenario and Product+Service scenario has been calculated. Moreover, according to the literature review conducted about sustainability approaches, the methodology overview shown in Figure 12 and the related PSS lifecycle has been adopted.

About the analysis of the traditional product scenario, the Manufacturing phase considers all the WM components used for the production and the final assembly, and data are organized according to the main functional entities (e.g. oscillating group, balancing and suspensions, electrical components, hydraulics, aesthetics, cabinet). A 5% cut-off is applied to not consider those parts that have a limited impact. The Use phase considers the habits of the investigated user profile (HM, ES, D) over the lifetime (1-10 years). A realistically decrease of performance corresponding to efficiency losses is estimated, as suggested by real data monitoring. Performance decrease is expressed by a cut percentage according to the number of the executed cycles: 5% reduction after 500 cycles, 10% reduction after 1000 cycles, 20% reduction over 2000 cycles. Costs are generated by the resource consumptions and are considered with their actual prices: electric energy (0,2 €/kWh), water (0,0011 €/lt), detergents (2,5 €/lt), softener (1,4 €/lt), calcium remover (0,33 €/cycle). In the End-of-Life phase analysis, LCA follows European Directive on Electric Equipment Waste (WEEE) for managing the product components: recycling (55%), reuse (10%) and landfill (35 %). Instead, for the End of Life (EoL) phase, the Company pays a specific amount (6 €) per each WM to a consortia that is responsible for its dismissing.

About the assessment of Product+Service (PSS) scenario, the Product Manufacturing & Service Implementation phase considers all the product components (as in the previous case), the additional components that provide the service functionalities and the system infrastructure to create the PSS. Furthermore, a new cost item is represented by the "service expense" considering call-centre services, the personnel employed there and the wiring network. The Product Use & Service Operation phase considers the same user profile analysed for the traditional scenario but for the PSS it is affected by the higher performances due to a continuous control of the machine status and a real-time monitoring and assistance (i.e. PSS machine is monitored and parts can be substituted in advance to guarantee a high quality performance for the whole lifetime). Finally, the Product Disposal & Service Decommission phase differs from traditional product because the manufacturer directly manages product disposal and the extended enterprise manages the service decommission.

Table 7 shows the obtained results for both product and PSS sustainability assessment along 10-years lifetime. It contains values derived from separated analysis (i.e. environmental impacts from LCA, economic impacts from LCC, social impacts calculated as QALY by the LCA results), as well as the global Sustainability Impact (SI), which is calculated as the sum of the three impacts after the normalization that allows referring to both environmental and social impact as economic impacts. SI has been calculated per each user profile (i.e. House Managers – HM –, Efficient Seekers – ES –, Delegators – D –) defined above.

It is worth to notice that, for 10-years lifetime, PSS is convenient for any user profile, regardless the user habits.

Table 7. *Sustainability assessment: Traditional product vs Product+Service*

10-years lifetime	*Traditional product scenario*			*Product+Service scenario*		
	HM	*ES*	*D*	*HM*	*ES*	*D*
Environmental Impact (Pt)	*6,00E+02*	*7,72E+02*	*6,44E+02*	*4,57E+02*	*6,08E+02*	*5,02E+02*
Economic Impact (€)	*5.994,32*	*6.688,50*	*6.071,67*	*4.544,01*	*5.577,53*	*4.513,08*
Social Impact (QALY)	*1,00E-02*	*1,29E-02*	*1,05E-02*	*6,64E-03*	*9,14E-03*	*7,09E-03*
SI (€)	*6.849,99*	*7.772,95*	*6.955,65*	*5.118,80*	*6.355,90*	*5.120,02*

Furthermore, data can be investigated also over the years along the lifetime, in order to better understand how the PSS advantages evolve during the lifetime. Figure 42 shows the SI trend over the years in respect with the three user classes: the product impact is constantly higher and frequently users (ES) are more charged. Services have always less impact, even if the advantages are greater along in years. Moreover, PSS is particularly good for average users (both HM and D), especially after 5 years. Interesting analysis can be also carried out about some specific aspects: indexes can be separately mapped over the years to compare product and PSS relatively to one specific contribution.

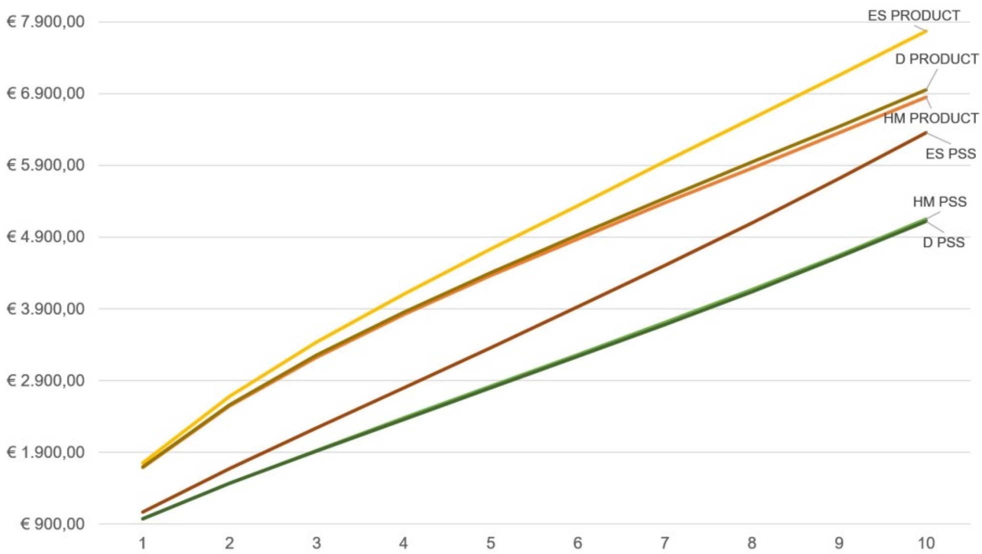


Figure 42. *Sustainability assessment along 10-year lifetime*

Figure 43 shows the cost analysis along 10-years lifetime, considering the Company expenses and the consumer rates. Company costs are obviously lower than consumer and slightly in growth in both cases; finally, PSS is marginally more expensive. Contrariwise, the consumer perspective is very interesting: washing as a service is much cheaper than buying the machine and the benefits for consumers are great and steady growth over the years.

The results of this analysis play a key role during the requirements elicitation, where different parameters are analysed (e.g. sustainability impacts, technical constrains, economic constrains, etc.). Moreover, the Sustainability assessment can be conducted after the definition of the network of partners and suppliers that joint in the PSS development, in order to have more defined and realistic data.

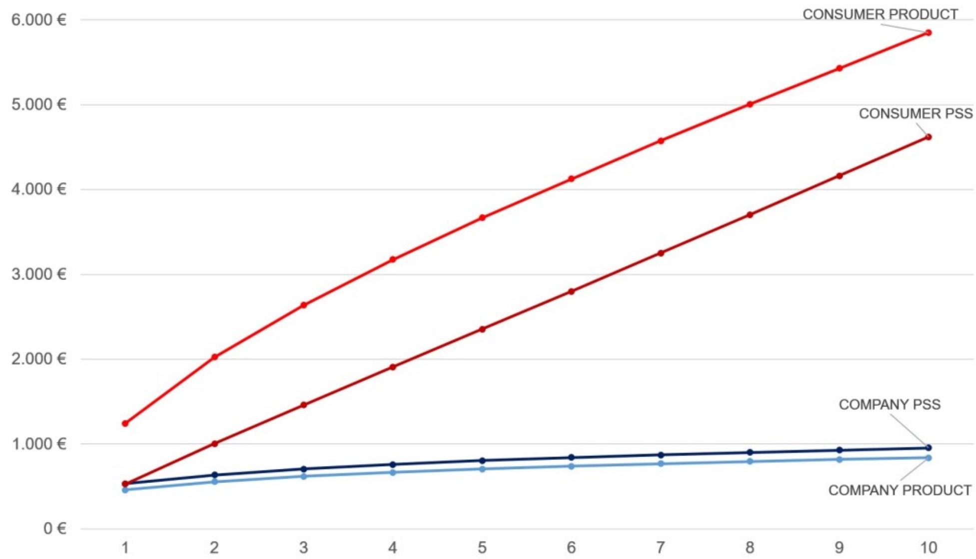


Figure 43. *Cost analysis along 10-year lifetime: Company vs Users costs*

6.6. Proposed methodology application

In this paragraph, the method applied to the Indesit use case already described (paragraph 6.2) is shown in detail, but, due to the company privacy policies, some of sensitive data cannot be displayed. Anyway, a clear discussion about each methodology step, data involved and main results derived will be given.

6.6.1 Step 1: Market analysis

The Market analysis has been conducted by marketing department of Indesit Company to investigate its main market (i.e. Europe) and analyse the main users' behaviours and trend, in order to define the main customers segments and their related needs. According to use case described above (paragraph 6.2), the appliance involved in this investigation is the washing machine (WM).

The Company European market that involve the WM as household appliance has been divided into two main areas: West Europe (WE) and East Europe (EE). The first area involves Italy, Spain, France, Germany and UK markets, while the second one includes Poland and Russia markets. The Market analysis conducted on these two areas have faced several users habits; in the following it will be shown the main investigations done: where is placed the WM, which are the main users of the appliance, what is the average value about the number of cycles per week, what are the most often washing types used, what are the main detergents used, how the WM has load, and finally what are the main type of laundry washed. For each of this analysis a related graph has been shown. The resulted values have been calculated through the analysis of data collected along the 2014, thanks to the adoption of questionnaires that have been requested to answer to customers after their WM purchase, directly on the Company web-site, where each new user needs to register its product to be sure to can take advantage by the guarantee, and also to extend it.

More in detail, Figure 44 shows the results about the place (i.e. bathroom, laundry room, kitchen, spare room, garage, tavern, or other) where the WM has located inside the home. The values calculated for both West and East areas have been shown as percentage values. The graph highlights how the main WE trend is to have the WM in the kitchen, and then in the bathroom or laundry room, while the EE trend is to have the WM in the bathroom, and then in kitchen (they not prefer the laundry room)

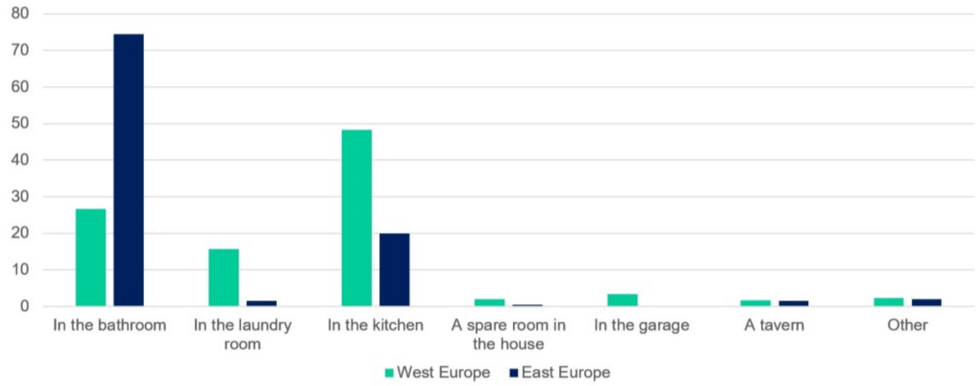


Figure 44. *Market analysis – Where is the WM placed*

Figure 45 shows the percentage results about what are the main users of the appliance, and the resulted trend in Europe (both in West and East) demonstrates how the appliance owner is also the main user.

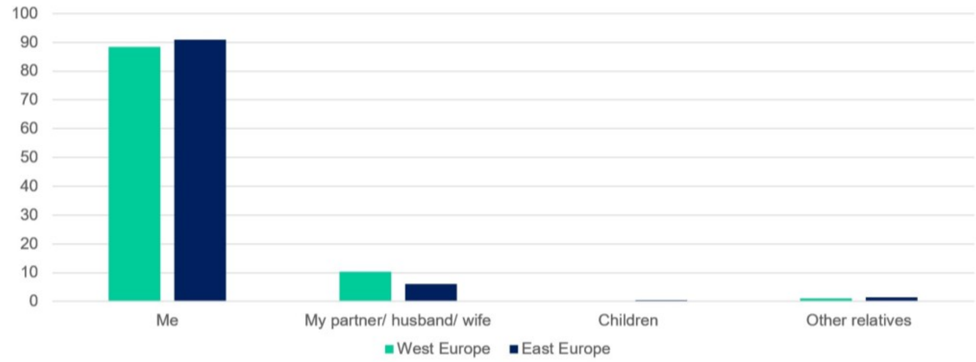


Figure 45. *Market analysis – Main users of the appliance*

Figure 46 highlights an interesting result about the number or washing cycle per week per each European area: 4,9 is the number of washing cycles per week in WE (green line), while 3,1 is the number of washing cycles per week in EE (blue line). At the same time, the graph shows what is the West and East European percentage trend in terms of number of cycles per week.

Figure 47 defines what are the most used washing cycles in Europe per week. The trend resulted is similar both in West and East area, where the main exploited is the short/economic cycle.

Figure 48 identifies the main detergents or additives used by users, and it highlights a different trend in WE and EE. Indeed, while in WE users adopt mainly the liquid detergent and then the softener and powder, in EE users prefer mainly the powdered and then liquid and softener.

