Doctoral Research in Economics And Management of Technology –DREAMT

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University of Bergamo, Department of Information, management and production Engineering

Engineering and assessing Industrial Product-Service System (IPSS) solutions

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The

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Executive summary

I. The context

In the last decades, "Servitization" of manufacturing (Vandermerwe and Rada 1988) has revealed as a good strategy to face the continuous reduction in sale profit margins and to cope low cost countries competition. Servitization is described as the integration of the traditional product-based offer with value-added services that can support manufacturing companies in generating value from multiple points of view (Brax and Visintin 2017).

Hence, through the servitization, many companies change their value proposition from a traditional product to a mixture of product and services. Such interconnected mix is referred as Product-Service System (PSS): "A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models" (Mont 2002).

The servitization brings many advantages to the companies among which greater differentiation from competitors and the possibility to 'lock-in' customers creating long-term relationships (Neely 2008). More than the benefits boosted by servitization, the PSS itself provides benefits in terms of sustainability and resources efficiency (A. Tukker 2015).

On the other hand, the shift toward the provision of a new value proposition based on PSSs offering poses several challenges (Wanrong and Sujit 2017) due to the complexity of managing intangible services in association to tangible artefacts. One major obstacle to properly manage PSS value proposition since the beginning is the integration of service engineering activities with the traditional product engineering approach as a mean to develop marketable PSSs. Hence, designing and developing PSS is a complex task (Pezzotta, et al., 2012) and to do so proper methods and tools are required.

According to this, the present thesis aims at contributing to the extant literature in the area of PSS engineering proposing methods to support the assessment of the engineering activities along the different phases of the engineering process.

II. Literature gaps and analysis of industrial needs

This research boasts a two-folded aim since it yearns for provide a contribution to both theory and practice in the area of PSS engineering. The first step toward the clarification of the research objective is the analysis of the state of the art. Moreover, to the extent of context clarification, a literature analysis and exploration in the industrial field were carried out.

A literature analysis was developed in the context of PSS engineering. In particular, specific methods to support the engineering phase of PSS were investigated. A variety of methodologies, approaches and methods are available. The methods are all characterized by advantages and disadvantages. The study highlights that there is a lack of common and shared terminology and nomenclature and that the existing methods are not integrated with each other. In addition, the overall PSS engineering would result fragmented and characterised by a heterogeneous mixture of stand-alone methods and approaches. The methods available in the literature, are in general used in a specific phase of the engineering process. Detailed cross analysis of the methods and of the lifecycle phase in which they have been adopted was developed. In particular, there exist several methods for the design phase of the PSS engineering whereas methods to be adopted in the concept evaluation phase lack as well as methods to engineer the middle and the end of life of the PSS. Furthermore, among the available methods for the early phase of PSS design, very few have been proposed for the assessment and the evaluation of the PSS solutions. Finally, yet importantly, the analysis reveals that the majority of methods are prevalently focused on the customers without considering provider viewpoint in association with a PSS. The complete analysis of literature is reported in Chapter 2 of the thesis.

In parallel to the analysis of the state of the art, additional analyses were carried out to study the PSS evolution and the PSS engineering practices in the industrial context. First, a Special Issue in the International Journal of Production Research (IJPR) was launched on the topic of industrial servitization and digitalization. The issue was meant at collecting good practices, concrete experiences and relevant knowledge gained in industry about the transition toward PSS. The management of the special issue publications as a guest editor, allowed a wide analysis of the ongoing research and practices in the industrial context. Second, more insights in the industrial approach toward PSS, i.e. the benefits, the challenges and the complexity of managing the new solutions, were collected through the direct participation into the everyday industrial business in ABB throughout the three years of PhD research. As a result, a general overview of the main needs of ABB with respect to PSS engineering and development was settled. All the research concerning industrial needs are reported in Chapter 3 of the thesis.

III. Aim and research questions

The analysis on literature shed light on the main gaps in the field of PSS. In parallel to the lack of specific methods for PSS evaluation and assessment, the need for methods to engineer the middle of life and end of life phases of the PSS was also mentioned together with the scarcity of practical case applications and quantitive studies.

In parallel high interest of companies in the current advancement of PSS research was registered. This is demonstrated by the scholarship for this PhD research in Product-Service Systems Engineering founded by ABB Spa (http://new.abb.com/it) and by the collection of the latest advancement in PSS and industry collected in a special session of the International Journal of Production Research.

In line with the literature analysis, this thesis aims at contributing to the research in the area of PSS engineering. It particularly it aims at covering two critical phases of the PSS engineering, the early concept development and the late engineering of the PSS that are two critical phases for the development of a successful PSS. Moreover, the objective of the research refers to the engineering of product-oriented PSS and mainly build the knowhow considering a traditional value chain where the main stakeholders involved in the provision of PSS are the customer and the provider. Hence, the goal of this thesis is **to develop decision making methods, applicable in industry, for the assessment of industrial Product Service System in strategic phases of the PSS engineering. The methods shall assist decision makers in considering the trade-off between the customer and the provider viewpoints during multiple engineering phases of PSS.**

It is noteworthy to stress the two main features characterizing the overall research goal:

i. The quest for the balance between the excellence in the value provided to the customer and high efficiency and productivity from provider viewpoint. This aims at covering the problem of literature to focus the attention on customer perspective;

ii. The applicability of the methods into the industrial context in order to ensure the practical validity of the research and to cover the lack of big scale quantitative studies identified by (Xin, Ojanen and Huiskonen 2017) (as emerged from the industrial analysis).

To reach this objective, two main research questions were identified:

1. ***RQ1 - How to support decision makers in assessing PSS concepts in the early design phase***
2. ***RQ2 - How to engineer and assess service processes to deliver the identified PSS?***

RQ1 refers to the early design phase of the PSS engineering process while RQ2 focuses on the later stage assessment of the solutions, specifically on the assessment of the middle of life process of the service component of a PSS for which methods and tools are missing. Hence, the research aims to propose methods that can fulfill such needs and support the engineering phase of PSS, both in the early design phase and in later stages of development. Special attention is devoted to the identification of a proper balance between customer satisfaction and company operational excellence. A detailed description of the thesis goal and associated research question is reported in chapter 4 of the following thesis.

IV. Research plan and structure

To answer the two RQs and to satisfy the concurrent needs of practical relevance and academic contribution research was structured as in Fig. 1.

An extensive literature analysis on the PSS domain was planned in order to explore the research in the domain, to identify the main gaps and to consequently identify a specific research aim. In parallel, a specific analysis of the main industrial requirements was developed in collaboration with ABB. The cross comparison of the literature gaps together with the practical needs allowed the identification of a specific research goal and two main research questions.

Further work was developed, and two specific methods were identified, one for each research question. In order to develop the two methods, a specific literature analysis was developed to specifically review the state of the art concerning the specific topic. Then, based on the gaps and on the industrial requirements, a first proposal of the methods was developed. The validation of the methods was finally pursued through the real cases. The validation cases adopted were mainly performed in collaboration with ABB, then, whenever possible (in particular in relation to RQ1) additional applications were pursued in heterogeneous industries to extend the applicability and generalizability of the method. The complete overview of the research structure and the adopted methods is reported in chapter 4 of the thesis.

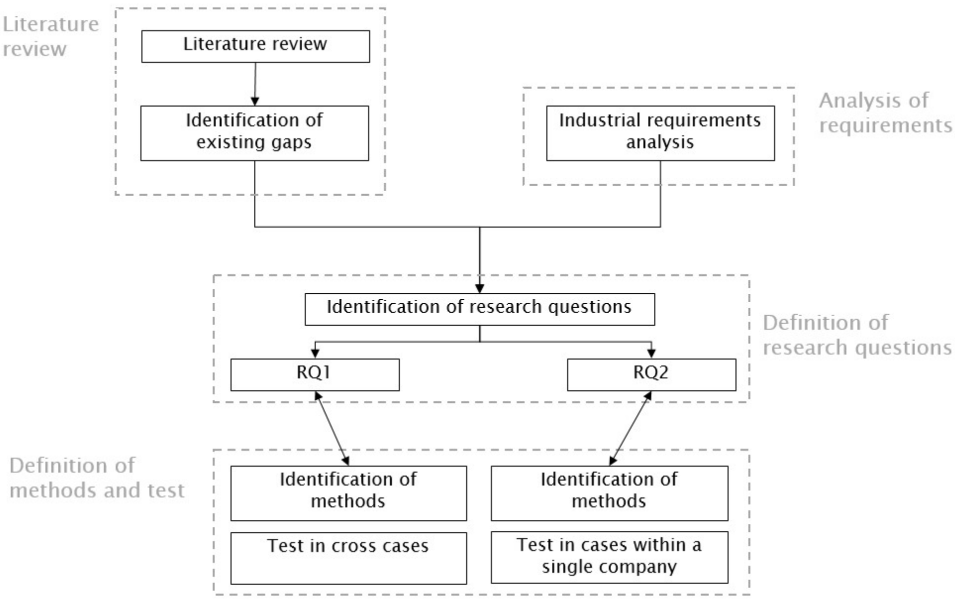


Fig. 1 Research structure

V. Research outcome

For each of the two research questions, a method for the PSS assessment was proposed.

a. The Engineering Value Assessment (EVA) method for PSS

For what concerns RQ1, the literature on the early stage of the PSS engineering process was studied. This phase refers to the moment in which possible PSS concepts (solutions) are identified, but their features are not yet specifically detailed. Among the main features of this step, it is possible to mention the lack of specific information about the PSS concept and the general need to spur the discussion and the communication among the engineering team. Therefore, it is complex to carry out an assessment through prototyping or detailed economic and feasibility analysis.