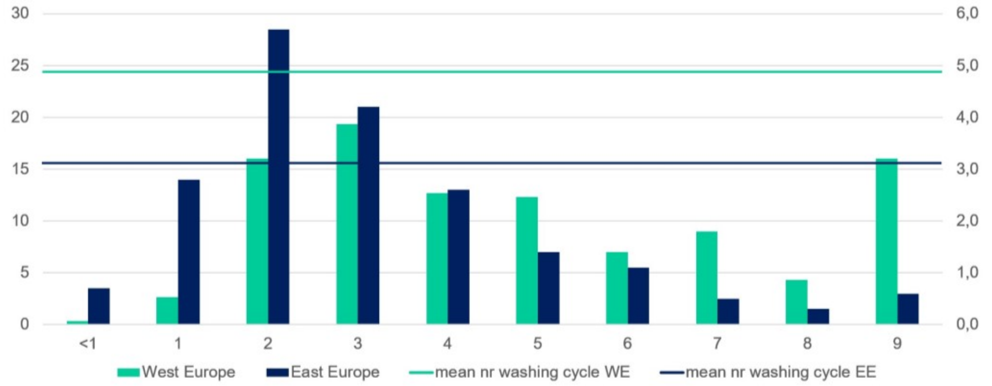


Figure 46. *Market analysis – Number of cycles per week*

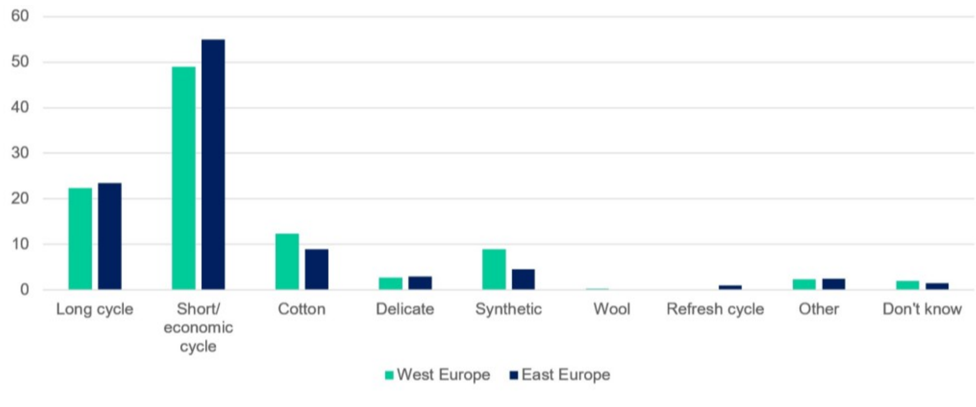


Figure 47. *Market analysis – Type of cycles used per week*

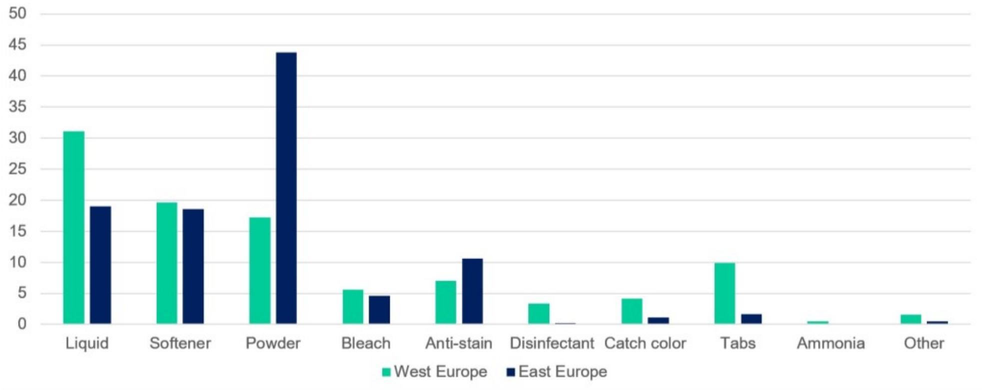


Figure 48. *Market analysis – Detergents and additives used*

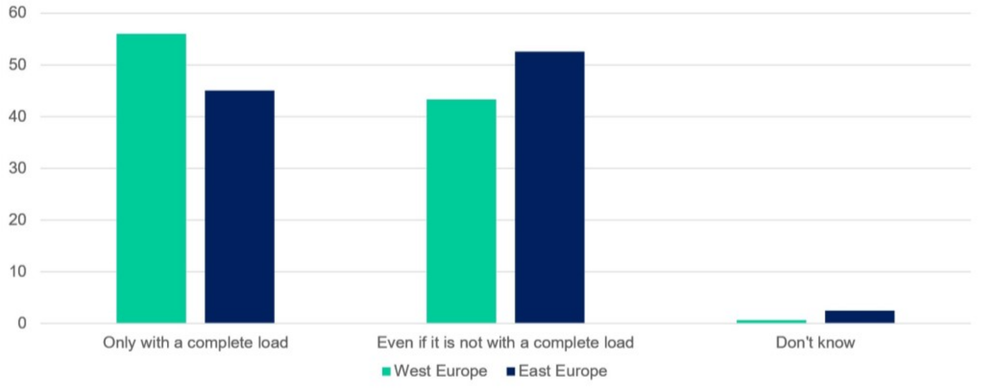


Figure 49. *Market analysis – Usage of the WM (full or partial load)*

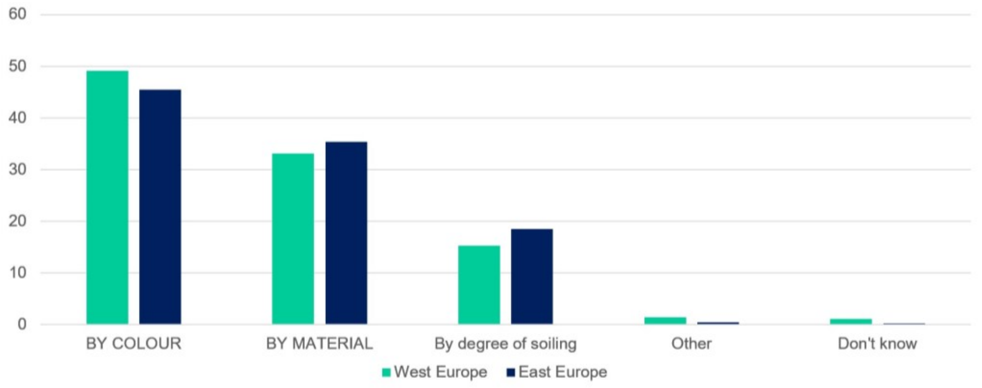


Figure 50. *Market analysis – Load separation process*

Figure 49 and Figure 50 show different aspects of the load activity. While the first one shows if users prefer have a complete or partial WM loading, Figure 50 discriminates what is the users' criteria to separate dirty clothes (e.g. by colour, by material, degree of soiling, etc.)

Finally, Figure 51 gives an overview about what kind of laundry has been washed by European users.

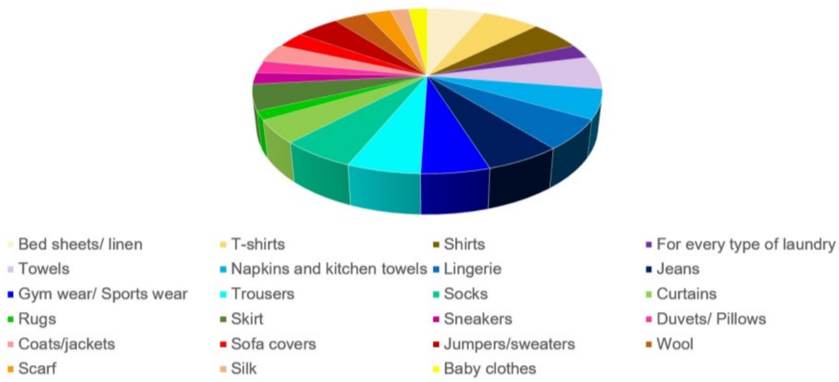


Figure 51. *Market analysis – Type of laundry washed (average values in Europe)*

The Market analysis conducted has allowed the Company marketing department to identify the main customers segments in Europe.

The segmentation process is based on lifestyle statements and statements on attitudes towards domestic appliances. It starts with the factors analysis on the statements in order to identify the main attributes that are linked to such the attributes or factors involved. This allows the reduction of a large set of statements to a much smaller set of factors, which provides to define the main users clusters. In the following (Figure 52), the main factors that have been involved to define the users cluster are shown.

They are grouped in four main attitudes, which are: attitudes towards home, towards life and friends, towards the user involved ("myself"), and towards the appliance itself (i.e. WM).

Figure 52. *Factors identified*

According to such the facts analysis, six main users' profiles have been identified by Indesit marketing department: House Managers (HM), Statics (S), Efficiency Seekers (ES), Classy Ladies (CL), Delegators (D), and Wannabe Trendsetters (WT). Figure 53 shows such the profiles and how they are percenlty distributed both in East and West Europe.

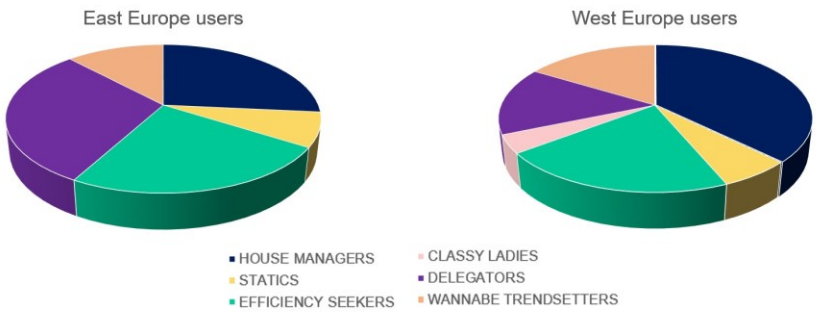


Figure 53. *Users' profiles in Europe*

More in detail:

- *House Managers (HM)*. They are people who invest a lot in house management, want their house to reflect their personality and creativity, and dedicate a lot of time to their family. They pay attention to prices in the management of purchases, not only as concerns household appliances. Generally, they less likely to use new technologies. They are mostly mature women, above all housewives, retired, or part-time workers. Their social-economic level is different in the various countries, but it is high in East Europe.
- *Statics (S)*. They are people very linked to their daily routine, who love their home and family and say they do not want to change their life. They have a social life only if it is worth it and are little interested in new technologies, from internet and anything new in general. Usually, household appliances help them lead a simple life. Considering also that Statics do not like to use appliances when they are not at home, so they are not interested in latest generation of household appliances and not even particularly in the environmental sustainability. They are mainly mature males, often retired, which have low social-economic and cultural level. They are mostly separated, widowers, or also unmarried.
- *Efficiency Seekers (ES)*. They are people with intense social lives, even if often virtual, through Internet. Hence they often seek a practical and fast management of the house, which they do not consider to be their domain or an expression of their personality and creativity. They aims to have easy-to-use appliances, which can also be used by other members of the family, and they are not particularly interested in aesthetics. They are males, young, married and with a large family. They meet their practical and fast house management needs by using Internet to gather information and do their shopping.

- *Classy Ladies (CL)*. They are people who use internet very much also buy online and are naturally more familiar in new technologies. They desire a house that reflects their creativity and they surround themselves with things that represent them quality objects, brands, and refined things. More for personal pleasure then to stand out from the crowd. They are mostly women, a little more mature than average, who have a higher social level and a good level of education. They are mainly full-time workers.
- *Delegators (D)*. They do the minimum necessary in the house and they do not particularly care for it. Indeed, the house does not have to reflect their personality and it is not a place to show their creativity. They use internet and sometimes shop online, and occasionally they buy things they can't really afford, but not in the sector of household appliances, unless they are indispensable. They are mostly young men, belonged to the middle or middle-low social class, and they are often single or unmarried living with parents.
- *Wannabe Trendsetters (WT)*. They say they are the first to use new technologies and that are inspired from advertising to always be kept up to date and to have new ideas. Sometimes they spend more than what they can afford. They are strongly focused on themselves and they want to be considered leaders even though. They do not like being surrounded by friends, or people in general, in fact they would change their life for something completely different. The home and the family are not so important to them, doing the minimum necessary. Technology is a useful tool for housework because they are the ones who do it. They do not want other members of the family to use the household appliances. They are very active, they are often out and they think they are one step ahead of the rest of the world. Generally, they are women that belong to the upper or upper-middle class. They are mostly people single or not married.

6.6.2 Step 2: Matching between customer needs and PSS ideas

After the Market analysis, the customer segments have been identified and thus alto their main needs. Indeed, the Company marketing department people involved in this new PSS design team have applied the UCD role-playing techniques to reach this scope. They have organised focus groups according to the different customers' segments identified (i.e. House Managers, Statics, Efficiency Seekers, Classy Ladies, Delegators, Wannabe Trendsetters) and playing the different customers' roles, in order to simulate sample users' behaviours and reactions. The resulted information has been collected in matrix 1 (Figure 54 – a better view of the matrix is shown in Appendix A, inside A1 and A2 sections).

At the same time, the Company is able to recognise also all the ideas proposed both by internal and external actors, through the Idea Manager tool delivered by FLEXINET project (paragraph 6.4.1). All these data are the inputs of the first matrix of the proposed methodology, where customers' needs and the collected ideas are put in correlation in order to identify the relevant needs, which will be used to define the tasks, object of the next matrix, and the significant ideas, which will be useful to identify the main ecosystem requirements (see Figure 54).

CUSTOMERS' SEGMENTS

USERS' NEEDS / IDEAS	HM											S							
	APP for smartphone and tablet	Balance between quality and price	High washing cycle performance	Energy efficiency	Optimised detergent consumption	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Care for fibres	Care for colours	Appliance reliability	Gaming activity	Easy to use appliance	Easy to use interface	Online purchase	High washing cycle performance	Appliance reliability	Clean clothes	Monitoring WM outside home
weight	2	5	4	5	5	3	3	5	4	4	4	1	4	4	3	2	3	5	1
Autodose technology	1	0	3	0	9	3	1	3	0	0	0	0	0	0	0	3	0	3	1
Remote control	9	1	3	1	1	1	9	0	0	0	0	9	9	9	9	3	0	0	9
Washing cycles monitoring	9	1	3	3	1	1	9	0	0	0	0	1	1	3	1	3	0	0	9
Energy monitoring	3	1	1	9	0	3	1	0	0	0	0	3	1	3	0	1	0	0	1
Water control & monitoring	1	1	3	0	0	3	1	0	0	0	0	3	1	3	0	3	0	0	1
Preventive maintenance practices	9	3	3	0	0	1	9	0	0	0	9	3	1	3	3	3	9	0	9
Automatic recognition of garments colours	0	0	9	0	0	0	0	3	0	9	0	0	3	0	0	9	0	3	0
Pre-treatment of stain	0	0	9	0	0	0	0	9	0	0	0	0	3	0	0	9	0	9	0
WM provided of led technology	0	0	9	0	0	0	0	3	9	0	0	0	3	0	0	9	0	3	0
WM provided of professional cycles	0	0	9	0	0	0	0	9	3	3	0	0	3	0	0	9	0	9	0
New technology for treating coloured clothes	0	0	9	0	0	0	0	3	0	9	0	0	3	0	0	9	0	3	0
WM provided new technology for sweet wash/drying	0	0	9	0	0	0	0	3	9	0	0	0	3	0	0	9	0	3	0
WM connected	9	1	3	3	3	1	9	0	0	0	1	3	9	9	9	3	1	0	9
Appliance with smart interface	3	0	0	0	0	0	1	0	0	0	0	1	9	9	0	0	0	0	1
WM connected to dryer	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3
Double door	0	0	3	0	0	0	0	9	0	0	0	0	3	0	0	3	0	9	0
Professional cycles at home	0	0	9	0	0	0	0	9	9	9	0	0	3	3	0	9	0	9	0
Relevant NEEDS	**90**	**40**	**340**	**80**	**70**	**39**	**129**	**255**	**120**	**120**	**40**	**23**	**220**	**168**	**66**	**170**	**30**	**255**	**43**

USERS' NEEDS / IDEAS	ES														
	Gaming activity	Easy to use appliance	Easy to use interface	APP for smartphone and tablet	Balance between quality and price	Online purchase	High washing cycle performance	Energy efficiency	Optimised detergent consumption	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Care for fibres	Care for colours	Appliance reliability
weight	2	5	5	4	3	4	4	3	5	3	4	5	3	3	5
Autodose technology	0	0	0	1	0	0	3	0	9	3	1	3	0	0	0
Remote control	9	3	9	9	1	9	3	1	1	1	9	0	0	0	0
Washing cycles monitoring	1	1	3	9	1	1	3	3	1	1	9	0	0	0	0
Energy monitoring	3	1	3	3	1	0	1	9	0	3	1	0	0	0	0
Water control & monitoring	3	1	3	1	1	0	3	0	0	3	1	0	0	0	0
Preventive maintenance practices	3	1	3	9	3	3	3	0	0	1	9	0	0	0	9
Automatic recognition of garments colours	0	3	0	0	0	0	9	0	0	0	0	3	0	9	0
Pre-treatment of stain	0	3	0	0	0	0	9	0	0	0	0	9	0	0	0
WM provided of led technology	0	3	0	0	0	0	9	0	0	0	0	3	9	0	0
WM provided of professional cycles	0	3	0	0	0	0	9	0	0	0	0	9	3	3	0
New technology for treating coloured clothes	0	3	0	0	0	0	9	0	0	0	0	3	0	9	0
WM provided new technology for sweet wash/drying	0	3	0	0	0	0	9	0	0	0	0	3	9	0	0
WM connected	3	9	9	9	1	9	3	3	3	1	9	0	0	0	1
Appliance with smart interface	1	9	9	3	0	0	0	0	0	0	1	0	0	0	0
WM connected to dryer	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0
Double door	0	3	0	0	0	0	3	0	0	0	0	9	0	0	0
Professional cycles at home	0	3	3	0	0	0	9	0	0	0	0	9	9	9	0
Relevant NEEDS	**46**	**245**	**210**	**180**	**24**	**88**	**340**	**48**	**70**	**39**	**172**	**255**	**90**	**90**	**50**