Furthermore, the literature brought to the fore the lack of assessing methods to be adopted in the critical step of the concept evaluation phase of the engineering process. Few exceptions, such as what proposed by (Matschewsky, Sakao and Lindhal 2015), can be listed but none of the methods supports a structured evaluation of the PSS solutions while also balancing the customer value and the provider value. With respect to the above-mentioned problem, this thesis proposes a new method called *Engineering Value Assessment (EVA) method.* The EVA method, which structure is represented in Fig. 2, is composed of already existing methods that are combined as a mean to properly evaluate a PSS. In particular, it proposes:

- A two-step procedure for the evaluation of PSS concepts under multiple viewpoints (provider and customer)
- The adoption of existing MCDM methods to carry out the PSSs assessment (Pugh Matrix (Frey, Herder, et al. 2010) and TOPSIS (Chang and Tseng 2008)) and to match the multiple viewpoints evaluation (IPA (Martilla and James 1977)).
- A complete set of criteria to be adopted in each step and within each method for a “holistic” assessment of PSSs considering its multiple facets;

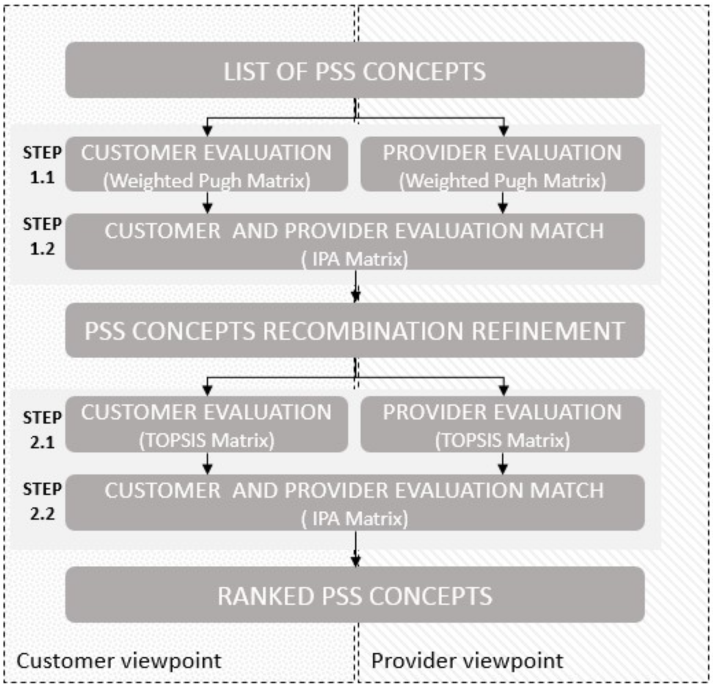


Fig. 2 EVA method structure

For each of the two foreseen steps, the EVA method considers at the same time the customer and the provider perspective since it requires a double evaluation of the PSS concepts. The final scores that the solutions get from the evaluations are used to visualize the results in the IPA matrix that enable trade-off identification between the value perceived by the customers and the value bothered by the company.

In order to verify the benefits and the applicability of the method, the EVA method was adopted in multiple cases: i) to select a valuable PSS in the low voltage unit of ABB; ii) to identify the most suitable configuration and business model for an asphalt roller producer; iii) to prioritize PSSs in the context of Bergamo smart city and iv) to identify the most valuable self check-in service in the airport context.

According to the cases analysed the main strengths of the EVA method, the feedbacks collected from the practical validation, generating consensus and pushing the discussion among team members could be highlighted as one relevant advantage of the EVA method. The immediate visualization of the value perceived by the involved decision makers is another major benefit of the method. The quick value visualization enables the creation of a general understanding of the value contribution of concepts, their features, their benefits and their costs and provides support while defining a trade-off between the different decision makers. The method easiness of use and applicability reported by the people involved in the validation cases constitutes an additional value added motivation for the method validity.

Finally, the wide set of evaluation criteria included into the EVA method have been described valid to achieve the evaluation of a PSS as a "whole".
The whole detailed description of the EVA method and of the validation cases is described in **part II** of the thesis.

b. The Final Assessment of Service (FASt) method for service delivery process assessment

The research concerning RQ2, as previously indicated, is focused on a later stage of the engineering process: either when a concept is selected and its features are well established or when a concept is implemented and its functioning has to be evaluated. The work on this second research question specifically refers to the assessment of the middle of life of the service component of the PSS given that methods for product assessment and selection are well established both in theory and in practice.

As done for the first research question, literature was screened with regard to traditional methods for business process assessment, and a detailed overview of analytical solutions and simulation was identified. After this initial analysis and the first analysis of Discrete Event Simulation (DES), multiple topics were explored and the final FASt method was identified (Fig 3). It consists of two steps. First, it proposes a standardization technique based on modular engineering that facilitates the process modelling and the identification of a common nomenclature to be used into the company while referring to the service delivery process. Second, it proposes the dynamic assessment of the identified standard process through a hybrid simulation approach based on Discrete Event Simulation (DES) and Agent Based Modelling (ABM). DES represent the process whereas the agent represents the customers.
In order to highlight how the method works in industry, a complete validation case in collaboration with ABB demonstrates the capabilities of the FASt method in modelling and assessing the service delivery process. In line with the objective of the thesis, the approach also allows the assessment from two perspectives: customer and provider.

The case demonstrates that the FASt is actually supporting the service delivery process assessment providing statistics about KPIs from both the customer and the provider perspectives. Moreover, the case highlights how the approach o make managers capable of taking structured and justified decisions considering resources utilization and customer perceived performance. Moreover, the service process modularization, make the service delivery process assessment quicker and less costly. Hence, having a set of standard process modules, acting as a reference implies that all the service processes could be engineered by putting together the modules. Based on this, each process assessment can be done "dragging and dropping" the modules into the simulation model.

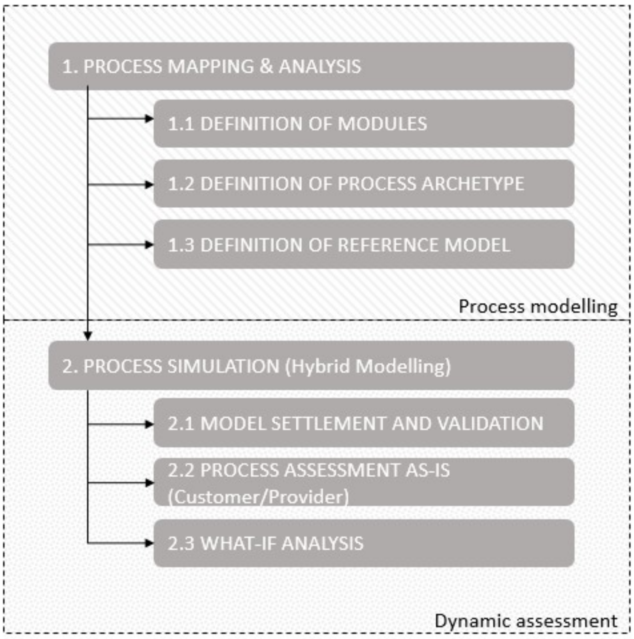


Fig. 3 FASt method

An exhaustive description of the FASt method is reported in Part III of the thesis. It reports all the details of the method and the research steps followed to achieve it.

VI. Scope and limitation of research

The work presented in this thesis tries to summarize all the research advancements. Being the results of three years of research, some facets of the work were not completely explored both with respect to the expansion as well as the extent of research. In particular, the present work gravitates around the SErvice Engineering Methodology (SEEM) (Pezzotta, G., et al. 2016), an existing design methodology developed in the author's research group. This implies strong connection of both the findings in the two RQs to the SEEM steps and advancements.

Moreover, since an ABB scholarship founded the research, the current work is characterized by a strong influence from industry, especially from ABB. Continuous verification of the research advancement is a common pattern throughout the work. All the findings were verified through industrial cases and from each application feedbacks and suggestions were analyzed and used to improve the results in terms of industrial applicability. The main limitations of the work are also related to this. As it is possible to observe through the remaining part of the manuscript, the majority of industrial applications are carried out in collaboration with ABB. This is particularly noticeable in the results regarding the second research question since the validation case requires high commitment from the company in order to be completed. To partially overcome such limitation, when possible,cases from other contexts and business were analyzed.

The second main limitation is the strong emphasis of the work on the service component of PSS espacially for what concern RQ2. This is mainly justified by the existence of well established methods from the product design and development. This research indeed wouldn't argue with concepts that are freezed and well adopted by companies but instead aims at proposing new and useful methods to cover the gaps.

VII. Published and submitted papers

Throughout the three years, the research has been presented at international conferences and submitted to international peer reviewed journals. In the following table (Tab.1) the list of the submitted papers in relation to the different areas of the research is reported.

Tab. 1 Summary of published and submitted papers

Research area	Papers
RQ1	▪ Rondini, A., Pezzotta, G., Pirola, F., Rossi, M., Pina, P. 2016. «How to Design and Evaluate Early PSS Concepts: The Product Service Concept Tree» 26th CIRP Design Conference. Stockholm: Procedia CIRP. 366-371 ▪ Rondini, A., Bertoni, M., Pezzotta, G. 2017« An IPA based method for PSS design concept assessment» 9th CIRP IPSS Conference, Circular Perspectives on Product/Service-Systems, Copenhagen 19th-21st June 2017 ▪ Bertoni, M., Rondini, A., Pezzotta, G. 2017« A systematic review of value metrics for PSS design» 9th CIRP IPSS Conference, Circular Perspectives on Product/Service-Systems, Copenhagen 19th-21st June 2017 ▪ Rondini, A., Lagorio, A., Pezzotta, G., Pinto, R. 2017. « Adopting a Multi Criteria Decision method for the introduction of PSSs in the smart city context » XX Summer school Francesco Turco. Palermo, 13-15 September. ▪ Rondini, A., Bertoni, M., Pezzotta, G. «At the origins of Product Service Systems: supporting the concept assessment with the EVA method» **Submitted to CIRP Journal of Manufacturing of science and technology** ▪ Rondini, A., Lagorio, A., Pezzotta, G., Pinto, R. «A Multi-Criteria Decision Making approach for prioritising Product-Service systems implementation in smart cities» **Submitted to International Journal of Management and Decision Making- Major Revision**
RQ2	▪ Curiazzi, R., **Rondini, A**., Pirola, F., Ouertani, M.Z., Pezzotta, G. 2016. «Process standardization to support industrial service delivery» 8th CIRP IPSS conference - Product-Service Systems across Life Cycle. Bergamo, 20-21 June: Procedia CIRP ▪ **Rondini, A.,** Pezzotta, G., Pirola, F., Cavalieri, S., Ouertani Z.M. «Standardizing delivery processes to support the service transformation: an approach and its industrial application» **Submitted to "Computers in industry"—Major revision.**

	▪ Pezzotta, G., **Rondini, A.,** Pirola, F., Pinto, R. 2016. «Evaluation of Discrete Event Simulation software to design and assess service delivery» processes. Vol. 8, 83. "Service Supply Chain Systems: A Systems Engineering Approach ▪ **Rondini, A**., Tornese, F., Gnoni M. G., Pezzotta G., and Pinto R. «Hybrid simulation modelling as a supporting tool for Sustainable Product-Service Systems: a critical analysis» **International Journal of Production Research (IJPR) Vol 55, pp 1-14 .**
Service Engineering and industrial applications	▪ Pezzotta, G., Pirola, F., **Rondini, A.**, Pinto, R., Ouertani, M. Z. 2016. «Toward a methodology to engineer industrial product-service system - Evidence from power and automation industry» CIRP Journal of manufacturing science and technology. In press ▪ Benedetti, M., **Rondini, A.,** Introna, V., Cesarotti, V., Cavalieri, S. 2016. «SErvice Engineering Methodology and Energy Services: applicability analysis and case study» 8th CIRP IPSS conference - Product-Service Systems across Life Cycle. Bergamo, 20-21 June: Procedia CIRP ▪ **Rondini, A**., Lagorio, A., Pezzotta, G., Pinto, R. 2016. «Exploiting the SErvice Engineering Methodology to re-engineer Bergamo's bike sharing Product Service System» XXI Summer school Francesco Turco. Naples, 13-16 September. ▪ Cavalieri, S. Ouertani, M.Z., Zhibin, J., **Rondini, A. 2017.** «Service Transformation in Industrial companies» Editorial **International Journal of Production Research (IJPR)**

VIII. International experiences and conference participation

Furthermore, during the three years, the research advancements were presented at national and international conferences in the area of PSS and Service Engineering. PhD workshops and schools were also part of the dissemination activities among young researchers. During the third year of PhD courses, a visiting period of three months was spent in BTH Blekinge Institute of Technology.