USERS' NEEDS / IDEAS	CL								D									
	APP for smartphone and tablet	Online purchase	High washing cycle performance	Gaming activity	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Optimised detergent consumption	Easy to use appliance	Easy to use interface	APP for smartphone and tablet	Online purchase	Energy efficiency	Optimised detergent consumption	Clean clothes	Care for fibres	Care for colours	Monitoring WM outside home
weight	5	5	3	5	2	4	5	2	3	3	3	1	4	3	5	2	2	1
Autodose technology	1	0	3	0	3	1	3	9	0	0	1	0	0	9	3	0	0	1
Remote control	9	9	3	9	1	9	0	1	3	9	9	9	1	1	0	0	0	9
Washing cycles monitoring	9	1	3	1	1	9	0	1	1	3	9	1	3	1	0	0	0	9
Energy monitoring	3	0	1	3	3	1	0	0	1	3	3	0	9	0	0	0	0	1
Water control & monitoring	1	0	3	3	3	1	0	0	1	3	1	0	0	0	0	0	0	1
Preventive maintenance practices	9	3	3	3	1	9	0	0	1	3	9	3	0	0	0	0	0	9
Automatic recognition of garments colours	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	0	9	0
Pre-treatment of stain	0	0	9	0	0	0	9	0	3	0	0	0	0	0	9	0	0	0
WM provided of led technology	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	9	0	0
WM provided of professional cycles	0	0	9	0	0	0	9	0	3	0	0	0	0	0	9	3	3	0
New technology for treating coloured clothes	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	0	9	0
WM provided new technology for sweet wash/drying	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	9	0	0
WM connected	9	9	3	3	1	9	0	3	9	9	9	9	3	3	0	0	0	9
Appliance with smart interface	3	0	0	1	0	1	0	0	9	9	3	0	0	0	0	0	0	1
WM connected to dryer	1	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	3
Double door	0	0	3	0	0	0	9	0	3	0	0	0	0	0	9	0	0	0
Professional cycles at home	0	0	9	0	0	0	9	0	3	3	0	0	0	0	9	9	9	0
Relevant NEEDS	**225**	**110**	**255**	**115**	**26**	**172**	**255**	**28**	**147**	**126**	**135**	**22**	**64**	**42**	**255**	**60**	**60**	**43**

USERS' NEEDS / IDEAS	WT						Significant IDEAS	
	Online purchase	APP for smartphone and tablet	High washing cycle performance	Monitoring WM outside home	Clean clothes	Gaming activity		
weight	3	5	1	3	5	4		
Autodose technology	0	1	3	1	3	0	**326**	5%
Remote control	9	9	3	9	0	9	**820**	11%
Washing cycles monitoring	1	9	3	9	0	1	**500**	7%
Energy monitoring	0	3	1	1	0	3	**311**	4%
Water control & monitoring	0	1	3	1	0	3	**193**	3%
Preventive maintenance practices	3	9	3	9	0	3	**629**	9%
Automatic recognition of garments colours	0	0	9	0	3	0	**333**	5%
Pre-treatment of stain	0	0	9	0	9	0	**432**	6%
WM provided of led technology	0	0	9	0	3	0	**333**	5%
WM provided of professional cycles	0	0	9	0	9	0	**486**	7%
New technology for treating coloured clothes	0	0	9	0	3	0	**333**	5%
WM provided new technology for sweet wash/drying	0	0	9	0	3	0	**333**	5%
WM connected	9	9	3	9	0	3	**862**	12%
Appliance with smart interface	0	3	0	1	0	1	**301**	4%
WM connected to dryer	0	1	0	3	0	0	**67**	1%
Double door	0	0	3	0	9	0	**348**	5%
Professional cycles at home	0	0	9	0	9	0	**630**	9%
Relevant NEEDS	**66**	**225**	**85**	**129**	**255**	**92**	7237	

Figure 54. *Matrix 1 – Correlation between Customers' needs and Ideas*

The correlation between needs and ideas has been expressed by a 0-1-3-9 scale, as described by the methodological approach (paragraph 5.2). The relevant needs have been calculated by summing all the correlation values in corresponding rows along the same column, and multiplying it for the related need's weight; at the same time, the significant ideas have been calculated by multiplying each correlation values of the different columns along the same line with its related need's weight, and then summing all these results together. Moreover, in order to identify which customer segment profile is mostly affected, all the same needs belonged to the different users' profiles have been aggregated together.

According to the results obtained, the most relevant needs for the case study are: APP for smartphone and tablet, high washing cycle performance, monitoring WM outside home, clean clothes, online purchase, easy to use application and easy to use interface. At the same time, the most significant ideas are: remote control, washing cycles monitoring, preventive maintenance practices, WM connected, appliance with smart interface, WM provided of professional cycles and professional cycles at home.

According to these results, a preliminary definition of the relative Business Model (BM) can be done; indeed, also according to the proposed methodology approach, after this first matrix definition, both the Value Proposition and the Customers' Segments can be defined. Figure 55 shows this preliminary BM.

The value proposition as defined in the BM can be expressed as follows: "a connected device able to monitor energy and other resources consumption, to guarantee the remote control and to support the customers when a failure occurs. Such the connected device is also able to deliver high washing performances and it is equipped with a new, smart and easy to use interface to access at the service functionalities".

In this way, two areas of the BM are automatically filled in from the early conceptual design stages.

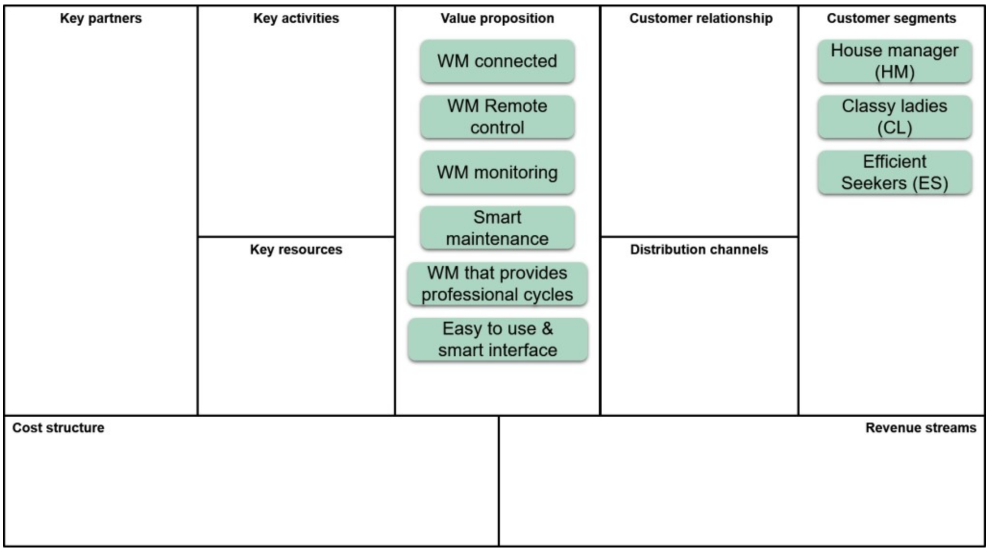


Figure 55. Business Model after matrix 1

6.6.3 Step 3: Definition of the user tasks

Identified all the relevant needs from matrix 1 (Figure 54), the new Design team has been focused on the recognition of the main task that make possible to realise and develop the new PSS solution. According to this aim, the Business Use Case (BUC) technique has been adopted and the PSS scenario has been defined.

Figure 56 and Figure 57 proposes an example of how the BUC has been modelled by Indesit company (it is not allowed showing all the BUCs developed due to privacy issue): the starting point had been resulted by the users' needs analysis and a preliminary model of the relative actions required by customers (Figure 56); then, a more deeply model has been conducted where both the customers and Indesit actions have been identified (Figure 57).

This is only a preliminary BUC analysis, which should support the definition of the main tasks (i.e. actions that should be exploited to develop the PSS solution); another and more detailed BUCs have been realised during this phase, but also after the definition of the new ecosystem, in order to identify and model all the roles and activities involved.

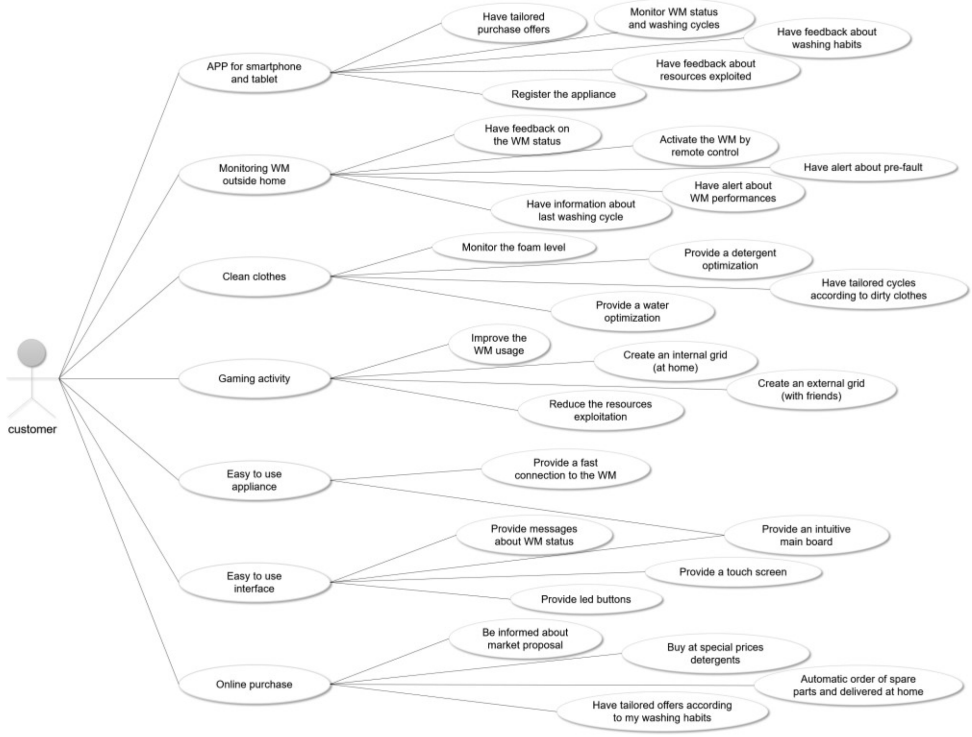


Figure 56. *BUC – general overview*

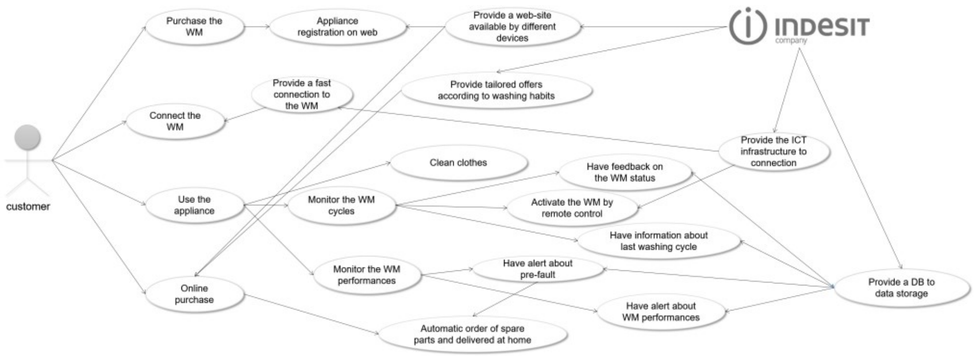


Figure 57. *BUC – preliminary PSS proposal analysis*

The task recognised according to the application of BUC approach are the following:

- Monitor WM status and washing cycles;
- Monitor WM performances;
- Have feedback about washing habits;
- Have feedback about resources exploitation;
- Have feedback about WM status;
- Provide messages about WM status;
- Have information about last washing cycle;
- Register the appliance on web site;
- Activate the WM by remote control;
- Have alert about pre-fault;
- Have alert about WM performances;
- Provide a detergent optimization;
- Provide a water optimization;
- Reduce the resources exploitation;
- Have tailored cycles according to dirty clothes;
- Improve the WM usage;
- Create an internal grid (at home);
- Create an external grid (with friends);
- Provide a fast connection to the WM;
- Provide an intuitive main board;
- Provide a touch screen;
- Provide led buttons;
- Be informed about market proposal;
- Buy detergents at special prices;
- Automatic order of spare parts and delivered at home;
- Provide tailored offers according to washing habits;

- Have a virtual maintainer always available;
- Provide a web-site available by different devices;
- Provide the ICT infrastructure to connection;
- Connect the WM.

They have been implemented in the second matrix involved by the methodology proposed, where they are put in correlation with the ecosystem requirements.

6.6.4 Step 4: Requirements elicitation

In order to identify the main ecosystem requirements that will provide at the definition of the PSS functionalities to develop, a team composed by technical people from the Company and experts from University has been composed.

They have analysed all the significant ideas resulted by matrix 1 (Figure 54). Such the ideas have been described in terms of Insight, Consumer Promise, and Reason why. Insight is referred to the relative hidden need, Consumer Promise expresses the benefits by the development of a specific PSS solution for the final consumer, and finally, Reason why highlight why consumers need of the development of this solution. Table 8 shows the results of this analysis.

After this preliminary analysis, the Serious Games has been conducted with the aim to collect all the ecosystem requirements.

Each requirement involves and affects a specific process into the company, from the PSS Ideation process to PSS Delivery process. This phase is very important because allows identifying the main changes that a product-oriented company should do to move in order to arrive developing a PSS solution. Moreover, in this phase, the results obtained by the sustainability assessment conducted in the paragraph 6.5 have been involved in order to identify the most affected requirements that are really required to satisfy.

Table 8. *Ideas defined by Insight, Consumer Promise, and Reason why*

IDEAS	INSIGHT	CONSUMER PROMISE	REASON WHY
Auto-dose technology	Optimised detergent consumption	Reduce environmental impacts Reduce detergents costs Have more care about clothes	Respect sustainable principles Make more efficient the appliance
WM monitoring and control	Monitoring WM outside home	Monitoring WM status and washing cycles Activate washing cycles Make easier washing clothes Have feedback about the way to wash	Provide an appliance with high performance Simplify the users life Support users in washing clothes to optimise the resources
Energy monitoring	Energy efficiency	Have feedback about energy used	Respect sustainable principles Make appliance more efficient Support users in washing clothes to optimise the resources
Water control & monitoring	High washing cycle performance	Have feedback about the way to wash Reduce environmental impacts	Respect sustainable principles Make more efficient the appliance Support users in washing clothes to optimise the resources
Preventive maintenance practices	Appliance reliability	Have feedback about WM performances Monitoring the main WM pre-fault Have a maintenance service always available	Provide an appliance with high performance Simplify the users life
Pre-treatment of stain	High washing cycle performance	Have care for clothes Have good results from washing cycle Easy to use appliance WM with high performances	Provide an appliance with high performance Simplify the users life
WM connected	Monitoring WM outside home	Washing cycles information shared to optimise the WM usage Provide tailored offers to users about detergents	Simplify the users life Support users in washing clothes to optimise the resources
Appliance with smart interface	Easy to use appliance	Easy to use appliance	Simplify the users life
WM connected to dryer	Smart home	Have care for clothes Easy to use appliance WM with high performances	Provide an appliance with high performance Simplify the users life

Automatic recognition of garments colours	High washing cycle performance	Have care for colours Easy to use appliance WM with high performances	Provide an appliance with high performance Simplify the users life
WM provided of led technology	Easy to use appliance	Easy to use appliance Several washing programs to satisfy any need	Simplify the users life
WM provided of professional cycles	High washing cycle performance	Have care for colours and fibres WM with high performances	Provide an appliance with high performance Simplify the users life
New technology for treating coloured clothes	High washing cycle performance	Have care for colours WM with high performances	Provide an appliance with high performance
WM provided new technology for sweet wash	High washing cycle performance	Have care for colours and fibres WM with high performances	Provide an appliance with high performance Simplify the users life
Professional cycles at home	High washing cycle performance	Have care for colours and fibres Several washing programs to satisfy any need WM with high performances	Provide an appliance with high performance Simplify the users life

Data collected during the Serious Game refer to showing all the requirements identified that affects also the sustainable principles:

- New sensors to provide auto-dose
- New sensors to monitor WM cycles
- New sensors to adopt preventive maintenance
- WM redesign
- Improve and redesign the main board
- Improve and redesign the WM interface
- Development of ICT infrastructure to connect WM
- SW system development
- HW infrastructure development
- Web and mobile apps development
- Rules definition to apply preventive maintenance

- Consumer habits monitoring
- Detergent suppliers involvement
- Involve the EoL consortia to develop the new WM
- Create the Smart Home environment
- Foresee the gaming activities
- Efficient and effective WM connection

6.6.5 Step 5: Functional analysis

The ecosystem requirements identified and collected according to the previous analysis (paragraph 6.6.4) have been correlated to the tasks identified through the BUC approach described in paragraph 6.6.3. The correlation has been done through the implementation of the functional analysis by a team of Company people that involves R&D department, IT department and designers, as well as people from the Service department.