Hereafter is a list of the conferences and workshops attended.

International and National conferences

- 21st ICE Conference, "Engineering Responsible Innovation in Products and Services", Bergamo 23rd – 25th June 2014
- XIX Summer School “Francesco Turco”, Industrial Mechanical Plants – SSD Ing-Ind/17, 9th - 12th September 2014, Senigallia, Italy
- 7th International EurOMA Service Operations Management Forum (SOMF),Tilburg, The Netherlands, September 21st -23rd 2014.

- 7th CIRP Industrial Product-Service Systems Conference (IPSS). PSS Industry transformation for sustainability and business. 21st -22nd May Saint Etienne, France
- 8th CIRP Industrial Product-Service Systems Conference (IPSS). Product-Service Systems across Life Cycle. 20th -21st June 2016, Bergamo, Italy
- 9th CIRP Industrial Product-Service Systems (IPSS) conference. Circular perspectives on PSS. 19th -21st June 2017, Copenhagen, Denmark
- XXII Summer School "Francesco Turco", Industrial Mechanical Plants – SSD Ing-Ind/17, 13th - 15th September 2017, Palermo, Italy

PhD Workshops

- 6th Doctoral workshop PALM (products and assets lifecycle management), Les Diablerets, Switzerland 26th-29th January 2014
- 1st "PhD on the go" Doctoral Workshop 2014, Lecce 10th -12th April 2014
- 2nd IFIP WG5.7 Associates Spring School, Milan 22nd -24th May 2014
- 2nd "PhD on the go" Doctoral Workshop 2015, Lecce 15th -17th April 2015
- 7th IPS2 Spring School, Sustainable Product-Service System Design. Grenoble, Saint Etienne 18th – 21st May 2015
- 7th Doctoral Workshop PALM (products and assets lifecycle management), 1st -4th July 2015, Belfort- Montbéliard, France
- Eden Doctoral seminar on research methodology in operation management. February 1- 5 2016, Brussels, Belgium
- 8th Industrial Product-Service Systems (IPS2) Doctoral Spring school "Operations Management methods and Technologies for PSS Delivery". 13th-17th June 2016, Brescia, Italy
- 8th Doctoral Workshop PALM (products and assets lifecycle management), 16th -19th October 2016, Urrugne, Saint-Jean de Luz, France
- IV "PhD on the go"- Marco Garetti Doctoral Workshop, Salerno 3rd-5th May 2017

1 Introduction

The economic globalization, combined with an increasing products homogenization, fleeting obsolescence and continuous reduction in sale profit margins, have been radically changing companies' competitive environment. Slow-moving markets have progressively transformed themselves into dynamic contexts where new players emerged. In particular, low cost countries production made cost competition an unsuitable strategy for manufacturing companies located in the developed economies. Consequently, many companies move over their traditional business strategies integrating existing products with additional services along with their entire lifecycle (Neely 2008) (Kowalkowski, et al. 2015). This transformation toward the provision of services in addition to products is known as "Servitization" of manufacturing (Vandermerwe and Rada 1988). It has been demonstrated a possible key to boost the companies' competitiveness and generate value from multiple points of view (Brax and Visintin 2017). Greater differentiation from competitors and the possibility to 'lock-in' customers and 'lock-out' competitors (Neely 2008) are probably the most appealing. Moreover, extending the business around services might allow manufacturers to achieve stable economic returns, reduce costs, save time, increase contact with customers and enhance the company image.

From a customer perspective, the provision of services could be even more valuable than pure physical goods. First services imply high customizability of the offer and, second, they grant a tight relationship with the provider that would support the customer in managing and operating the product through the lifecycle. In some cases, the selling and sharing mechanism is such that the product ownership is still with the provider that is bothering all the risk of malfunctioning or failure. This thesis refers to servitization as the shift from selling products to selling an integrated combination of products and services that deliver value in use (T. Baines, et al. 2009). Hence it could be seen as the transition that companies undertake to change their value proposition from a traditional product to a mixture of product and services. Such interconnected mix is defined as Product-Service System (PSS): "A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models" (Mont 2002).

In parallel to the outstanding benefits coming from the servitization, the shift toward services and integrated PSS offering also poses several challenges (Wanrong and Sujit 2017). It requires an utter switch in terms of mindset, processes, relationships and organization that, if not adequately supported with the right know-how, can drive to limited payoffs and unsuitable revenues, namely "Service Paradox" (Gebauer, Fleisch and Friedli 2005).

Indeed, the major managerial challenge for product-service providers during their servitization is to transform their business models (Barquet, et al. 2013) in terms of organizational principles, structures, and processes (Gebauer and Fleish 2007), their capabilities (Ceci and Masini 2011), the relationships with customers (Galbraith 2002) and the supplier network (Evans, Partidário and Lambert 2007). This new paradigm entails a cultural shift that should be thoroughly understood by product-service providers. Among the organizational issues and the business models changes entailed by the servitization, one noteworthy difficulty is related to the design and engineering activities that a company have to undertake to change its value proposition from products to PSS. Indeed companies that traditionally dealt with products have to appropriately integrate service design activities into the traditional product design procedures as a mean to develop marketable PSSs. Designing and developing PSS is a complex task, especially due to the unpredictability of the solution lifecycle and to the number of interactions existing between the involved actors and the constituent components (Pezzotta, et al., 2012).

Therefore, to succeed in the servitization, companies have to adapt the methods that they were used to adopt for the simple product engineering, with methods that could take are capable of managing services that involve people's emotional needs and expectations (Berry, Carbone and Haeckel 2002) (Cavalieri, Pezzotta and Shimomura 2012). To support this, Service Engineering (SE) has emerged as a discipline explicitly addressing the design and the development of service offerings. In fact, SE is defined as a "technical discipline concerned with the systematic development and design of service using suitable models, methods, and tools" (Bullinger, et al., 2003). Hence, SE could help for the definitions of methods for the design and engineering of the service component of the PSS. SE methods should be used in conjunction with product engineering methods in order to support PSS engineering.

So far, the existing models in SE (Alonso-Rasgado, Thompson and Elfström 2004) (T. Baines, H. Lightfoot, et al. 2007) (Kett, et al. 2008) (Rapaccini, et al. 2013) (Aurich, Fuchs and Wagenknecht 2006) (Shimomura and Tomiyama 2005) focused specifically on the service engineering area mainly deal with either on designing solutions able to technically satisfy customer needs or on analysing external environment and market conditions (Maussang, Zwolinski and Brissaud 2009). Moreover, since they belong to the SE discipline, they specifically focus on service engineering and development. For what concern the integration of SE method with product design methods for the engineering of PSS, commonly accepted methodologies and tools for the integrated PSS design are still under development, and they all focus on the complacency with customer needs and are poorly applicable in the industrial context dominated by product-oriented mind-set and requiring easy to use tools.

The urgency of the integrated PSS design tools is also relevant in order to support companies in developing proper PSSs that could actually bring the well-known benefits of sustainability and resources efficiency. It is therefore relevant to properly engineer and assess the PSS solutions to make them in line with the company goals and objectives and to make sure that it is actually bringing the expected benefits.

According to this, the present thesis aims at contributing to the extant literature in the area of PSS proposing methods to support the engineering phase. In the next section, a more comprehensive description of PSS is presented together with the main features and the analysis of literature in the area of PSS design.

1.1 Readers guide

To guide the reader through a proper understanding of the research, this thesis is structured into three parts as shown in figure 1 with respect to the overall research structure.

Part I includes the introduction to the thesis context and topic, describing the state of the art in PSS engineering and the analysis of industrial requirements. It includes the following chapters.

Chapter 2 describes the literature analysis developed in the area of PSS and shows the main gaps to which this thesis aims at contributing.

Chapter 3 provides an overview of the industrial advancements in relation to PSS summarizing the main needs that companies have with respect to the PSS engineering and development.

Chapter 4 summarizes the aim of this thesis with respect to the literature gaps and to the industrial requirements and proposes the two main research questions that are going to be discussed in the remaining. Moreover, it includes the general structure of the research performed during the three years and the research methodologies adopted throughout the work.

Part II of the thesis includes the main advancements with respect to the first RQ. It includes chapter 5 and 6.

Chapter 5 proposes one of the main findings of this thesis: the Engineering Value Assessment (EVA) method that is aimed at supporting companies during the evaluation of PSS concepts during the early engineering phase.

Chapter 6 describes the validation cases of the EVA method in four different cases.

Part III of thesis includes the output of the research regarding RQ2. It includes four different chapters.

Chapter 7, 8, 9 present the second major contribution of this work: the FASt method that is meant to support companies in the assessment of the service component middle of life, namely the service delivery process, exploiting a modular modelling approach coupled with hybrid simulation.

Chapter 10 includes a validation case to show the functioning of the FASt method.

Finally, ***Chapter 11*** concludes the thesis *by* summarizing future research directions that are considered relevant for the extension and improvement of the findings presented in this thesis.

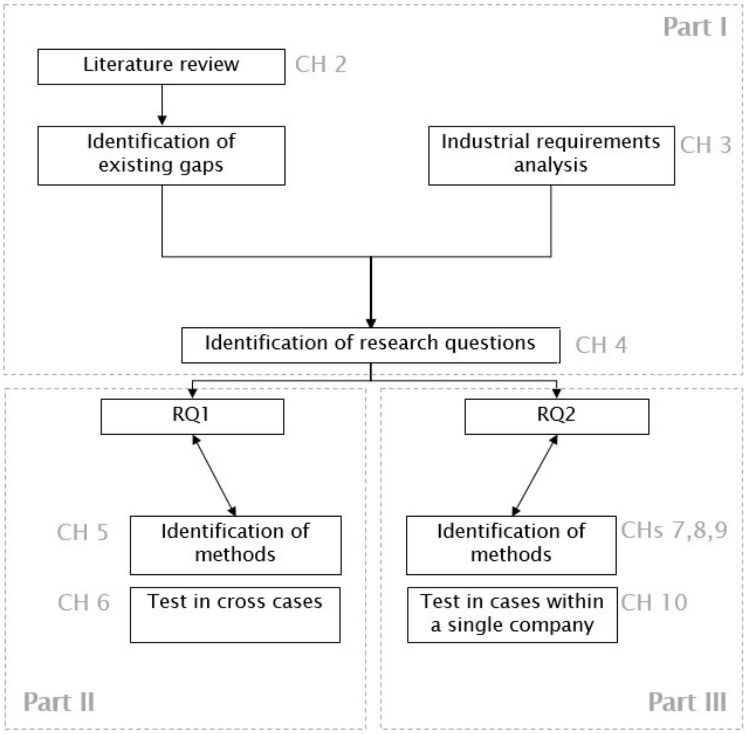


Figure 1 Summary of thesis parts and chapters considering with respect to the research structure

1.2 Abbreviations

PSS - Product Service System

SE - Service Engineering

KPI - Key Performance Indicator

BOL - Beginning of Life

MOL - Middle of Life

EOL - End of Life

EVA - Engineering Value Assessment

FASt - Final Assessment of Service

DES - Discrete Event Simulation

SD - System Dynamic

ABM - Agent-based modelling

SEEM - SErvice Engineering Methodology

Part I

The first part of this thesis aims at describing the domain and the context in which this thesis was developed. It first proposes an overview of the state of the art and of the industrial requirements. According to these and considering the gaps, the objective of the thesis is also described in this initial part.

In detail, chapter 2 summarizes the available literature on the topic of PSS with a specific focus on engineering methods. It ends with the identification of eight gaps concerning the available methods for PSSs engineering. Among them, a strong focus on the customer and the lack of approaches that deal with PSS in an integrated manner could be highlighted. Chapter 3 describes the PSS state of the art from the industrial perspective. The industrial advancements were collected from a special issue in the International Journal of Production Research and through a three-year participant observation held in the company founding this PhD research. In general, companies are still moving toward the development of PSS but, according to what emerged from the analysis they lack structured methods to do it mainly because the available are complicated to understand and to use. In the light of literature gaps and industrial requirements and needs, chapter 4 describes the thesis objective that is further cascaded down into two research questions. The primary objective of this thesis is to develop methods, applicable in industry, for the assessment of industrial Product-Service System. The methods shall assist decision makers in considering the trade-off between the customer satisfaction and the provider profitability during multiple engineering phases of PSS. The overall research structure and the specific methods adopted in this work are also summarized in chapter 4.

2 Product Service System in literature

The concept of Product-Service System has been developed in the last decades and research concerning the topic is still under development. Many researchers are studying the topic from multiple scientific perspectives and for this reason, literature and researches around PSS are wide. This chapter aims at summarizing the state of the art in the topic. First, it provides a general overview in the area of PSS (section 2.1) then it includes a specific focus in the literature concerning PSS engineering (section 2.2). Based on this, the final section of the chapter summarizes the current gaps concerning PSS engineering methods (section 2.3).

2.1 Product-Service Systems

As hinted in the introduction, this thesis focuses on Product-Service Systems (PSS): "a specific type of value proposition that a business (network) offers to (or co-produces with) its clients" (A. Tukker 2015)

2.1.1 Definition and terminology

The concept idea of PSS arose in Europe, in the late 1990s, and the first definition was given by (Goedkoop, et al. 1999), that defined it as "Product(s) and service(s) combined in a system to deliver required user functionality in a way that reduces the impact on the environment''. This definition highlights the opportunity associated to PSS to reduce the material consumption, while increasing the productivity and, hence, reduce the environmental impact of a product during its life cycle.
After the first definition, the PSS meaning has steadily grown in the research communities in the following years. PSSs have consequently been considered as a specific type of value proposition that enables companies to fulfil customers' needs or a possible innovation strategy. Some other authors referred to the same concept with a different term: "functional Products" (Alonso-Rasgado, Thompson and Elfström 2004). In Table 1, a general summary of the PSS definitions is reported. Most of those listed in table 1, describe PSS as a system to offer value to the customer toward product and service bundling (hard element and soft elements).

The definition proposed by (Mont 2002) is used as a reference in this work. It constitutes the reference to identify the four main components of PSS: product, service infrastructure and network.

Throughout the definitions and the associated literature, it is also possible to identify the main benefits and drawbacks associated with PSS.

Among the main advantages of PSS, it is recognised to introduce changes in production and consumption patterns that could lead to many advantages from both the provider and the customers' side. From what concern the companies' side, the improvements of the relationships and the extension of product lifecycle because of increased servicing and service components are the most mentioned (Mont 2002). The advantage on the customer side is related to a higher level of productivity because of the better utilization of the machine performance and the longer operation possibility. Therefore customers can concentrate on their core competencies and outsource secondary tasks (Meier, Roy and Seliger 2010). Generally, the possibility of service personalization and the reduction of consumption through alternative product use are also considered as possible PSS benefits, together with a higher loyalty and customer trust (Beuren, Ferreira and Miguel 2013).

Regarding the drawbacks, it is worth mentioning the difficulties that a company has while introducing the new value proposition based on PSS since new responsibilities and higher financial risks have to be faced. In parallel, the resistance to change is a relevant barrier to be overcome (Kuo 2011).

Indeed, to develop and deliver PSS the complexity of processes by customer integration and interdisciplinary issues must be taken into account (Meier, Roy and Seliger 2010). Furthermore, as stated by (A. Tukker 2015) not all the PSS turn out to be sustainable as promised, so it is crucial to accurately engineer and assess the PSS since the early stages of the engineering. It is of utmost importance to carefully plan for the implementation of the PSS before putting the PSS into practice (Kimita, Shimomura and Arai 2009).

Table 1 PSS Definitions

Author(s)	**PSS Definitions**
(Goedkoop, et al., 1999)	"A product service-system is a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have lower environmental impact than traditional business models".
(Mont 2002)	"A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models".
(Manzini and Vezzoli 2003)	"An innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands".
(Brandstotter, et al., 2003)	"A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally PSS tries to reach the goals of sustainable development".
(Alonso-Rasgado, Thompson and Elfström 2004)	"Functional Products, also known as 'total care products', are products that comprise combinations of 'hard' and 'soft' elements. Typically, they are described as comprising hardware combined with a service support system".
(Wong, 2004)	"Product Service-Systems (PSS) may be defined as a solution offered for sale that involves both a product and a service element, to deliver the required functionality".
(T. Baines, H. Lightfoot, et al. 2007)	"A PSS is an integrated product and service offering that delivers value in use. A PSS offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity".
(Tan, et al., 2009)	"A shift in business strategy from a product-oriented to a service oriented focus, where instead of the product itself, the activity, its utility and performance associated with the use of the product are considered to be of more value to the customer".

2.1.2 Product-Service features

As hinted in the previous paragraphs the evolution to a "system" perspective is quite critical for companies. There are many reasons behind it. First, the service component of PSS is new and complex to manage. The main features of service, intangibility, perishability, simultaneity and uncertainty (Jaw, Lo and Lin 2010), (Aurich, et al., 2010), make it difficult to engineer and to assess with the well-known and established methods traditionally used for product engineering. Indeed, "Intangibility means that services are not physical and cannot be "possessed", "perishability" means that it is not possible to store services for future use while "Simultaneity" implies that the production of the services cannot be separated from its consumption. Furthermore, services are characterized by intense uncertainty because they are delivered by people, and human behaviour is difficult to control. Customer-provider interaction (Visintin, et al., 2014) contributes to increasing the "system" complexity. PSS indeed "are mixed product-service offerings with features of heterogeneity, interaction, stakeholder participation and customization, which makes the PSS requirement difficult to be captured, analysed, concretized and forecasted" (W. Song 2017).

A general analysis of literature shed light on the central critical features characterizing PSS that could influence the system complexity.

1. *Resources and customers involved in PSS are prevalently people.* As such, their behaviour is hardly predictable. They have different preferences, attitudes towards collaboration (Duckwitz, Tackenberg and Schlick 2011) and the outcomes of their interaction generate high system variability and complexity, at least higher with respect to systems with automated resources (Phumbua and Tjahjono 2010). This makes the uncertainty in PSS the very critical to predict and to manage.
2. *Customers have different preferences, behaviours and attitudes* (Lee, Han and Park 2015). Customers being served, often represent people that may have a somewhat complicated behaviour and preferences that are difficult to predict. They can be considered as heterogeneous stakeholders that usually do not behave in a standard way. This also influences the uncertainty of the demand of PSS.
3. *Customer and company interaction.* As described before, services are perishable and inseparable, and due to this, during the value creation process, the customer and the company interact to generate the offer and the value for themselves (Phumba and Tiahiono 2012). The PSS provision is not the mere delivery of a traditional product: it implies the relentless participation of the customer in the provider's processes and their continuous interaction. Given such interaction and the different types of customers involved, PSS solution results in a

plethora of possible outcomes depending on factors such as customer needs, company's resources, and features of the external business environment.

4. *Provider resources operate at customer's premises.* As the value creation takes place through the interaction of customer and providers, the PSS delivery is usually performed at customers' premises when the customer is present. Therefore, having an available resource when and where it is needed is quite complex to predict before the actual event hapenns (Lagemann, Boblau and Meier 2015). The distance of customer premises from the provider is also a factor of complexity.
5. Service components. Differently from product manufacturing and engineering, often in the PSS engineering phase the set of components are not clearly identified. Service environment rarely has specific drawings, specifications and production organization.
6. Waiting time. In a PSS scenario, waiting time tends to have much higher importance than throughput: a service cannot be stocked. Therefore, the process and waiting times have great relevance in a service environment: people hate to wait to be served.
7. *Resources' skills and qualifications are diverse*. Due to this, the engineering of the PSS delivery and development is even harder. (Lagemann, Boblau and Meier 2015), and this contributes to increase the difficulty in designing and managing the service process.

2.1.3 PSS Classification

The definition of PSS highlights the main features and components of PSS. The interaction of such components contributes to the complexity of the system. However, there exist different types of combination of products and services. The type of such interaction could enable different classifications of such offer. The most commonly used PSS are two. (Baines and Lightfoot 2013) distinguish PSSs in three types of propositions differing on the base of who is responsible for deciding when and why services should be provided. *Base services* are offered to customers "who want to do it themselves"; I*ntermediate product-services* include solutions for customers "who want us (the provider) to do it with them", and finally A*dvanced product-services* bundle together products and services in a sophisticated offering for customers "who want the manufacturer take care of everything".

On the other hand, (A. Tukker 2004)suggests three main types of PSS, differing in terms of: (i) ownership structure, (ii) mode of producer/user interaction, and (iii) reason that customers pay value content. The three types are *product-*, *use-* and *result-oriented* services (Figure 2). Under the first category falls the traditional selling of a product accompanied by a maintenance or repair service. In use-oriented PSS, the customer pays only for the use of the product and without having ownership, while in result-oriented category customer pays only for the provision of agreed results, and he may or may not have the ownership. This thesis refers to this last classification as the reference PSS classification.