The functional analysis conducted has allowed both the definition of the main PSS functionalities that the PSS should deliver, and the highlight of the main requirements that, through the application of the UCD role-playing technics, were the starting point to define the tangible and intangible assets and the main resources needed to involve in the ecosystem. Figure 58 shows the matrix 2 (a better figure is provided at Appendix A, A3 section) that collects both ecosystem requirements and tasks, and shows also the general overview of the UML 2.0 model conducted to design the PSS functionalities.

According both to the use case described in paragraph 6.2 and the requirements and tasks derived by the first matrix analysis, in the following, the main PSS functionalities that the new PSS solution should be able to deliver.

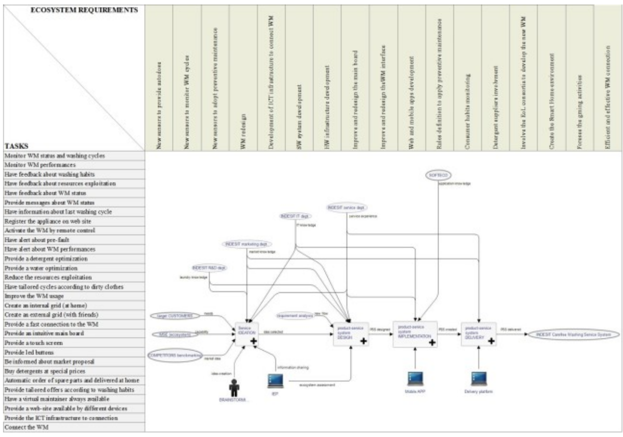


Figure 58. *Matrix 2 – Correlation between Tasks and Requirements*

- *Washing cycles data monitoring* (i.e. last cycle temperature / speed / washing type / date / timing, each washing cycle date / timing), which provides the monitoring of the WM usage and the collection of the related data that users can check by web or mobile application.
- *Smart maintenance*, which provides the maintenance management through the WM monitoring of the pre-fault events. In this way, whenever specific event (mapped by Indesit service) appears, a message to customer is sent, in order to both advice customer itself and guide him in the management of that specific event. This implies that a real fault occurs.
- *My best practices*, which, according to the WM monitoring, provides to customer a set of practices to follow in order to optimise his WM usage, for example in terms of detergent used, washing cycle selection, or temperature set.
- *My tailored offers*, which, according to the WM monitoring, provides to customer a set of purchasing offers that are completely in line with the related customer habits.

In the following (from Figure 59 to Figure 70), all the PSS functionalities will be modelled in detail through the adoption of SLMToolBox.