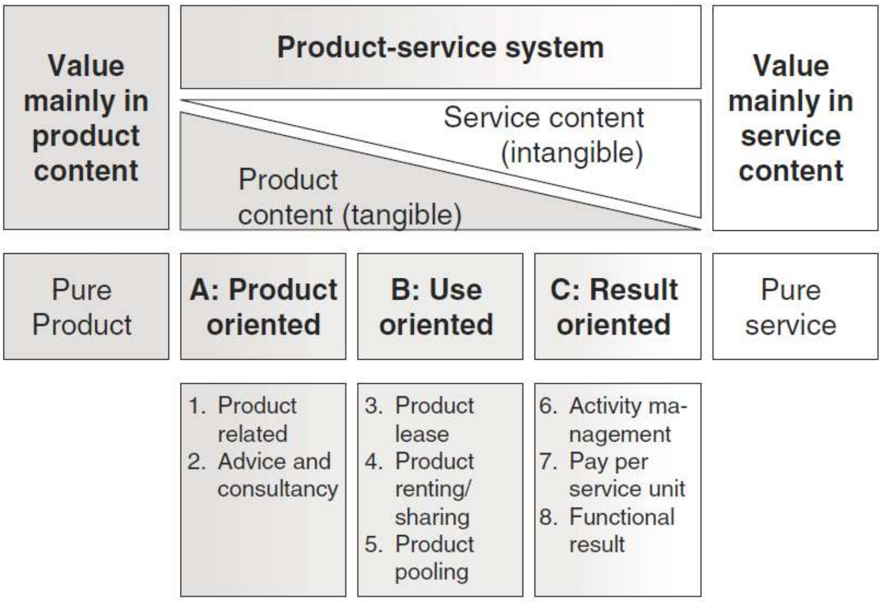


Figure 2 PSS classification proposed by (A. Tukker 2004)

2.1.4 Product-Service Systems Lifecycle

Even if the PSS lifecycle can be intuitively associated with product lifecycle, few models describing the PSS lifecycle are available in the literature. Generally, all the models include the three main areas of the PSS : Beginning Of Life (BOL), Middle Of Life (MOL) and End Of Life (EOL) and also a detailed description of the main PSS engineering phases to be adopted in the BOL. (Rese, et al., 2012) mention six main phases: planning, development, implementation, delivery and use, and closure. (Wiesner, et al. 2015) try to identify the PSS lifecycle as the interaction of service lifecycle and product lifecycle and identify 7 phases that also include the PSS engineering: Ideation, requirements, design, realization, delivery, support and evolution. Figure 3 shows the lifecycle model.

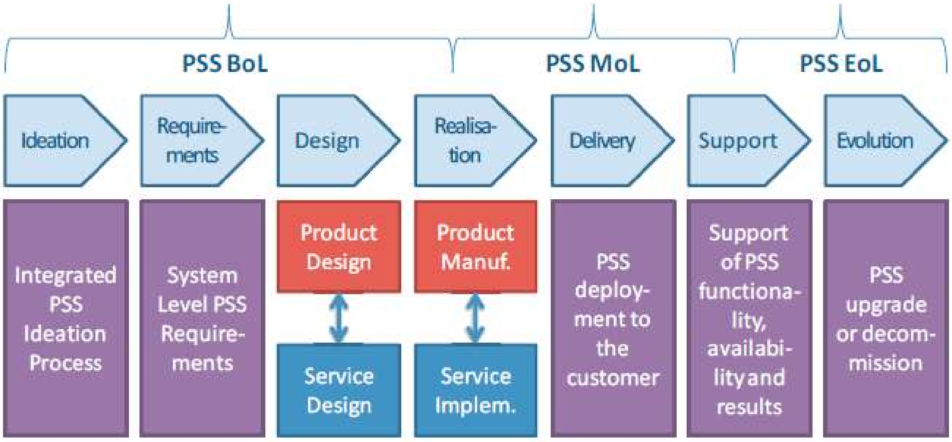


Figure 3 PSS Lifecycle proposed by (Wiesner et al., 2015)

(Hepperle, et al. 2010) state that a separate perspective of product and service lifecycle is not sufficient in order to plan PSS in an integrated way. They proposed a reference integrated lifecycle model of product-service systems emphasizing the strong interaction between the adaptation/improvement of service and the modernization lifecycle of the product. It is based on three main phases: PSS planning, PSS development, PSS production, delivery and decomposition. An overview of the approach is provided in figure 4.

(Beuren, Ferreira and Miguel 2013) stress the importance of considering the life cycles of all the products, the services, the actor's network and the infrastructure. According to them, the PSS lifecycle is composed of five different stages: consumer requirements, development of PSS, implantation of PSS, use of PSS, destination after use (Figure 5).

Additional considerations are proposed by (Marilungo, et al. 2016) who claim that a substantial interconnection between product and service elements during the PSS design process means that they cannot be handled as independent entities by applying product lifecycle management and service lifecycle management separately. Thus, a holistic approach is necessary to achieve the concurrent evaluation of PSS.

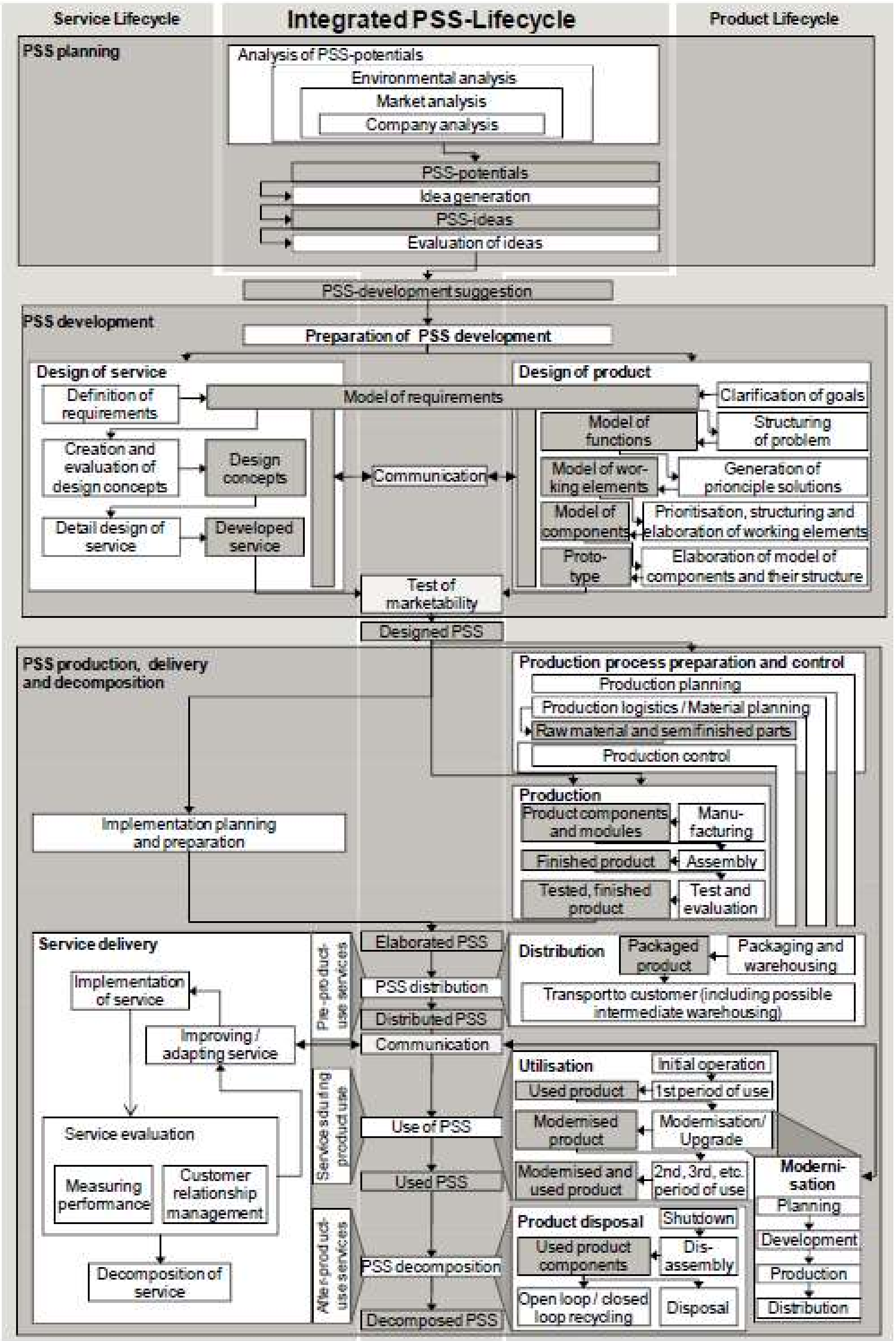


Figure 4 PSS Lifecycle proposed by Hepperle et al., 2010

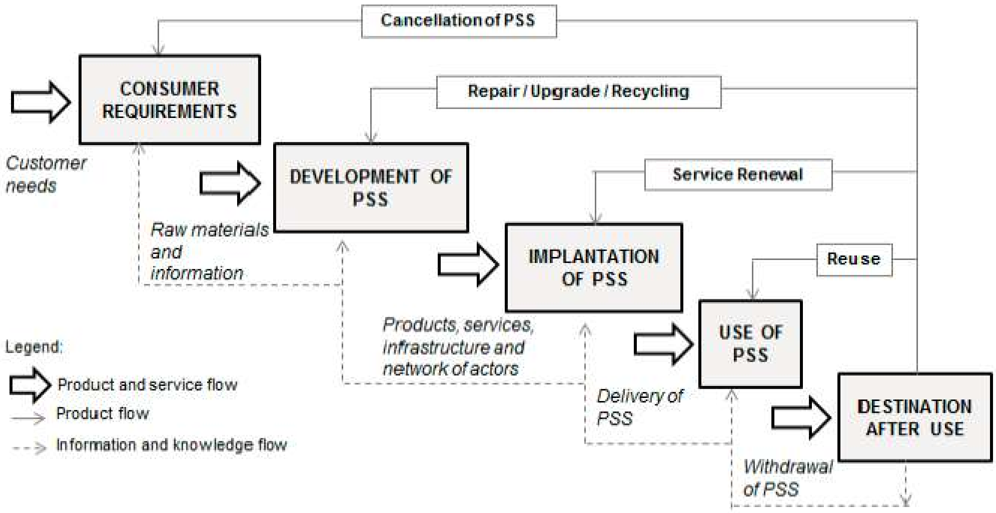


Figure 5 PSS lifecycle proposed by (Beuren, Ferreira e Miguel 2013)

A more detailed lifecycle model also highlighting the main phases of the engineering and the development of PSS is also proposed by (Cavalieri and Pezzotta 2012) (Figure 6).

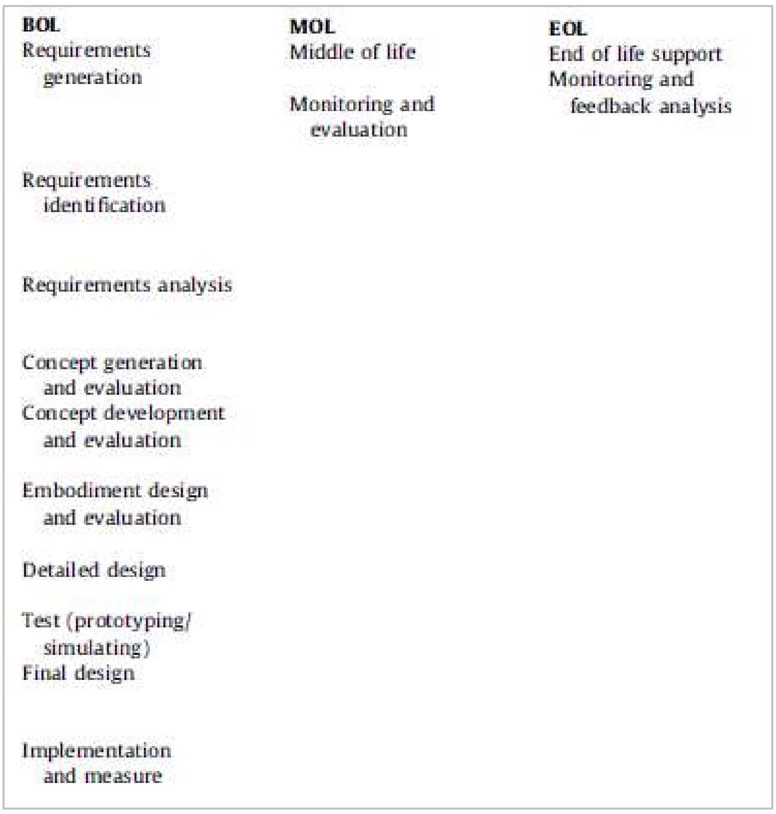


Figure 6 Phases of PSS lifecycle proposed by (Cavalieri and Pezzotta 2012)

Even though there are few different lifecycle classifications, it could be possible to observe that the phases proposed for the PSS development are almost similar among each other, and they vary according to the level of detail adopted. Throughout this work, the model proposed by (Wiesner, et al. 2015) is used as a general reference. For what concerns the specific phases of the PSS engineering those proposed by (Cavalieri and Pezzotta 2012) are followed.