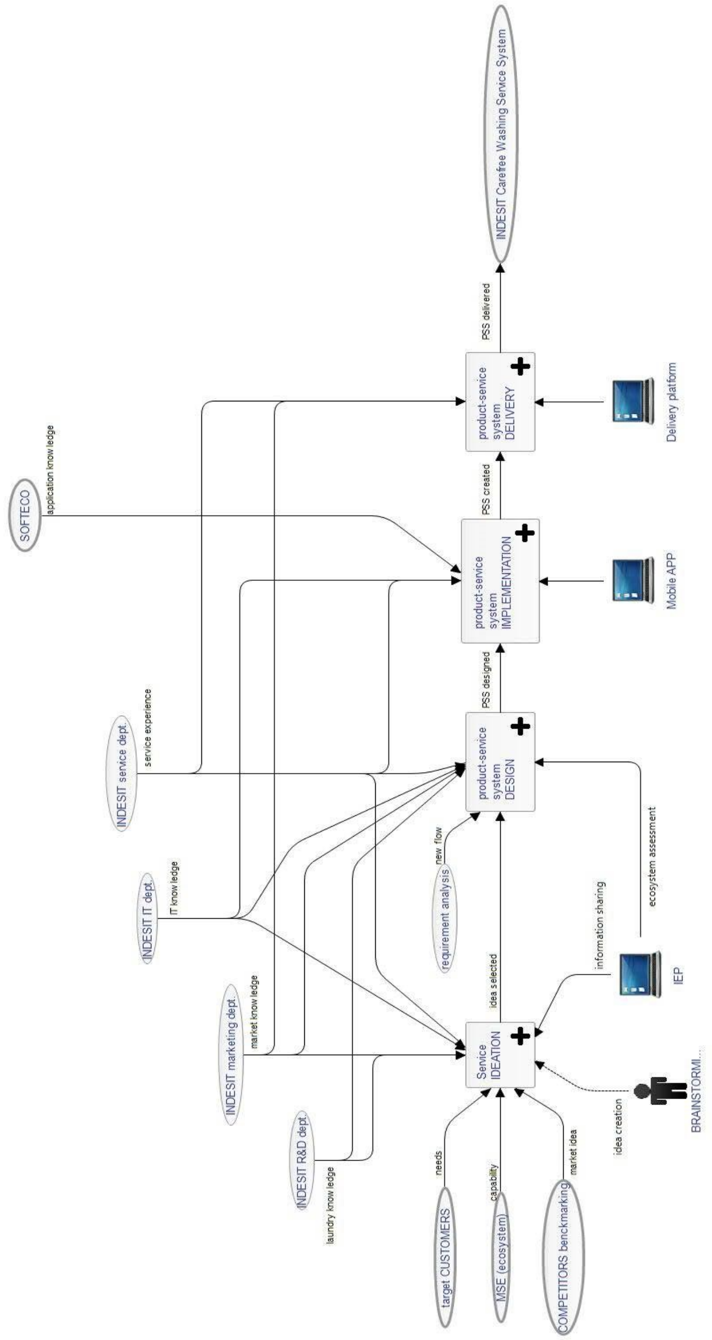


Figure 59. *UML2.0 model – General overview*

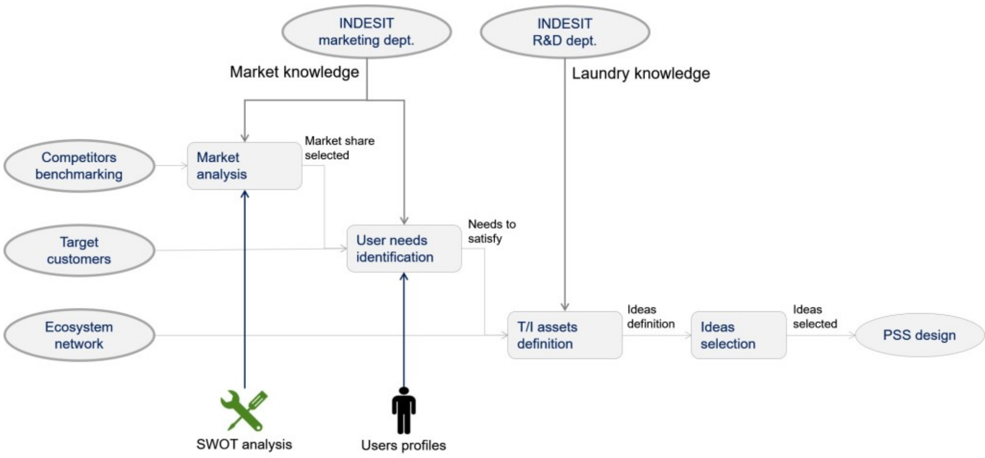


Figure 60. *UML2.0 model – Service ideation*

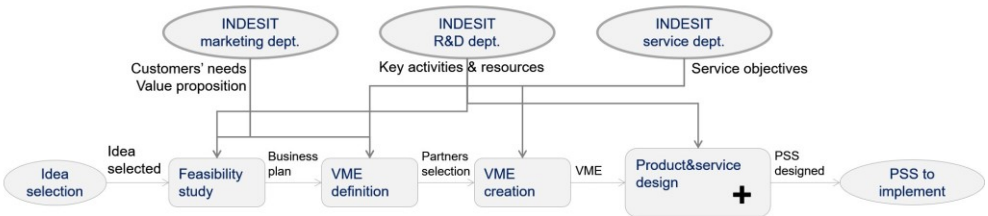


Figure 61. *UML2.0 model – Product Service System design*

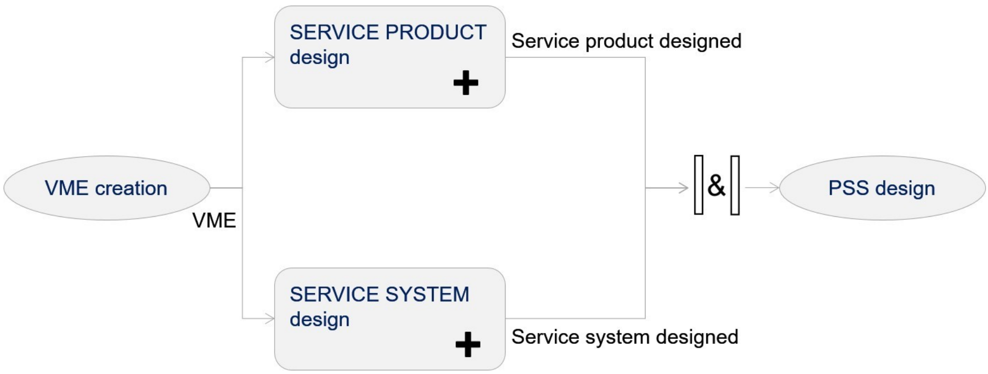


Figure 62. *UML2.0 model – Product&service design*

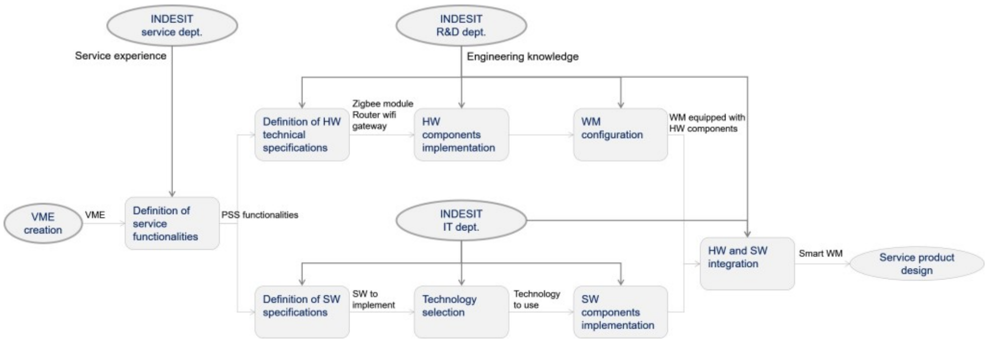


Figure 63. *UML2.0 model – Service Product design*

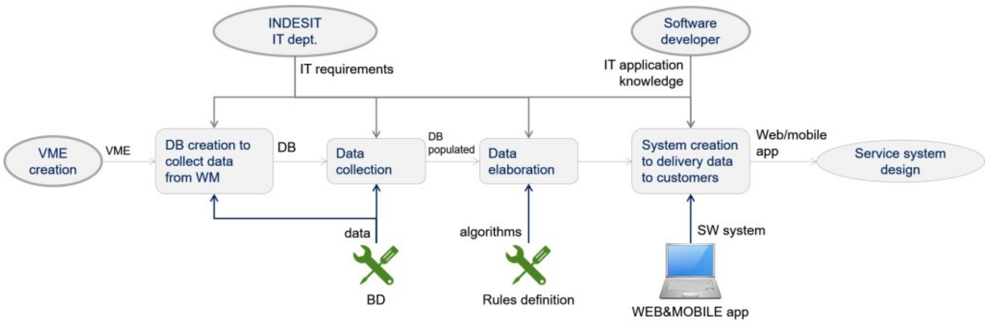


Figure 64. *UML2.0 model - Service System implementation*

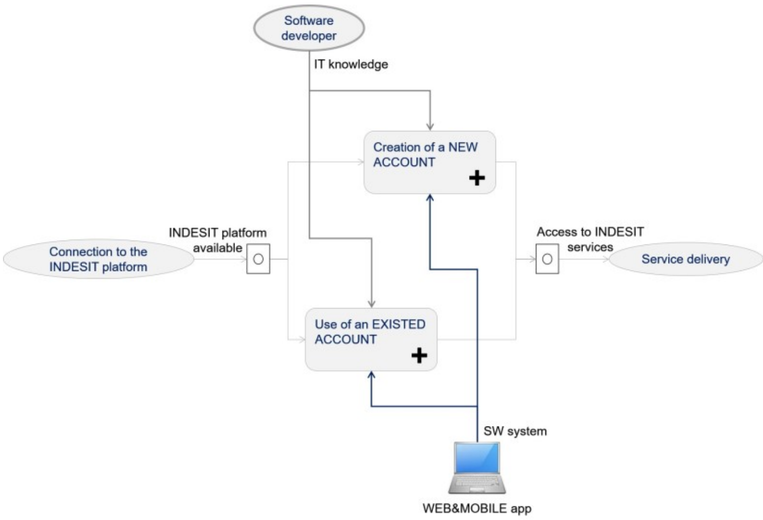


Figure 65. *UML2.0 model – Product Service implementation*

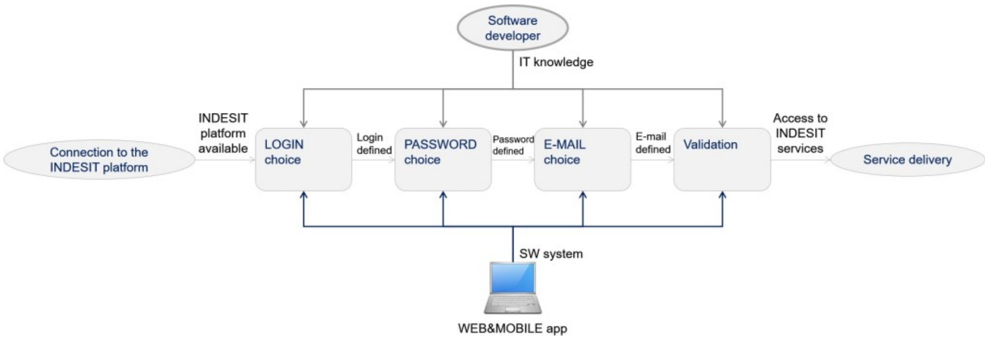


Figure 66 *UML2.0 model – Creation of a new account detail*

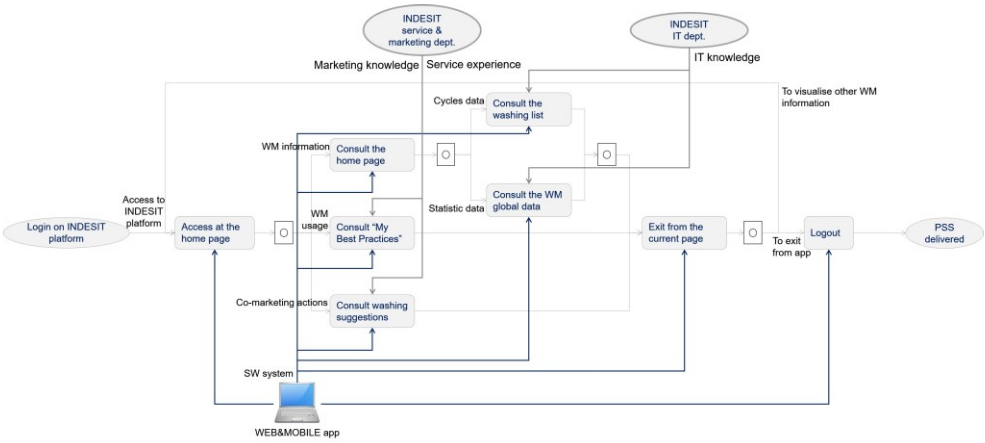


Figure 67. *UML2.0 model – Use an existed account*

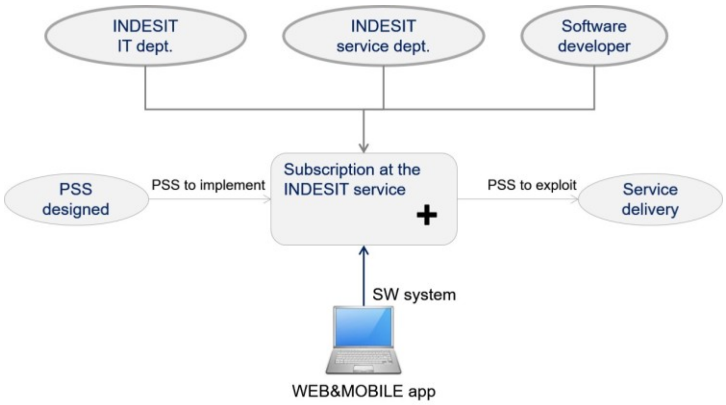


Figure 68. *UML2.0 model – Product Service System delivery*

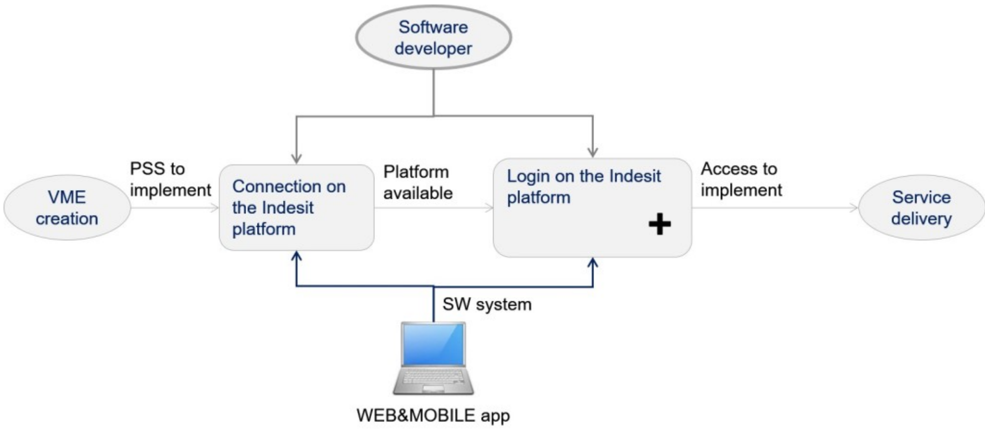


Figure 69. *UML2.0 model – Subscription at Indesit service*

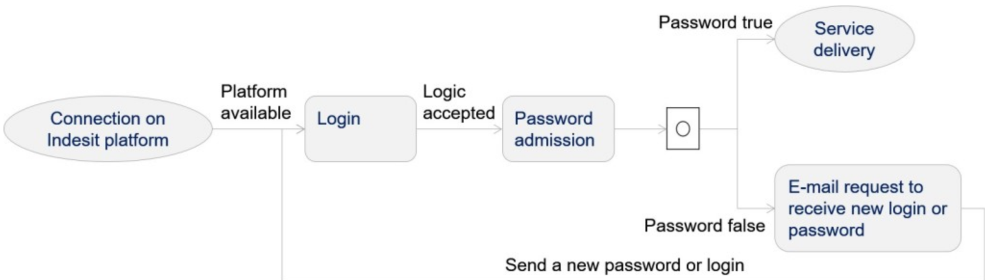


Figure 70. *UML2.0 model – Login on the Indesit platform*

After the correlation between requirements and task conducted by functional analysis (which represents the second correlation matrix along the integrated method proposed by this thesis) the Business Model can be filled about also the Key activities required to develop the PSS solution and the Customer relationship to create, in order to foresee the PSS continuous use and exploitation. Figure 71 shows how the BM appears at the end of this stage, where in green has been highlighted the new areas defined after this stage, while in blue has been highlighted the previous areas described. Moreover, at this stage also the Distribution channels has been derived by the customer relationship definition.

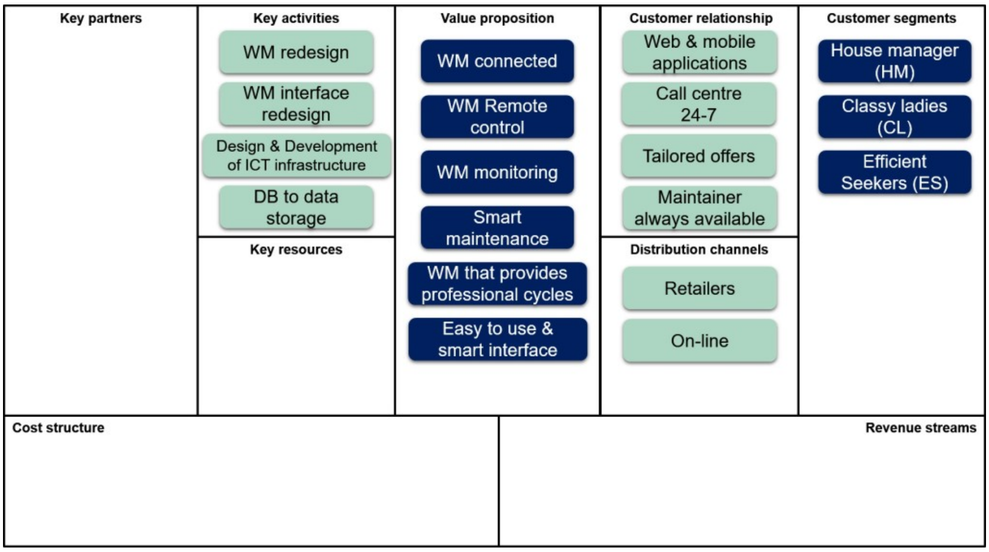


Figure 71. *Business Model resulted by Tasks and Requirements correlation*

6.6.6 Step 6: Main assets and resources definition

After the PSS functionalities definition, both the main tangible and intangible (T/I) assets, and the ecosystem resources have been defined. To reach this scope, a new focus group has been started, at which different people from different Indesit department have attended. The aim was to analyse the ecosystem requirements derived from the previous step to identify both T/I assets and main resources.

The results of the application of the UCD role-playing technique at this stage have shown in Table 9, in the following:

Table 9. *The derived T/I assets and Ecosystem resources*

REQUIREMENTS	*T/I assets*	*Ecosystem RESOURCES*
New sensors to provide auto-dose	*Sensors inside WM basket* *Sensors to monitoring WM running* *Sensors to identify detergent amount*	*INDESIT company* *Suppliers of electronic components* *Detergent providers* *Detergent providers*
New sensors to monitor WM cycles	*Sensors to monitoring WM running*	*INDESIT company* *Suppliers of electronic components*

New sensors to adopt preventive maintenance	*Sensors to monitoring WM running*	*INDESIT company* *Suppliers of electronic components*
WM redesign	*Detergent boxes* *WM components*	*INDESIT company*
Improve and redesign the main board	*led light* *new buttons*	*INDESIT company*
Improve and redesign the WM interface	*WM interface*	*INDESIT company*
Development of ICT infrastructure to connect WM	*router Wi-Fi* *gateway* *module ZigBee* *SW system* *DB* *Rules to deliver different functionalities*	*INDESIT company* *Partners in research (electronics, informatics, etc.)* *Technological partners*
SW system development	*SW system*	*INDESIT company* *Technological partners* *Software developers*
HW infrastructure development	*router Wi-Fi* *gateway* *module ZigBee*	*INDESIT company* *Suppliers of electronic components*
Web and mobile apps development	*applications*	*Software developers*
Rules definition to apply preventive maintenance	*Rules to manage the smart maintenance*	*INDESIT company - Service call centre* *Technological partners*
Consumer habits monitoring	*Sensors to monitoring WM running* *Rules to manage data collected* *Rules to deliver different functionalities*	*INDESIT company* *Suppliers of electronic components* *Technological partners*
Foresee the gaming activities	*applications* *Sensors to monitoring WM running*	*INDESIT company* *Suppliers of electronic components*
Efficient and effective WM connection	*router Wi-Fi* *gateway* *module ZigBee* *SW system* *DB* *Rules to deliver different functionalities*	*INDESIT company* *Partners in research (electronics, informatics, etc.)* *Technological partners*

6.6.7 Step 7: Correlation between T/I assets and PSS functionalities

At this stage, all the T/I assets resulted by the previous analysis have been put in correlation with the main PSS functionalities derived by the functional analysis conducted in paragraph 6.6.5. At each asset, a weight has been assigned by the Company design team that is involved in such the PSS design. The correlation values in the matrix shown in Figure 72 has been assigned considering a 0-1-3-9 scale. The needed assets resulted have been calculated as the sum of all the values in the same line, multiplying for the related weight, while the key functionalities have been calculated as the sum of all the assets' weight multiplying for the involved functionality. A better figure of this third matrix has been shown at Appendix A, A4 section.

PSS FUNCTIONALITIES / T/I ASSETS	weight	WM connected	WM monitored	Smart maintenance	Best practices proposals	Marketing offers proposal	Smart interface	Temperature monitoring	Water used monitoring	Detergent used monitoring	Energy used monitoring	Total costs per cycle	Foresee gaming among the grid	NEEDED ASSETS	
Sensors inside WM basket	5	0	9	3	9	9	0	9	9	9	0	1	3	**305**	10%
Sensors to monitoring WM running	5	0	9	9	3	3	0	3	3	3	9	9	3	**270**	8%
Sensors to identify detergent amount	3	0	9	0	9	9	0	0	0	9	0	1	3	**120**	4%
Detergent boxes	1	0	0	0	0	1	0	0	0	9	0	0	0	**10**	0%
WM components	2	3	3	9	0	0	9	1	1	1	0	0	0	**54**	2%
led light	2	0	0	0	0	0	9	0	0	0	0	0	1	**20**	1%
new buttons	2	0	0	1	1	1	9	0	0	0	0	1	0	**26**	1%
WM interface	4	0	0	1	3	3	9	0	0	0	0	3	0	**76**	2%
router wifi	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
gateway	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
module zigbee	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
SW system	5	1	3	9	9	9	0	0	0	0	0	3	9	**215**	7%
applications	5	3	3	9	9	9	0	0	0	0	0	3	9	**225**	7%
DB	5	1	3	0	0	0	0	9	9	9	9	9	0	**245**	8%
Rules to manage the smart maintenance	5	9	9	9	0	0	0	0	0	0	0	0	0	**135**	4%
Rules to manage data collected	5	9	9	0	0	0	0	9	9	9	9	9	0	**315**	10%
Rules to deliver different fuctionalities	5	9	9	0	9	9	0	0	0	0	0	0	9	**225**	7%
Knowledge in Service system	5	1	1	9	9	9	0	0	0	0	0	1	9	**195**	6%
Knowledge in IoT	5	9	9	0	0	0	0	0	0	0	0	0	9	**135**	4%
KEY FUNCTIONALITIES		**351**	**488**	**309**	**326**	**327**	**90**	**167**	**167**	**203**	**150**	**207**	**401**	3186	
		11%	15%	10%	10%	10%	3%	5%	5%	6%	5%	6%	13%		

Figure 72. *Matrix 3 – Correlation between PSS functionalities and T/I assets*

As result of this analysis we have obtained two main results:

- identification of the main assets that are needed to develop the new solutions (Table 10). This result allows defining a new set of weight for T/I assets (see the last column in Table 10) that will be used in the next and final matrix (see next paragraph);

Table 10. *Assets resulted by matrix 3*

T/I assets	*Resulted values %*	*Weight*
Sensors inside WM basket	*10%*	*5*
Sensors to monitoring WM running	*8%*	*4*
Sensors to identify detergent amount	*4%*	*2*
Detergent boxes	*0%*	*0*
WM components	*2%*	*1*
led light	*1%*	*0*
new buttons	*1%*	*0*
WM interface	*2%*	*1*
router Wi-Fi	*6%*	*3*
gateway	*6%*	*3*
module ZigBee	*6%*	*3*
SW system	*7%*	*3*
applications	*7%*	*4*
DB	*8%*	*4*
Rules to manage the smart maintenance	*4%*	*2*
Rules to manage data collected	*10%*	*5*
Rules to deliver different functionalities	*7%*	*4*
Knowledge in Service system	*6%*	*3*
Knowledge in IoT	*4%*	*2*

- identification of the main functionalities that will be sold to customers. Indeed, not all the functionalities identified have been the same value for customers and also according to the assets involved. For this reason, it is important to understand what kind of functionalities it is better to sell and what kind should remain hidden to customers, always according to the value proposition already defined. According to the resulted PSS functionalities of matrix 3, Table 11 provides all them with the relative values obtained by the correlation between assets and functionalities and the related percentage value.

Which of them highlighted in red are the main functionalities that will be involved into the PSS solution to deliver to customers.

Table 11. *PSS functionalities resulted by matrix 3*

PSS FUNCTIONALITIES	*Resulted values*	*Resulted values %*
WM connected	*351*	*11%*
WM monitored	*488*	*15%*
Smart maintenance	*309*	*10%*
Best practices proposals	*326*	*10%*
Marketing offers proposal	*327*	*10%*
Smart interface	*90*	*3%*
Temperature monitoring	*167*	*5%*
Water used monitoring	*167*	*5%*
Detergent used monitoring	*203*	*6%*
Energy used monitoring	*150*	*5%*
Total costs per cycle	*207*	*6%*
Foresee gaming among the grid	*401*	*13%*

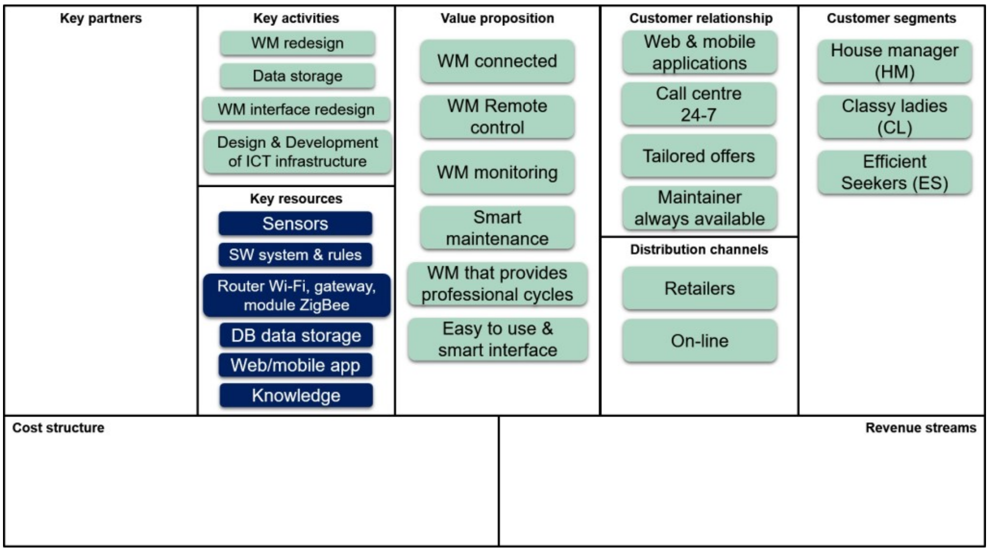


Figure 73. *Business model resulted after matrix 3*

At the end of this stage it is possible to identify what are the main key resources inside the business model (see Figure 73).

6.6.8 Step 8: GPN definition

This is the last stage of the proposed methodology, where the T/I assets opportunely weighted are put in correlation with the ecosystem resources in order to identify the Global Production Network (GPN) that should be created to deliver the new PSS solution. To reach this aim, the risk assessment has been conducted, also considering the internal and external factors (i.e. STEEP analysis) analysis that has been done in paragraph 6.3.3.

In order to conduct the risk assessment, a template to identify the main risks and incidents has been created (see Appendix B, C1 section), and also a template to define the main interdependencies between different suppliers that are able to provides diverse resources (see Appendix B, C2 section).

Due to Indesit privacy issues, the detailed results of this analysis cannot be shared. Anyway, those results translated into a 0-1-3-9 scale has been shown in Figure 74 (a better figure is shown in Appendix A, A5 section). Here, also the results coming from the correlation between assets and resources has shown. According to them, the main ecosystem resources to acquire in terms of suppliers or actors to involve in the current supply chain to develop the new PSS solution are: electronic components designers and suppliers, partners in research (e.g. electronics, informatics, etc.), research centre as Universities, software developers to design and develop the new web and mobile applications, and the Smart Home providers, to study and implement the IoT paradigms.

According to the results collected after this stage, the definitive business model can be defined (Figure 75). Indeed, the result of the correlation between assets and resources allows defining the Key partners needed to design and develop the new

PSS solution. Moreover, all the information gathered inside the business model can define what kind of costs and revenues are spent and generated.

T/I ASSETS / ECOSYSTEM RESOURCES	Sensors inside WM basket	Sensors to monitoring WM running	Sensors to identify detergent amount	Detergent boxes	WM components	led light	new buttons	WM interface	router wifi	gateway	module zigbee	SW system	applications	DB	Rules to manage the smart maintenance	Rules to manage data collected	Rules to deliver different fuctionalities	Knowledge in Service system	Knowledge in IoT	GPN	
weight	5	4	2	0	1	0	0	1	3	3	3	3	4	4	2	5	4	3	2		
INDESIT company	3	3	3	9	3	9	9	9	3	3	3	9	1	3	9	9	9	3	3	239	21%
Suppliers of eletronic components	9	9	9	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	137	12%
Detergent producers	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	9	3	0	45	4%
Detergent providers	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	9	3	0	45	4%
Partners in research (electronics, informatics, etc.)	0	0	0	0	0	0	0	1	3	3	3	3	3	3	9	9	9	9	9	204	18%
Universities	0	0	0	0	0	0	0	1	0	0	0	3	3	3	9	9	9	9	9	175	15%
Technological partners	0	0	0	0	0	0	0	1	0	0	0	3	9	1	1	1	1	1	1	63	5%
Software developers	0	0	0	0	0	0	0	0	0	0	0	9	0	9	1	1	1	3	3	91	8%
Energy utilities	0	3	0	0	1	1	0	3	0	0	0	3	3	3	0	3	3	1	0	78	7%
Smart Home providers	0	0	0	0	0	0	0	0	3	3	3	0	3	0	0	0	0	9	9	86	7%

Figure 74. *Matrix 4: correlation between T/I assets and Ecosystem resources*

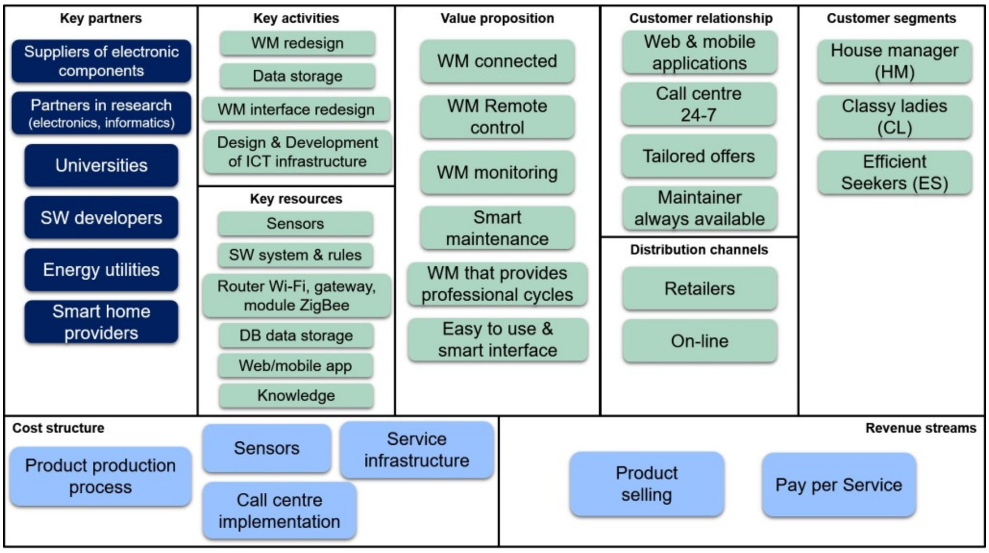


Figure 75. *Business model at the end of methodology implementation*

In this way, at the end of the design process, also all the business aspects have been identified and quantified, reducing the design process inside a traditional manufacturing company. At this point, the business model can be assessed by different point of view by both technical and business units in the company, but this aspect is out of the scope of this research work.

6.7. Main results

The results achieved applying such the methodology to the Indesit use case demonstrated how this integrated approach could support a manufacturing company product-oriented to define a new PSS solution in a successful way.

In particular, project manager can be supported by the methods' matrices in strategic decision-making and detailed design. Indeed, matrix 1 highlights a set of ideas generated by different actors that opportunely analysed (i.e. insight, consumer promise, reason why) are able to define a specific market direction to follow in order to satisfy the market needs, which are fundamental in decision-making process. Matrix 2, after the elicitation of the main ecosystem requirements, focuses on the definition and modelling of the most important PSS functionalities to realise. Matrix 3 gives into the detail of what are the main T/I assets required to satisfy the functionalities derived before, while matrix 4 analyses both functional and ecosystem requirements of the new PSS solution in a pragmatic and clear way, supporting technical decisions, operational planning and the GPN configuration.

These effects are demonstrated by the methodology results at Indesit use case, addressing innovation in washing machines. For instance, in this case, analysis of the ideas as insight, consumer promise, reason why revealed that offering a connected and monitored appliance that supports the users into the product usage, but without the improvement of its performances is not the key to reach customer satisfaction. Moreover, such the analyses have allowed the company easily differentiating how the new PSS solution has perceived by the different user profiles. This aspect allows identifying the specific value proposition to develop and deliver to the related consumer segment. Furthermore, the analysis on the redefined ideas also highlighted that an energy monitoring service and a preventive maintenance service could be positively accepted by the target market, as well as the necessary redesign of the WM and its interface. All these changes will imply stronger modifications to the current product structure, even if their implementation provides to have a positive impact on sustainability and environmental issues, according to the sustainability assessment conducted in paragraph 6.5.

About the ecosystem, results highlighted that addressing the target customers are fundamental as well as realising cooperation and data sharing among the network partners. As a conclusion, reading the matrixes, they tell an interesting 'story' about which is the most successful PSS and how to implement it from a technical viewpoint. In a nutshell, results demonstrated that the proposed method could be validly used to find out the more promising innovation factors by promoting an integrated approach. Moreover, the methodology application has demonstrated that the business model defined (Figure 75) is a realistic example of the model to implement.

The benefits in such the method application at Indesit design process have been shared by Table 12. The main benefits achieved thanks to the UCD methodology application can be inferred from the last column.

A sensible reduction in the global process time was due to less and more effective design reviews, as well as the reduced number of design interactions and physical prototypes. At the same time, the correspondence to the brief requirements and the higher user satisfaction highlighted how the new UCD method forced people to pay more attention to the users' needs and expectations from the preliminary ideation stages and also in the evaluation stages. Indeed, in the previous process, ideation was supported by brainstorming and the Marketing department defined the users' need; now ideation is more structured and supported by different tools (i.e. role-playing for needs' analysis, BUC for scenario definition, QFD for requirements elicitation, idea manager, etc.) which guarantee a more user-centric needs' analysis.

Table 12. *Comparison between traditional and PSS design*

EVALUATION HEURISTICS	METRICS	UNIT OF MEASURE	TRADITIONAL PRODUCT DESIGN	UCD PSS DESIGN	UCD BENEFITS
PROCESS QUALITY	*Design iteration*	No.	9	2	78%
	Design review	No.	15	6	60%
	Time to market	Months	18	10	44%
DESIGN REVIEW QUALITY	*Design reviews duration (average)*	Hours	4	3	25%
	Physical prototypes	No	5	1	80%
PSS QUALITY	*Brief requirements correspondence*	%	60	85	29%
	Customer needs satisfaction	%	54	80	33%

Data collected in Table 12 have been calculated by Indesit Company thanks to the creation of the first PSS prototype of the connected and monitored WM, at the end of the design method application. Indeed, the company has developed about 50 prototypes that have used as a first test case before to deliver such the solution on the market. These prototypes have been developed also according to the business model defined at the end of the methodology application, in order to validate the model generated.

In this way, the validity of the proposed methodology has been tested by measuring the customer satisfaction of the new PSS and comparing the results with those, about the traditional product. Groups of target users were involved in usability testing. Of course, such the analysis is preliminary and should be investigated on the final PSS performances. However, usability tests highlighted the improvement of the general customer satisfaction in respect of the traditional solution before servitization. The testing has been based on an ad-hoc questionnaire (see Appendix C, C1 section). Results collected refer to the first WM prototype with the Carefree Washing Service released. End-users have used the WMs plus Service for three months and at the end they have answered to the tailored questionnaire. According to the questionnaire and relative answers provided by the users, several strengths and weakness were identified.

The main advantages of the PSS solution after the first test with customers are:

- Greater awareness about the WM consumption at each washing cycle;
- Consultation of the historical data about washing cycles' consumption;
- Be encouraged to save money and avoid unnecessary consumption;
- Help in avoiding overloads.

The weaknesses can be inferred from the customers' feedbacks; they are:

- User interface optimization;
- Smart help to manage some fault

Anyway, the results of this first "Carefree Washing Service" evaluation allowed:

- assessing the robustness of the product-service solution proposed;
- identifying the more useful and used functionalities;
- understanding each customer behaviour;
- understanding what may be the substantial changes to implement in the final prototype.

Chapter 7. Conclusion and discussion

This present research thesis investigates the main issues of PSS design when it is applied in the context of product-oriented manufacturing companies, and proposes a structured and integrated methodology to support the PSS design process from its earliest ideation stages. The methodology has been defined starting from the analysis of current product design methods in manufacturing industry, focusing on white goods sector, and it adopts a QFD-based approach to rigorously correlate and measure different PSS aspects (from insights to requirements and functionalities, until the GPN configuration), with the final scope to overcome the main problems of a manufacturing company facing the PSS design for the first time.

The proposed method has been applied to an industrial case study to check its validity and demonstrate its concrete support provided not only to the main company, but also to the entire ecosystem made up of large (LEs) and small and medium enterprises (SMEs). Indeed, the involved case study ecosystem comprehends an appliances' manufacturer (LE) that wanted to innovate their products by designing a new PSS solution, and involves a set of suppliers (SMEs) as strategic partners.

According to the main research questions highlighted in Chapter 1 (paragraph 1.3), such the research thesis answers as in the following:

a. *What are the main links between Product Lifecycle Management (PLM) and Service Lifecycle Management (SLM) during product and service engineering?*

A structured Product-Service Lifecycle Management (P-SLM) process has been proposed (Figure 9, Peruzzini et al., 2014a) and a deep discussion has been faced about the current models of both product (PLM) and service (SLM) lifecycle management approaches. The result of this analysis have allowed identifying where (in terms of lifecycle steps) build the main links between PLM and SLM. About how build such the links, the methodological approach proposed by this research thesis offers a structured framework that is user-centred design and not product-oriented, fostering the continuous interconnection between product and service configuration.

b. *If in PSS engineering the tangible asset is represented by the product, how is it possible identify and thus design the intangible assets?*

The PSS design needs to involve the configuration of four main components, which are: the product, the service, the infrastructure that allows the service delivering, and the partnership able to support such the PSS configuration. According to this description, the product in completely a tangible component, while the others are intangible ones at different level. Indeed, the infrastructure is a tangible asset in terms of the technology used, but it involves intangible assets, for example about the typology of data required to develop the service provided. Instead, the service and the partnership assets are completely intangible. For this reason, a user-centred design methodological approach has been proposed by this research thesis, because it is able not only configure the tangible assets (i.e. product design), but analysing also the user requirements and investigating the partners knowledge, skills and resources allows designing all the intangible assets involved in the PSS design.

c. *How ICT and IoT technologies are involved in PSS engineering?*

According to the discussion at the previous research question, one of the T/I asset involved in the PSS design is the infrastructure that allows the service delivering. Such the infrastructure is generally an ICT infrastructure, which exploits the IoT technology to connect the product and service assets. A deep discussion about these technologies widely used todays also at manufacturing level has been proposed at Chapter 2.

d. *How change the business model from product proposal to PSS value proposition? What are the main affected areas in the new business model?*

The application of the proposed methodology for PSS designing allows building the business model concurrently at the technical design configuration. In this way, the delay between the product is designed and it is assessed by a business point of view has been considerably reduced. This because the approach proposed by this research thesis allows a concurrent engineering of both technical and business aspects, identifying the value proposition, the customer segments, the key partners, the key activities and resources, and the customer relationships – which are some of the business model areas – during the PSS technical design.

e. *How to support manufacturing companies in the approaching of Servitization process?*

As already highlighted during this research work, currently does not exist a structured methodology to support manufacturing companies to face the Servitization process. They have available several approaches, which deal a specific aspect of Servitization, for example to engine the customer requirements or to configure a flexible set of partners. This research thesis goes through this direction, offering a structured approach able to follow all the PSS design steps for the eraly stages (i.e. ideation and customer requirements analysis) to the definition of the business model.

In the following, the main strengths and opportunities have been highlighted, as well as the bottlenecks and improvements required to do.

7.1. Strengths and Opportunities

The present research thesis has defined a user-centred methodology to successfully design PSS taking into account humans' factors. It integrates User-Centred Design (UCD) techniques in order to involve users from the early stages of design process. Indeed, users' appraisal is usually evaluated only at the end of the design process on physical prototypes, with an increase of time and costs. Indeed, a PSS is generally characterized by a great interaction with the users and, for its success, the satisfaction of users' needs and expectations is fundamental to reach. This is the preliminary methodology strength to identify, because it addresses also one of the main challenges defined inside this research work, at chapter 3.

Following the discussion, two types of contributions can be distinguished analysing the methodological approach proposed: theoretical and practical. From a theoretical point of view, the proposed method allows:

- schematising the PSS ideation process by defining the main inputs and outputs to be considered in the definition of requirements and the following design stages;
- easily supporting the definition of new PSS proposals by matching market needs and ecosystem requirements with technical and environmental issues;
- extending product design to include PSS by integrating the proposed model into the traditional product design process.