They can be described as follow:

- *Requirements generation*. This phase refers to the very beginning of the PSS engineering process. It focuses on real value proposition and on the strategic decision to start the development of a new solution.
- *Requirements identification.* This phase refers to the collection of the requirements according to customer requests and demand.
- *Requirements analysis.* Once the requirements are collected this phase focuses on the analysis of the collected requests identifying commonalities.
- *Concept generation and evaluation.* Based on the collected requirements PSS concepts are generated and evaluated in order to identify the most suitable for the implementation.
- *Concept development and evaluation.* Once selected the concept it is then further developed and engineered in detail. All the features of the concepts are again evaluated to select the concept configuration that better allows the satisfaction of the requirements.
- *Embodiment design and evaluation.* This phase refers to the integration of the identified solution into the overall company offer and systems.
- *Detailed design.* In this phase, a specific design of the identified concept with the related features is carried out.
- *Test.* The design is then tested, and its functionalities are proved.
- *Final design.* After the test, a final design is defined.
- *Implementation and measure.* This phase refers to the concept implementation and the measurements of its functions.
- *Middle of life.*
- *Monitoring and evaluation.* During the middle of life, the concepts are monitored and measured in order to understand if they are working correctly or not.
- *End of life support.* At the end of life, support in dismantling the solution is provided.
- *Monitoring and feedback analysis.* According to the PSS lifecycle and the PSS behaviour during it, possible feedback is collected to benefits the engineering phase.

2.2 Product-Service Systems Engineering

Besides the works dealing with PSS definition, classification and lifecycle, a significant effort is registered in the area of PSS engineering. As emerged before, one of the main difficulties of manufacturing companies embarking servitization is the design and engineering of the new PSS offer that is including "soft" components (services) in addition to the traditional products. Consequently, many studies are expanding in this direction exploring methods, models and tools to support industry in this shift.

Even though the PSS is a quite familiar concept and many similar definitions are available, the research on the topic is still ongoing and under development. It could be observed that the research community does not yet agree on one shared engineering approach for PSS. Different facets and perspectives are conveying into the domain and research tackles multiple areas such as economics, operations management, sustainability, design and so on. Moreover, in each sub-area researchers focus their effort on a variety of goals linked to different phases of the PSS engineering.

As a result, "Several are the methods and tools proposed in the literature to aid manufacturers to design those solutions in an integrated and systematized way but none of them is really able to consider together product and service components, according to both company and customer views" (Sassanelli, et al. 2017).

The latest literature review (Xin, Ojanen and Huiskonen 2017) (Qu, et al. 2016) (Cavalieri and Pezzotta 2012), also highlight some general gaps. Among them, it could be possible to mention:

- the need for large scale quantitative studies that at the moment are still scarce (Xin, Ojanen and Huiskonen 2017).
- the need of research for visualization and modularity approaches during the design phase of a PSS (Qu, et al. 2016),
- the need to overcome customer centricity analysing both the customer and the provider perspectives (Xin, Ojanen and Huiskonen 2017)
- the need to consider multiple lifecycle phases of the solution (Xin, Ojanen and Huiskonen 2017).

These gaps can be considered as the starting points for the positioning of this thesis. The next paragraphs report a structured literature analysis that summarizes the findings achieved in the PSS engineering domain. In particular, engineering methods proposed in the papers were screened and reviewed and current gaps among the methods were identified. In turn, the gaps lead to the definition of research questions (chapter 4) that are specifically focusing on the methods for PSS engineering.

2.2.1 Literature analysis methodology

The analysis of literature was carried out in the form a structured literature review ensuring the minimization of biases thanks to an exhaustive search of works published in the literature (Annarelli, Battistella and Nonino 2016).

In order to gather information about existing contributions in the area, publications were searched from Scopus and ISI Web of Knowledge Databases, the two most significant multidisciplinary search engines that cover research from many relevant publishers, including Elsevier, Emerald, Springer, Wiley and so on. A keyword search leads to the identification of 943 articles related to PSS Engineering and Design. The analysis focuses on the available research from 1997 to 2017 and on the contributions written in English. The last update of the research dates to July 2017. Given the possible contribution that the SE literature could bring to the PSS engineering area, the literature in SE field was also considered relevant in this research.

The search results in the two databases are reported in table 2. As it is possible to observe after the first document search, three main filters were applied:

- First Conference Paper; Review; Article; Article in Press and Editorial were considered in order to have a comprehensive set of papers. Conference contributions were kept in the dataset to collect the latest updates.
- In order to narrow the broad set of papers, a second filter was applied on the “subject area”. Only papers belonging to engineering domain were kept. The subject areas considered are: Engineering; Computer Science; Business, Management and Accounting; Mathematics; Decision Sciences; Environmental Science; Energy; Social Sciences; Economics, Econometrics and Finance; Multidisciplinary.
- A final manual filtering based on title and abstract was applied. Contributions not directly referring to PSS engineering were deleted from the sample. The total number of papers reached was 941.

In the next section, a general overview of the work in the area of PSS Engineering is summarized in Section 2.2.2. It is based on a high-level analysis of the 941 articles retrieved from the databases.

Table 2 summary of literature analysis on PSS methods

Search string	Scopus	ISI Web of knowledge	Total
“Product service system” OR "Functional Product" OR "Extended Product" AND “engineering” OR "Design"	1580	345	
Selection of "Conference Paper; Review; Article; Article in Press; Editorial".	1468	325	
Selection of Engineering subject area	1218	268	
Title and abstract filtering	914	173	
Final set of papers			1087
Total number of papers after duplicate removal	941		

2.2.2 General overview of the literature sample

The final set of papers dealing with PSS and Engineering is quite wide and heterogeneous. Figure 7 shows the distribution of the research throughout the last 20 years.

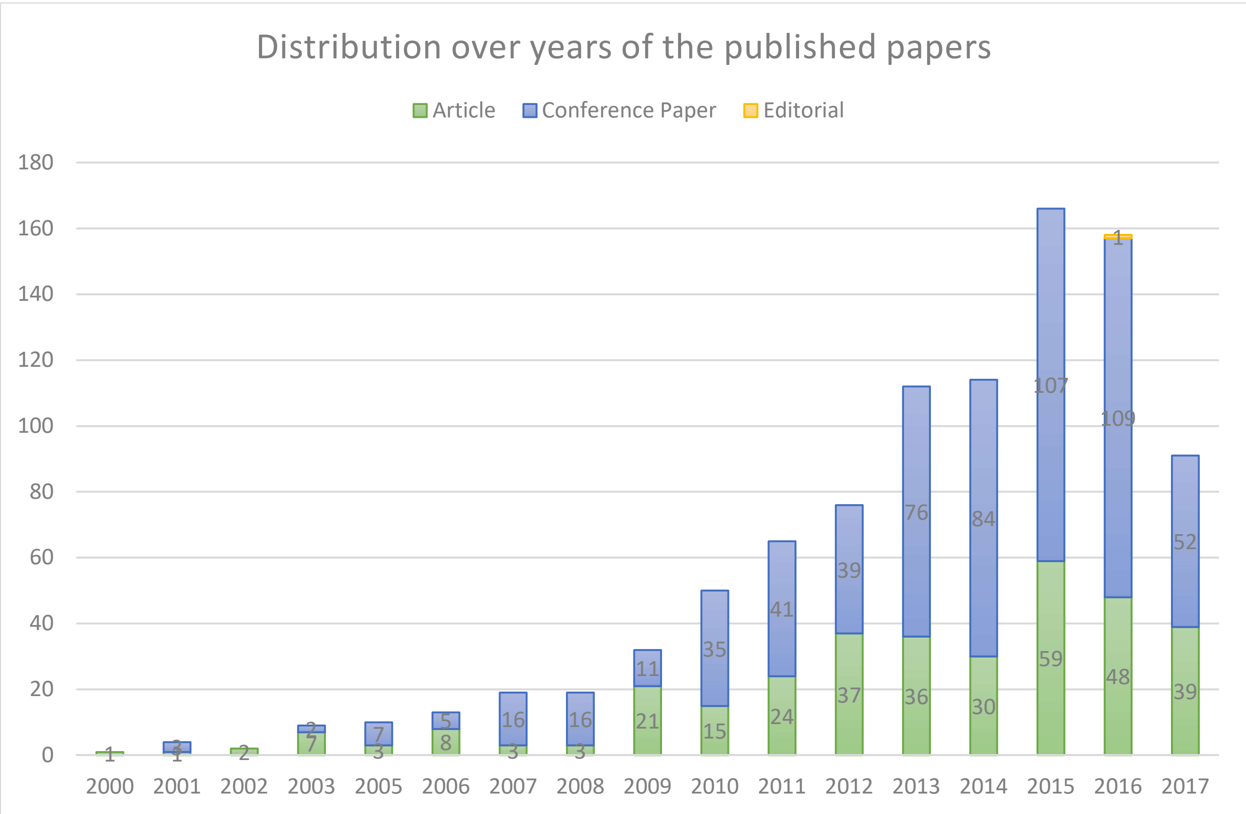


Figure 7 Distribution of the papers published on PSS throughout the years

As it is possible to observe, the first papers in the topic were written in 2000-2001 whereas the real diffusion of the research can be observed in 2009 with 32 articles. 2015 and 2016 are the years during which the highest number of contributions were published. 2017 cannot be compared since it is still ongoing. The majority of papers belongs to conference proceedings even if it could be noticed that in

2015-2016 the about 50 papers have been published in journals. This proves the relevancy of the PSS engineering topic into the research community.

The most common journal where research has been published are reported in table 3 whereas conferences are summarized in table 4.