From a practical point of view, the method application allows achieving the following objectives:

- rapid requirements identification for PSS in few steps;
- better communication between marketing and engineering staff with the leader company and among partner companies, foreseeing the knowledge sharing among all the company departments;

- the requirement list is more complete and broader than in respect with similar assessment carried out without the support of the proposed methodology;
- better analysis of all partners involved and punctual correlation with the assets, both tangible and intangible, which they are able to deliver (e.g. products, services, infrastructures, knowledge, people, etc.);
- flexibility and adaptation to different industrial sectors (transversality of the proposed methodology).

In respect with other studies about the application of QFD technique, the main contribution of the present research is the enlargement of the study perspective and the application to the PSS design process as a whole. Indeed, traditional QFD research is strongly oriented on the product-design issues; while more recent works focusing on PSS mainly refer to the customer RE, some of them arrive until the definition of the preliminary engineering characteristics, but none of them moves so ahead in the design process until the definition of functional and ecosystem requirements and their mapping with the ecosystem partners' assets.

Moreover, the proposed method innovation is also in offering an approach that is able to use several methods and tools already existed in literature, but giving them a new nature through the formalization of such the structured methodology. Here these methods and tools are used and managed in an integrated way, reducing PSS design time, costs, and proposing a prototype that is very close to the customers' needs and requirements, thanks to the UCD nature implicit into the methodology proposed.

However, having a PSS design process well-structured by a technical point of view is not the only main strengths, because such the methodology is also able to manage concurrently both technical and business analyses along the PSS design process. Maybe this result can be seen as the most important, because provides a business translation of the main technical results obtained. It is not so obvious the link proposed by such the method between QFD results collected by each matrix and the relative compilation of the business model area (considering the Canvas model). Indeed, in literature neither research work faces such the topic, even if several approaches that link the costs of a solution to its design impacts are shown. However, these methods aims to provide the quantification of that solution designed but not how the economic or business assessment can be done concurrently with the technical assessment.

All these discussion have reason to exist because manufacturing is moving always more to the PSS concept, developing solutions that are more service-oriented than the current product offer. In this context, such the companies needs tools and methods that can support the new design process, avoiding too long time procedures to arrive at the first prototype, and above all, to arrive the first prototype that is able to reach the customers' needs. Indeed, the main challenge in PSS design is to satisfy the customers' needs and requirements adopting a UCD approach, which is completely different from the current product-oriented design approaches.

7.2. Weaknesses and improvements

Despite this proposed methodology represents a great advantage for all those manufacturing companies that would approach PSS design instead the current product design, it needs to be tested a lot and also in other industrial use case and inside other sectors. This because to demonstrate the effective transversality of this methodological approach and also to highlight if some industrial sectors exist where such the method can have some criticalities.

Actually, its application to a German company belonged to the aviation sector has been started in the last months of the entire research project (i.e. Ph.D course), but it is too early discuss about this process. However, the company remained very interesting to exploit such the approach, because it is facing the transition to offering PSS solutions, but without having any design tool to use for reach this scope.

One improvement according to the proposed approach can be the development of an IT tool that is able to manage all the eight methodology steps involved. This need is also identified by the German company interesting in the method exploitation. It should allow reducing time and people effort during the definition of the correlation matrixes and in the calculation of the related results. Moreover, also the analysis of the outputs coming from each matrix can be optimised if involved in IT tool. Actually, to arrive at defining and developing such the IT tool, a more redefinition of the entire UCD approach through the adoption of QFD matrixes should be revised, in order to arrive at the definition of a methodology structure that is adaptable to each manufacturing sector. This obviously implies that the proposed methodology must be validated also into other industrial use case, belonged to different sectors.

Probably, one of the major weaknesses of the current methodology implementation is the management of the sustainability assessment. This because, according to the methodology applied to the Indesit use case, the sustainability assessment has been conducted as a preliminary analysis that affects the requirements elicitation step. Thus, sustainability has been saw as a strategic driver that guide the PSS design team in the definition of the main ecosystem requirements, which will be put in correlation to the tasks. Instead, the sustainability assessment can acquire a more strategic role inside the methodology steps if is used as a decision-making tool for evaluating different PSS solutions that can be generated by the application of the proposed method.

Indeed, a great advantage that has not disclosed by the methodology application in Indesit, is that such the method can generate several results in terms of possible business models to develop according to the same value proposition defined. This because the customers' segments involved can be different and have different needs and requirements that must be satisfied through the implementation of different business models. Or, for example, the same value proposition implies the involvement of different key activities and resources according to the key actors involved. For this reason, a decision-making tool able to assess the goodness or the better benefits of one solution rather than anther is fundamental. And in this context, the sustainability assessment can be the right solution, because the model proposed in this research work at the paragraph 5.3 involves both the environmental impacts assessment concurrently with the economic impacts assessment. Thus, a PSS solution represented by the related business model can be analysed not only considering the environmental impacts that will be generated along all the lifecycle phases, but also evaluating the related costs generated and saved along the same lifetime.

In conclusion, the methodology proposed represents a good example of PSS design tool to support manufacturing companies, also because it involves at the same time both technical and business analysis of the PSS solution to develop. Of course, some improvements must be done according to the main issues discussed in lines above, and also a more methodology exploitation at other manufacturing companies and in other sector is necessary. However, the advantages demonstrated by the methodology application in Indesit use case are significant and demonstrate a positive implementation and result.

Chapter 8. Future works

According to the methodology proposed and its specific context, the future works can be analysed by two main different point of view: short-medium period actions and long period actions.

The first ones are focused on several aspects already discussed in the previous chapter, which the main are:

- Methodology application in other manufacturing companies belonged to different industrial sectors;
- Structure more in deep the methodology steps to have a more robust method able to dynamically answer to the any customers' need;
- Implement the sustainability assessment as a decision-making tool to assess the resulted business models;
- Investigate other potential decision-making tool to evaluate the resulted PSS solutions at the end of the methodology implementation;
- Development of an IT tool able to manage the entire methodology application.

Instead, the long period activities involves inevitably the abstraction of PSS concept to be extended at the company level. This means foresee the Industry 4.0 vision, where the company processes are all connected and monitored to be managed in a proper way. Indeed, during the last years, the digitalization of manufacturing companies became always more and more a sensitive topic, that involves the use of different existed technologies on the market to connect the industrial processes and monitor their functionalities and performances in order to optimise such the processes, provide the energy efficiency, reduce the environmental and economic impacts and so on.

This topic is becoming to be always more actual also thanks to the availability of a set of technology existed and well-used by manufacturing companies and markets in general. This trend demonstrates how the current European markets and industry world are ready to use the PSS concept, the Servitization process to innovate their products and translate this concepts also at process level to make their factories more digital in order to reach and create at the same time the factory of future.

Appendix A. Methodology matrixes

A1. Matrix 1: correlation between Ideas and Consumers' needs (HM, S, ES)

CUSTOMERS' SEGMENTS — HM

IDEAS / USERS' NEEDS	APP for smartphone and tablet	Balance between quality and price	High washing cycle performance	Energy efficiency	Optimised detergent consumption	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Care for fibres	Care for colours	Appliance reliability
weight	2	5	4	5	5	3	3	5	4	4	4
Autodose technology	1	0	3	0	9	3	1	3	0	0	0
Remote control	9	1	3	1	1	1	9	0	0	0	0
Washing cycles monitoring	9	1	3	3	1	1	9	0	0	0	0
Energy monitoring	3	1	1	9	0	3	1	0	0	0	0
Water control & monitoring	1	1	3	0	0	3	1	0	0	0	0
Preventive maintenance practices	9	3	3	0	0	1	9	0	0	0	9
Automatic recognition of garments colours	0	0	9	0	0	0	0	3	0	9	0
Pre-treatment of stain	0	0	9	0	0	0	0	9	0	0	0
WM provided of led technology	0	0	9	0	0	0	0	3	9	0	0
WM provided of professional cycles	0	0	9	0	0	0	0	9	3	3	0
New technology for treating coloured clothes	0	0	9	0	0	0	0	3	0	9	0
WM provided new technology for sweet wash/drying	0	0	9	0	0	0	0	3	9	0	0
WM connected	9	1	3	3	3	1	9	0	0	0	1
Appliance with smart interface	3	0	0	0	0	0	1	0	0	0	0
WM connected to dryer	1	0	0	0	0	0	3	0	0	0	0
Double door	0	0	3	0	0	0	0	9	0	0	0
Professional cycles at home	0	0	9	0	0	0	0	9	9	9	0
Relevant NEEDS	**90**	**40**	**340**	**80**	**70**	**39**	**129**	**255**	**120**	**120**	**40**
	1323										
	17%										

CUSTOMERS' SEGMENTS — S

IDEAS / USERS' NEEDS	Gaming activity	Easy to use appliance	Easy to use interface	Online purchase	High washing cycle performance	Appliance reliability	Clean clothes	Monitoring WM outside home
weight	1	4	4	3	2	3	5	1
Autodose technology	1	0	0	3	3	0	3	1
Remote control	9	9	9	9	3	0	0	9
Washing cycles monitoring	9	1	3	3	3	0	0	9
Energy monitoring	3	1	3	0	1	0	0	1
Water control & monitoring	3	1	3	0	3	0	0	1
Preventive maintenance practices	3	1	3	3	3	9	0	9
Automatic recognition of garments colours	0	3	0	0	9	0	3	0
Pre-treatment of stain	0	0	0	0	9	0	9	0
WM provided of led technology	0	3	0	0	9	0	3	0
WM provided of professional cycles	0	3	0	1	9	0	9	0
New technology for treating coloured clothes	0	3	0	0	9	0	3	0
WM provided new technology for sweet wash/drying	0	3	0	0	9	0	3	0
WM connected	9	9	9	9	3	1	0	9
Appliance with smart interface	9	9	9	3	0	0	0	1
WM connected to dryer	0	0	0	0	0	0	0	3
Double door	0	3	0	0	3	0	9	0
Professional cycles at home	0	3	3	0	9	0	9	0
Relevant NEEDS	**46**	**208**	**168**	**93**	**170**	**30**	**255**	**43**
	1013							
	13%							

CUSTOMERS' SEGMENTS — ES

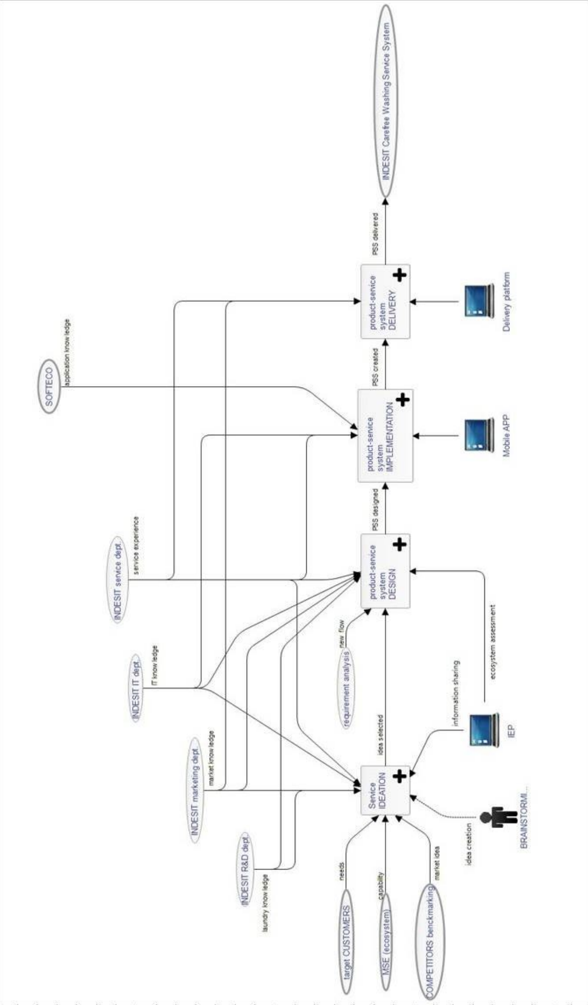
IDEAS / USERS' NEEDS	Gaming activity	Easy to use appliance	Easy to use interface	APP for smartphone and tablet	Balance between quality and price	Online purchase	High washing cycle performance	Energy efficiency	Optimised detergent consumption	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Care for fibres	Care for colours	Appliance reliability
weight	2	5	5	4	3	4	4	3	5	3	4	5	3	3	5
Autodose technology	1	0	0	1	0	3	3	0	9	3	1	3	0	0	0
Remote control	9	3	9	9	1	9	3	1	1	1	9	0	0	0	0
Washing cycles monitoring	9	1	3	9	1	3	3	3	1	1	9	0	0	0	0
Energy monitoring	3	1	3	3	1	0	1	9	0	3	1	0	0	0	0
Water control & monitoring	3	1	3	1	1	0	3	0	0	3	1	0	0	0	0
Preventive maintenance practices	3	1	3	9	3	3	3	0	0	1	9	0	0	0	9
Automatic recognition of garments colours	0	3	0	0	0	0	9	0	0	0	0	3	0	9	0
Pre-treatment of stain	0	0	0	0	0	0	9	0	0	0	0	9	0	0	0
WM provided of led technology	0	3	0	0	0	0	9	0	0	0	0	3	9	0	0
WM provided of professional cycles	0	3	0	0	0	1	9	0	0	0	0	9	3	3	0
New technology for treating coloured clothes	0	3	0	0	0	0	9	0	0	0	0	3	0	9	0
WM provided new technology for sweet wash/drying	0	3	0	0	0	0	9	0	0	0	0	3	9	0	0
WM connected	9	9	9	9	1	9	3	3	3	1	9	0	0	0	1
Appliance with smart interface	9	9	9	3	0	3	0	0	0	0	1	0	0	0	0
WM connected to dryer	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0
Double door	0	3	0	0	0	0	3	0	0	0	0	9	0	0	0
Professional cycles at home	0	3	3	0	0	0	9	0	0	0	0	9	9	9	0
Relevant NEEDS	**92**	**230**	**210**	**180**	**24**	**##**	**340**	**48**	**70**	**39**	**172**	**255**	**90**	**90**	**50**
	2014														
	26%														

A2. Matrix 1: correlation between Ideas and Consumers' needs (CL, D, WT) and total results