Both the bunches of journals and conferences are not really large. Among the journals, the "Journal of Cleaner Production" emerges for the high number of publications. The journal focuses on Cleaner Production, Environmental, and Sustainability research and practice stressing the sustainable connotation of the PSS concept. All the others journals are instead very different in scope and relevance, therefore, describing the heterogeneous nature of the research around PSS engineering. It is possible to observe journals that are focused on technology, some others dealing with product engineering and some others with manufacturing. For what concerns the conferences, a considerable percentage of articles are published by PROCEDIA CIRP. It probably collects the papers from the Industrial Product Service System (IPSS) conference explicitly dealing with PSS. Similarly to journals, the other conferences are dealing with technologies, product engineering and computer sciences. They are some of the area mainly interested in the PSS phenomenon.

Table 3 List of journals with at least 5 published papers on PSS Engineering

Journal Name	Number of papers
Journal of Cleaner Production	67
International Journal of Production Research	18
Journal of Manufacturing Technology Management	18
CIRP Journal of Manufacturing Science and Technology	16
Computers in Industry	13
CIRP Annals - Manufacturing Technology	10
International Journal of Advanced Manufacturing Technology	10
International Journal of Product Development	10
International Journal of Computer Integrated Manufacturing	9
International Journal of Operations and Production Management	8
Computers and Industrial Engineering	6
International Journal of Internet Manufacturing and Services	5
Journal of Intelligent Manufacturing	5
Sustainability (Switzerland)	5

Table 4 List of conferences with at least 10 published papers on PSS Engineering

Conference Name	Number of papers
Procedia CIRP	200
Proceedings of the International Conference on Engineering Design, ICED	39
IFIP Advances in Information and Communication Technology	32
Proceedings of the ASME Design Engineering Technical Conference	21
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	18
ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design	13
Proceedings of International Design Conference, DESIGN	10

Additional analyses are related to the citations of the papers. Among the analysed researches, some of them boast many citations suggesting high relevance. Table 5 reports the list of the articles cited at least 100 times. (Notice that in some cases the number of citations in Scopus and ISI web of knowledge was not the same, the Scopus data were kept.) Not surprisingly, (Mont 2002) (Meier, Roy and Seliger 2010) have the highest number of citations. Indeed, the papers deal with PSS definition and contextualization. The same motivation for the high number of citations also works (Tukker and Tischner 2006) (Maxwell and Van der Vorst 2003) (Roy 2000). Other papers among the most cited provide a literature analysis and this justifies the many citations received, i.e. (Beuren, Ferreira and Miguel 2013) (Cavalieri and Pezzotta 2012) (Vasantha, et al. 2012) (A. Tukker 2015). Finally, there is a small group of papers that propose design method or methodologies for PSS: (Aurich, Fuchs and Wagenknecht 2006), (Manzini and Vezzoli 2003) (N. Morelli 2006). Since they are the prior research in PSS design and engineering, they probably acted as a reference for the subsequent literature. This could explain the number of citations.

Table 5 List of papers with more than 100 citations

Reference	Number of citations
(Mont 2002)	736
(Meier, Roy and Seliger 2010)	382
(Aurich, Fuchs and Wagenknecht 2006)	321
(Tukker and Tischner 2006)	295
(Manzini and Vezzoli 2003)	249
(Maxwell and Van der Vorst 2003)	231
(Roy 2000)	154
(N. Morelli 2006)	189
(N. Morelli 2003)	135
(Beuren, Ferreira and Miguel 2013)	146
(Cavalieri and Pezzotta 2012)	122
(Spring e Araujo 2009)	121
(Maxwell, Sheate e Van der Vorst 2006).	110
(A. Tukker 2015)	108
(Boons, et al. 2013)	107
(Vasantha, et al. 2012)	107
(Pawar, Beltagui e Riedel 2009)	105

A general analysis of the leading authors contributing to this field was also performed (Figure 8). The author with the highest number of publication is Prof. Yoshiki Shimomura from the Tokyo Metropolitan University with 36 publications. Other authors such as Prof. Sakao and Prof. Pezzotta are also very active in the PSS research stream. It noticeable that, among the most active authors, only two of them also have a highly cited paper (table 5): Pezzotta Giuditta and Roy Rajkumar.

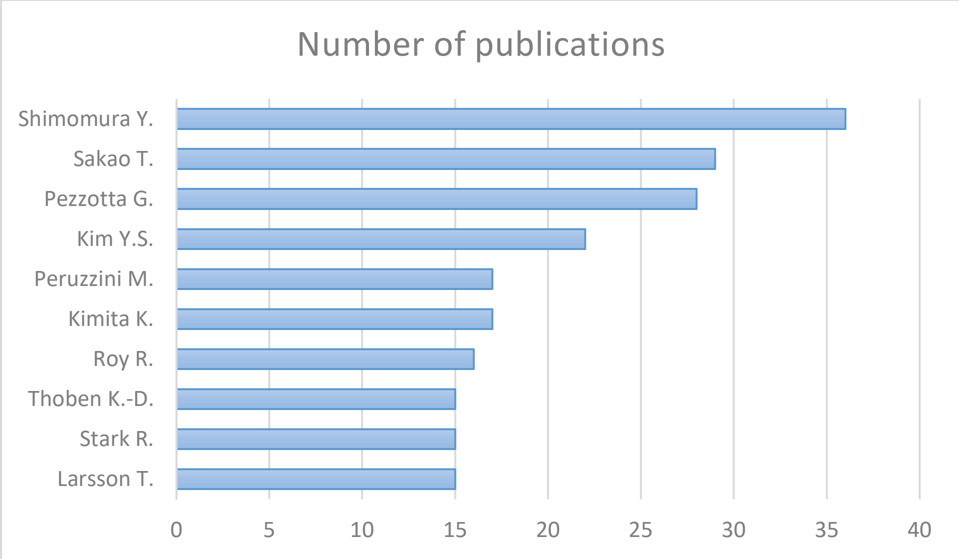


Figure 8 List of authors with more than 15 publications

Finally, the general overview of the 941 papers was completed with the analysis of the keywords. The final list of 4118 items includes 1630 different keywords that have been addressed as in the following table (table 6).

Table 6 Keyword recurrence in PSS literature

# times the keyword has been used	Number of keywords	Keywords
Used more than 50 times	6	Business Model; Industrial Product Service System (IPSS); Product Service System (PSS); Product Service System Design; Servitization; Sustainability
Used between 20 and 50 times	10	Case Study; Conceptual Design; Design; Design Method; Functional Product; Life Cycle; Quality Function Deployment (QFD); Service; Service Engineering; Simulation
Used between 10 and 20	20	Availability; Circular Economy; Decision Making; Design For Sustainability; Design For X (Dfx); Eco Design; Evaluation; Innovation; Integrated Product Service System; Knowledge Management; Literature Review; Maintenance; Manufacturing; Models; Product Development; Product Lifecycle Management (PLM); PSS Development; Remanufacturing; Services; Sustainable Product Service System
Used less than 10 times	1594	
Total number of keywords	**1630**	

The majority of the keywords (1594 words) are used less than 10 times. 1190 words are used only one time. This highlights the substantial heterogeneity and the broad scope of the research in the PSS area. Very few of the keywords are used frequently and, among them, a relevant group is providing the indication of the PSS research area without identifying a specific research objective. Figure 9 shows the recurrence of keywords without considering Product Service System (cited 701 times) that, of course, is the most adopted keyword.

The analysis reflects the state of the art in this discipline:

- Many researches are still working on the transition from product-oriented business model toward the PSS one. "Servitization" "business model" and "sustainability" are indeed widely used.
- Another track of research is focusing the attention on engineering the offer of the PSS value proposition. "Product-Service system design" "Service Engineering", "Design", "Design Method" and "conceptual design" refer all to this stream.
- Through the list, it is possible to highlight two keywords that directly refer to methods adopted in the area "Simulation" and "QFD". This suggests that these two methods are quite conventional in the area and that no other methods are widely adopted in this domain.
- The quite relevant adoption of "service" and "service engineering" also shed light on the strong focus on service engineering activities inside the extensive PSS research.

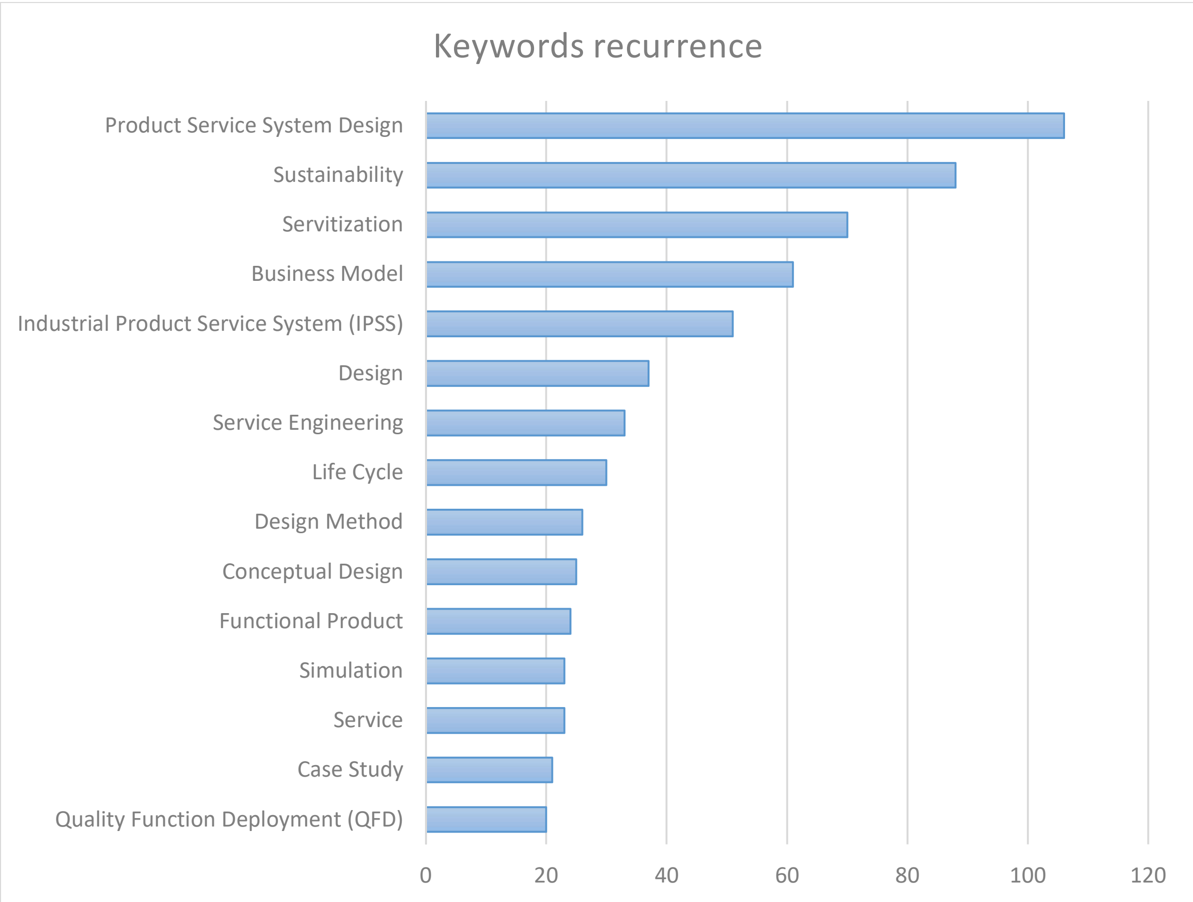


Figure 9 Most adopted keywords and respective recurrence rate

The general overview of the literature in PSS design demonstrates the heterogeneity and the variety of the state of the art. In particular, it shows that the research concerning engineering method is still scarce. As in figure 9, only 26 papers out of 941 propose "design method" as a keyword. In order to have a more comprehensive and detailed overview of the literature concerning engineering methods a specific analysis of the papers identified was developed. It is presented in the next section.