IDEAS / USERS' NEEDS (CUSTOMERS' SEGMENTS)	CL								D										WT						Significant IDEAS	
	APP for smartphone and tablet	Online purchase	High washing cycle performance	Gaming activity	Low environmental impacts WM	Monitoring WM outside home	Clean clothes	Optimised detergent consumption	Easy to use appliance	Easy to use interface	APP for smartphone and tablet	Online purchase	Energy efficiency	Optimised detergent consumption	Clean clothes	Care for fibres	Care for colours	Monitoring WM outside home	Online purchase	APP for smartphone and tablet	High washing cycle performance	Monitoring WM outside home	Clean clothes	Gaming activity		
weight	5	5	3	5	2	4	5	2	3	3	3	1	4	3	5	2	2	1	3	5	1	3	5	4		
Autodose technology	1	3	3	1	3	1	3	9	0	0	1	3	0	9	3	0	0	1	3	1	3	1	3	1	**386**	5%
Remote control	9	9	3	9	1	9	0	1	3	9	9	9	1	1	0	0	0	9	9	9	3	9	0	9	**820**	11%
Washing cycles monitoring	9	3	3	9	1	9	0	1	1	3	9	3	3	1	0	0	0	9	3	9	3	9	0	9	**628**	8%
Energy monitoring	3	0	1	3	3	1	0	0	1	3	3	0	9	0	0	0	0	1	0	3	1	1	0	3	**311**	4%
Water control & monitoring	1	0	3	3	3	1	0	0	1	3	1	0	0	0	0	0	0	1	0	1	3	1	0	3	**193**	3%
Preventive maintenance practices	9	3	3	3	1	9	0	0	1	3	9	3	0	0	0	0	0	9	3	9	3	9	0	3	**629**	8%
Automatic recognition of garments colours	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	0	9	0	0	0	9	0	3	0	**333**	4%
Pre-treatment of stain	0	0	9	0	0	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	9	0	9	0	**396**	5%
WM provided of led technology	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	9	0	0	0	0	9	0	3	0	**333**	4%
WM provided of professional cycles	0	1	9	0	0	0	9	0	3	0	0	1	0	0	9	3	3	0	1	0	9	0	9	0	**502**	7%
New technology for treating coloured clothes	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	0	9	0	0	0	9	0	3	0	**333**	4%
WM provided new technology for sweet wash/drying	0	0	9	0	0	0	3	0	3	0	0	0	0	0	3	9	0	0	0	0	9	0	3	0	**333**	4%
WM connected	9	9	3	9	1	9	0	3	9	9	9	9	3	3	0	0	0	9	9	9	3	9	0	9	**934**	12%
Appliance with smart interface	3	3	0	9	0	1	0	0	9	9	3	3	0	0	0	0	0	1	3	3	0	1	0	9	**445**	6%
WM connected to dryer	1	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	3	0	1	0	3	0	0	**67**	1%
Double door	0	0	3	0	0	0	9	0	3	0	0	0	0	0	9	0	0	0	0	0	3	0	9	0	**348**	5%
Professional cycles at home	0	0	9	0	0	0	9	0	3	3	0	0	0	0	9	9	9	0	0	0	9	0	9	0	**630**	8%
Relevant NEEDS	**225**	**155**	**255**	**230**	**26**	**172**	**255**	**28**	**138**	**126**	**135**	**31**	**64**	**42**	**255**	**60**	**60**	**43**	**93**	**225**	**85**	**129**	**255**	**##**		
	1346								954										971							
	18%								13%										13%							

A3. Matrix 2: correlation between Tasks and Ecosystem requirements

TASKS \ ECOSYSTEM REQUIREMENTS	New sensors to provide autodose	New sensors to monitor WM cycles	New sensors to adopt preventive maintenance	WM redesign	Development of ICT infrastructure to connect WM	SW system development	HW infrastructure development	Improve and redesign the main board	Improve and redesign theWM interface	Web and mobile apps development	Rules definition to apply preventive maintenance	Consumer habits monitoring	Detergent suppliers involvment	Involve the EoL consortia to develop the new WM	Create the Smart Home environment	Foresee the gming activities	Efficient and effective WM connection
Monitor WM status and washing cycles																	
Monitor WM performances																	
Have feedback about washing habits																	
Have feedback about resources exploitation																	
Have feedback about WM status																	
Provide messages about WM status																	
Have information about last washing cycle																	
Register the appliance on web site																	
Activate the WM by remote control																	
Have alert about pre-fault																	
Have alert about WM performances																	
Provide a detergent optimization																	
Provide a water optimization																	
Reduce the resources exploitation																	
Have tailored cycles according to dirty clothes																	
Improve the WM usage																	
Create an internal grid (at home)																	
Create an external grid (with friends)																	
Provide a fast connection to the WM																	
Provide an intuitive main board																	
Provide a touch screen																	
Provide led buttons																	
Be informed about market proposal																	
Buy detergents at special prices																	
Automatic order of spare parts and delivered at home																	
Provide tailored offers according to washing habits																	
Have a virtual maintainer always available																	
Provide a web-site available by different devices																	
Provide the ICT infrastructure to connection																	
Connect the WM																	



A4. Matrix 3: correlation between T/I assets and PSS functionalities

T/I ASSETS \ PSS FUNCTIONALITIES	weight	WM connected	WM monitored	Smart maintenance	Best practices proposals	Marketing offers proposal	Smart interface	Temperature monitoring	Water used monitoring	Detergent used monitoring	Energy used monitoring	Total costs per cycle	Foresee gaming among the grid	NEEDED ASSETS	
Sensors inside WM basket	5	0	9	3	9	9	0	9	9	9	0	1	3	**305**	10%
Sensors to monitoring WM running	5	0	9	9	3	3	0	3	3	3	9	9	3	**270**	8%
Sensors to identify detergent amount	3	0	9	0	9	9	0	0	0	9	0	1	3	**120**	4%
Detergent boxes	1	0	0	0	0	1	0	0	0	9	0	0	0	**10**	0%
WM components	2	3	3	9	0	0	9	1	1	1	0	0	0	**54**	2%
led light	2	0	0	0	0	0	9	0	0	0	0	0	1	**20**	1%
new buttons	2	0	0	1	1	1	9	0	0	0	0	1	0	**26**	1%
WM interface	4	0	0	1	3	3	9	0	0	0	0	3	0	**76**	2%
router wifi	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
gateway	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
module zigbee	5	9	9	3	3	3	0	1	1	1	1	1	9	**205**	6%
SW system	5	1	3	9	9	9	0	0	0	0	0	3	9	**215**	7%
applications	5	3	3	9	9	9	0	0	0	0	0	3	9	**225**	7%
DB	5	1	3	0	0	0	0	9	9	9	9	9	0	**245**	8%
Rules to manage the smart maintenance	5	9	9	9	0	0	0	0	0	0	0	0	0	**135**	4%
Rules to manage data collected	5	9	9	0	0	0	0	9	9	9	9	9	0	**315**	10%
Rules to deliver different fuctionalities	5	9	9	0	9	9	0	0	0	0	0	0	9	**225**	7%
Knowledge in Service system	5	1	1	9	9	9	0	0	0	0	0	1	9	**195**	6%
Knowledge in IoT	5	9	9	0	0	0	0	0	0	0	0	0	9	**135**	4%
KEY FUNCTIONALITIES		**351**	**488**	**309**	**326**	**327**	**90**	**167**	**167**	**203**	**150**	**207**	**401**	3186	
		11%	15%	10%	10%	10%	3%	5%	5%	6%	5%	6%	13%		

A5. Matrix 4: correlation between Partners resources and T/I assets

ECOSYSTEM RESOURCES \ T/I ASSETS	Sensors inside WM basket	Sensors to monitoring WM running	Sensors to identify detergent amount	Detergent boxes	WM components	led light	new buttons	WM interface	router wifi	gateway	module zigbee	SW system	applications	DB	Rules to manage the smart maintenance	Rules to manage data collected	Rules to deliver different fuctionalities	Knowledge in Service system	Knowledge in IoT	GPN	
weight	5	4	2	0	1	0	0	1	3	3	3	3	4	4	2	5	4	3	2		
INDESIT company	3	3	3	9	3	9	9	9	3	3	3	9	1	3	9	9	9	3	3	239	21%
Suppliers of eletronic components	9	9	9	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	137	12%
Detergent producers	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	9	3	0	45	4%
Detergent providers	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	9	3	0	45	4%
Partners in research (electronics, informatics, etc.)	0	0	0	0	0	0	0	1	3	3	3	3	3	3	9	9	9	9	9	204	18%
Universities	0	0	0	0	0	0	0	1	0	0	0	3	3	3	9	9	9	9	9	175	15%
Technological partners	0	0	0	0	0	0	0	1	0	0	0	3	9	1	1	1	1	1	1	63	5%
Software developers	0	0	0	0	0	0	0	0	0	0	0	9	0	9	1	1	1	3	3	91	8%
Energy utilities	0	3	0	0	1	1	0	3	0	0	0	3	3	3	0	3	3	1	0	78	7%
Smart Home providers	0	0	0	0	0	0	0	0	3	3	3	0	3	0	0	0	0	9	9	86	7%

Appendix B. Risk assessment

C1. Incident and risks' values template

Incident	
Brief Description	
Start Date/Time	Click here to enter a date.
End Date/Time	Click here to enter a date.
Type	☐ *Supply* ☐ *Production* ☐ *Demand* ☐ *Logistics* ☐ *External* ☐ *Information and Control (including Management)*
Cause	
Estimated Time Until Next Recurrence	*Expected to reoccur in the next …………. to …………. but most likely in ………….* ☐ *days* ☐ *months* ☐ *years*
Likelihood to happen in the next month	*Estimated value:* ☐*Very low* ☐ *Low* ☐ *Mildly Low* ☐ *Medium* ☐ *Mildly High* ☐ *High* ☐ *Very High* *Confidence in estimate:* ☐*Very low* ☐ *Low* ☐ *Mildly Low* ☐ *Medium* ☐ *Mildly High* ☐ *High* ☐ *Very High*
Consequences	
Estimated Financial Loss	*Between € …………. to € …………. but most likely € ………….*
Solution	
Lessons Learned	
Originated from Partners / Regions	

C2. Incident and risks' values template

Dependency of X on Y	
Description	*[a brief description of the dependency/relationship]*
Trade volume	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Inventory	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Substitutability of the product or service	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Substitutability of the supplier or customer	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Lead-time	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Distance	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*

Information transparency	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Collaboration agreement	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*
Compatibility of IT systems	*Estimated value:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High* *Confidence in estimate:* *☐Very low ☐ Low ☐ Mildly Low ☐ Medium ☐ Mildly High ☐ High ☐ Very High*

Appendix C. Prototype assessment

C1. Questionnaire shared to test users

GENERAL INFORMATION	
1.	**Name & Surname:**
2.	**How many cycles do you usually do in a week?**
	☐ Only 1 cycle ☐ 2 or 3 cycles ☐ 4 or 5 cycles ☐ More 5 cycles (please, let's indicate the number):
3.	**What kind of washing cycles do you usually use?**
	☐ Cotton standard ☐ Mix 30' ☐ Wool ☐ Ultra delicates ☐ Anti-Allergy ☐ Bed & Bath ☐ Duvets ☐ Shirts ☐ Darks ☐ Coloureds ☐ Whites ☐ Synthetics ☐ Spin ☐ Rinse
4.	**What kind of detergent do you usually use?**
	☐ Only powder ☐ Only liquid ☐ Powder + Additives ☐ Liquid + Additives ☐ Add Softener ☐ Other:
PRODUCT EXPLOITATION (DIALOGIC)	
5.	**Is it easy to select the correct washing cycle?**
	☐ It is not at all easy ☐ It is not very easy ☐ It is quite easy ☐ It is very easy
6.	**Is it clear to use the Dialogic user interface?**
	☐ It is not at all clear ☐ It is not very clear ☐ It is quite clear ☐ It is very clear

7. In your opinion, is it useful modify the washing cycle start time through the delay command and control the machine functioning?

☐ It is not at all useful
☐ It is not very useful
☐ It is quite useful
☐ It is very useful

8. In your opinion, is it useful having feedback about the washing functioning and visualize historical data?

☐ It is not at all useful
☐ It is not very useful
☐ It is quite useful
☐ It is very useful

9. In your opinion, is it useful having suggestions about your product usage and best practices to optimize it?

☐ It is not at all useful
☐ It is not very useful
☐ It is quite useful
☐ It is very useful

10. It was difficult for you connect the gateway to the modem or coordinator?

☐ It is not at all easy
☐ It is not very easy
☐ It is quite easy
☐ It is very easy

11. In general, what do you think about the Smart Aqualtis and the Carefree Washing Service?

☐ It is not at all satisfying
☐ It is not very satisfying
☐ It is quite satisfying
☐ It is very satisfying

12. How much frequently did you used the Carefree Washing Service?

☐ Every day
☐ Every day, exception when I am outside house for work or vacancy
☐ Few days
☐ Never

Only IF you have answer "*few days*" or "*never*" in the last question:
12a. Why did you have used for few days or never the Carefree Washing Service? (It is possible to give more one answer)

- ☐ Because the modem did not worked
- ☐ Because I had some problems with the gateway
- ☐ Because I had another technical problem (let's specify the problem)
- ☐ Because I did not liked have the modem always running 24 hours/day
- ☐ Because I did not like or it was inconvenient have the Carefree Washing Service
- ☐ Because I did not like or it was inconvenient have the smart gateway near the modem
- ☐ Because after understanding and reading my consumption, the service is not more useful
- ☐ Because some important product functionality lack (Which one?)
- ☐ Because it is not easy to use
- ☐ Because it is not useful
- ☐ Other comments:

CAREFREE WASHING SERVICE APPLICATION

13 In your opinion, is the Login/Registration page easy to understand and fill in?

- ☐ Very easy
- ☐ Enough easy
- ☐ Quite easy
- ☐ Not easy

14 Was it easy for you to track down all the information needed in the Registration page?

- ☐ Very easy
- ☐ Enough easy
- ☐ Quite easy
- ☐ Not easy

15 During your testing, how much frequently did you use the Carefree Washing Service app on your smartphone, tablet or PC?

- ☐ Every day
- ☐ About 2/3 times a week
- ☐ About 1 time a week
- ☐ About 1 time every 15 days
- ☐ About 1 time a month
- ☐ A the beginning, every day; then less and less
- ☐ Never

16 In your opinion, is it useful using the Carefree Washing Service app often?

- ☐ Very useful
- ☐ Enough useful
- ☐ Quite useful
- ☐ Not useful

Only IF you answer "*quite useful*" or "*not useful*" in the last question:

16a. Why it is quite or not useful? (It is possible to give more one answer)

☐ Because the information on the interface are not clear
☐ Because if I understand my consumption, it is not useful control the interface every day
☐ Because my consumption does not change a lot every day
☐ Because the historic data are hard to understand
☐ Because the best practices are not useful
☐ Other comments:

17 In your opinion, is the "Carefree Washing Service" app well organized?

☐ Very good
☐ Enough good
☐ Average
☐ Very Bad

Only IF you answer "*average*" or "*very bad*" in the last question:
17a. Why it is quite or not clear? (It is possible to give more one answer)

☐ Because the home page organization is not clear
☐ Because my interesting information are hided
☐ Because the "Carefree Washing Service" and its functionalities was not good explained
☐ Other comments:

18 Do you think that the "WM Global Data" interface contains all data to monitor you WM usage?

☐ Yes
☐ No

Only IF you answer "*No*" in the last question:
☐ Please, let's indicate what kind of data missing:

19 Do you think that the "Wash List" interface is clearly organized?

☐ Very good
☐ Enough good
☐ Average
☐ Very Bad

Only IF you answer "*Average*" or "*very bad*" in the last question:
☐ Please, let's indicate why:

20 Do you think that the "My Best Practices" interface contains useful information supporting the daily WM use?

☐ Yes
☐ No

Only IF you answer "*No*" in the last question:
☐ Please, let's indicate why:

21 In your opinion, what kind of information provided by the Carefree Washing Service about the WM data app is more interesting? You can choose more one answer.

- ☐ Program name
- ☐ Start time and data of the cycle
- ☐ End time and data of the cycle
- ☐ Cycle duration
- ☐ Spin value
- ☐ Total cycles number
- ☐ Total energy consumption
- ☐ Total water consumption
- ☐ Percentage of programme exploited
- ☐ Percentage of program spin (among 0, 600, 800, 1600)
- ☐ Percentage of program temperature (among 30°, 40°, 60°)

22 What do you think that today lack in the Carefree Washing Service app?

- ☐ Nothing, there are already all needed information
- ☐ The consumption costs
- ☐ The environmental impacts
- ☐ The extension of this smart system on the other home appliances
- ☐ An alert or message before to have a power cut
- ☐ An alert or message when I consume more of my usual usage
- ☐ The integration between the energy consumption value come from another source and the energy exploit by usual channels
- ☐ Other comments:

23 After having used the Carefree Washing Service app, could you highlight the main strengths?

- ☐ ____
- ☐ ____
- ☐ ____

24 After having used the Carefree Washing Service app, could you highlight the main weaknesses?

- ☐ ____
- ☐ ____
- ☐ ____

25 If the Carefree Washing Service will be a commercial service, shall you buy it?

- ☐ Yes
- ☐ No
- ☐ I do not; it up to the price

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