2.2.3 Analysis of PSS methods and methodologies

Since from the general overview of the 941 papers (Section 2.2.2) a scarcity of research related to design methods was highlighted, a detailed analysis of papers explicitly dealing with methods and approaches for PSS engineering was carried out. This analysis aimed at identifying all the proposed method or methodologies that have been studied during the years. To do so, first all the papers containing "method" or "methodology" among the keywords or in the title were selected, in total 118 articles. Then, an additional title analysis of all the 941 papers was performed and allowed the identification of papers suggesting specific methods for the PSS engineering: 24 additional papers were selected from the initial dataset leading to 142 papers. The papers were then read in detail collecting information about the method proposed and its features. During the reading, whenever the selected paper reported interesting references, they were also collected and analysed. Finally in order to verify that all the main contributions in the area were included in the analysis, up-to-date literature reviews on PSS Engineering and design have been screened ((Qu, et al. 2016) (Vasantha, et al. 2012) (Cavalieri and Pezzotta 2012) (Beuren, Ferreira and Miguel 2013)). Snowballing (Wohlin 2014) on the analysed papers and literature reviews allowed the identification of additional 13 papers. The final subset of papers related to PSS methods is composed of 155 contributions as described in table 7.

Table 7 Number of papers identified for the specific analysis of methods

Total number of papers after duplicate removal	**941**
Papers including "method" or "methodologies" into title of keywords	118
Filtering on abstracts selecting papers proposing PSS engineering methods	142
Snowballing	13
Total number of papers dealing with PSS methods	**155**

After a general overview of the literature in the area of PSS engineering, a specific analysis of methods and methodologies was performed. 155 selected papers were carefully read and analysed in detailed to have a proper understanding of the methods with which they were dealing. They were also classified according to the structure in figure 10 developed during the first review of the papers.

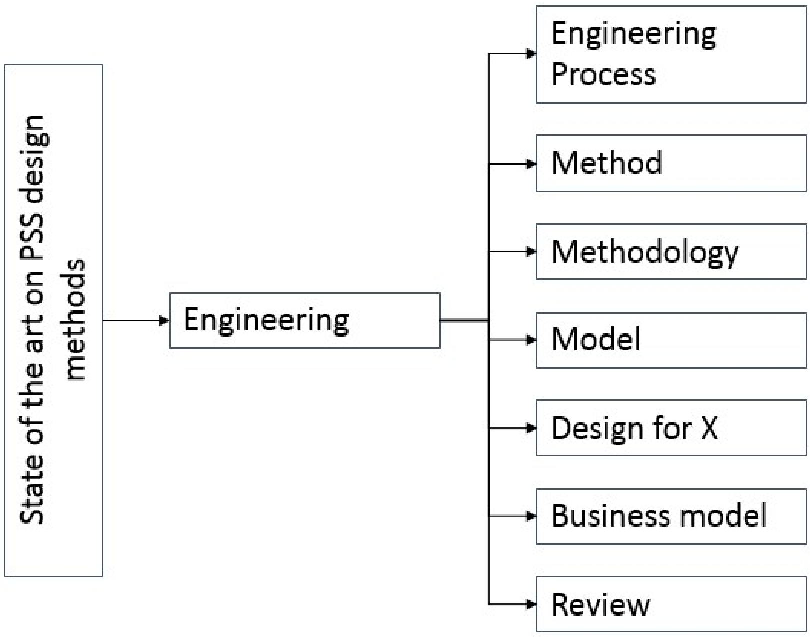


Figure 10 Classification framework for literature analysis

- *Engineering Process.* All the papers collected in this category refer to the overall engineering process. The methods proposed in this category are generally proposing specific approaches to enhance the performance of the engineering process, for example, supporting collaboration.
- *Method.* This category refers to all the papers proposing a particular procedure (or systematic approach) for the design of product service systems.
- *Methodology.* The papers including a system of methods used in the PSS engineering topics were collected in this category.
- *Model.* Into this category were grouped all the papers proposing approaches to represent or describe PSS.
- *Design for X.* In the analysed papers, some of them were referring to design approaches explicitly focusing on one aspect. Inside this category, for example, the papers dealing with "Design for sustainability", "Design for Service Supportability" were grouped.
- *Business model.* Some of the methods proposed by the papers analysed are dealing with the overall company structures that describe the rationale of how an organization creates, delivers, and captures value in relation to PSS. The process of business model construction is part of business strategy.

– *Review.* In this category, all the papers proposing literature reviews are included, either general or specific on methods.

Figure 11 shows the overall distribution of the papers under the categories.

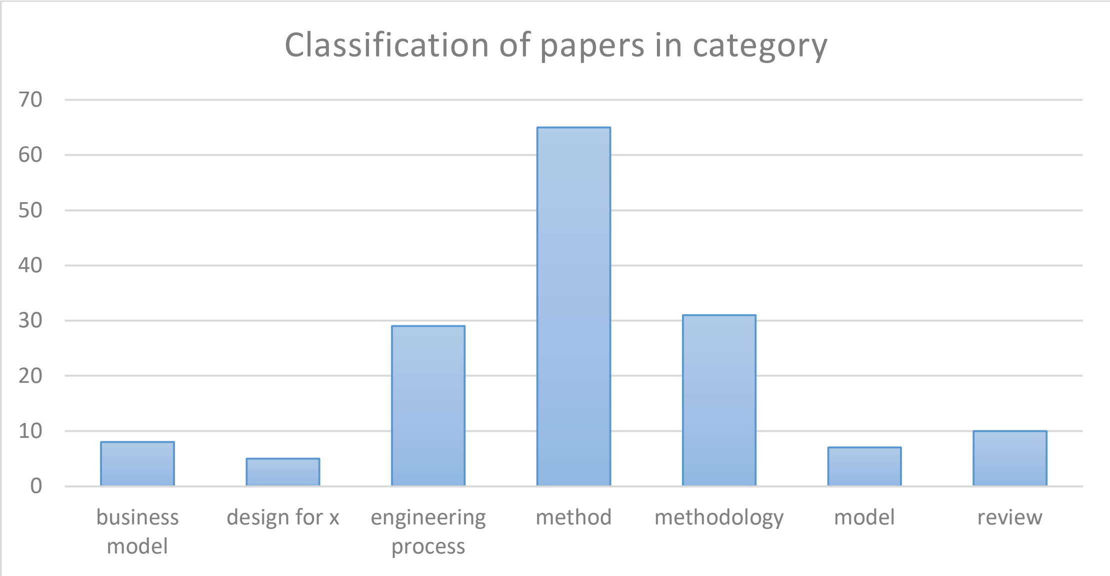


Figure 11 Distribution of the analysed papers according to the classification in figure 10

Given the criteria adopted for the selection of articles, the majority of the papers belong to the method group and only a minor part is from "business model" and "design for x", "model" and "review" categories. Review papers, (10) were used to verify the set of analysed papers. Concerning the "engineering process" category (29), it includes papers that are treating the organizational issues, the tools and the different steps to be followed in this phase. The two more significant groups are the papers proposing specific methods (65) or methodologies to cope with PSS engineering (31).

It is also worth mentioning that, among the identified papers, the majority of them are related to engineering phases of the PSS whereas very few of them (6) are dealing with challenges during the transition to PSS and proposing methods to deal with the servitization.

The detailed analysis focused on the papers dealing with methodologies and methods for PSS design. All the primary methods proposed in the papers were listed together with commonalities and differences. In addition, for each method, main weaknesses and strengths were also listed. The result of the analysis is reported in table 8 where the most relevant methods are mentioned with a brief description and the list of references adopting the method. The engineering phase in which the methods are used is also included. (Cavalieri and Pezzotta 2012) was used as a reference for the phases since it provides a quite detailed description of them. Whenever the method refers to a specific task inside a phase, the step was further split.

Table 8 Summary of methods in PSS engineering

Method	*Description*	*Phase based on (Cavalieri and Pezzotta 2012)*	*Reference*
Persona	Method mainly adopted in user-centred design. A persona is a fictional person created to represent a user type of a PSS. People belonging to the same persona would act in the same way.	Requirements identification and analysis	(Hara, Arai, et al. 2009) (T. Sakao, Y. Shimomura, et al. 2009) (Sakao and Shimomura 2007)
TRIZ	TRIZ a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature. The method is based on logic and data, not intuition.	Concept development Requirements identification and analysis PSS Idea generation	(Kim and Yoon 2012) (Shimomura e Hara 2010) (Song e Sakao 2016) (Song and Sakao 2017) (Chen e Jiao 2014)
Quality Function Deployment (QFD)	Quality Function Deployment (QFD) analysis is a structured method to define customer needs and translate them into product/service requirements.	Requirements analysis Concept Development	(Geng, et al. 2010) (Song and Sakao 2017)(Sousa-Zomer e Miguel 2017) (Kim and Yoon 2012) (Sakao, Birkhofer, et al. 2009) (Zhang e Chu 2010) (Shimomura and Sakao 2007) (Sheng, Lu e Wu 2015) (Lee e AbuAli 2011) (Kim, Son, et al. 2015) (Marilungo, Peruzzini e Germani 2015) (Peruzzini e Marilungo 2016) (Wang, Ming e Li, et al. 2011) (Sousa-Zomer e Miguel 2017) (Kim, Son, et al. 2015) (Kim and Yoon 2012) (Zhang e Chu 2010) (Lee e AbuAli 2011)
Kansei Engineering	Literally emotional engineering. This method aims at the development PSS by translating the customer's psychological feelings into requirements	Requirements identification and analysis Concept Development	(Carreira, et al. 2013) (Carreira, et al. 2013)
Actor's and System Maps	Method to map and visualize all the actors involved in the PSS provision process	Requirements identification and analysis PSS Design	(Lindahl, Sakao e Carlsson 2014) (N. Morelli 2006)
Analytic Network Process (ANP)	More general form of the AHP method	Requirements identification and analysis	(Geng, et al. 2010) (Lee, Geum and Park 2015) (Pan and Nguyen 2015)
Support Vector Machine (SVM)	SVM is a learning model with associated learning algorithms that analyse data used for classification and regression analysis	Requirements identification and analysis	(Long, et al. 2013)
Analytic Hierarchical Process (AHP)	Multi criteria decision making method for organizing complex decisions. It is based on pairwise comparison of different criteria	Requirements analysis Concept development	(Sheng, Lu e Wu 2015) (Song and Sakao 2017) (Sousa-Zomer e Miguel 2017) (Hara, Arai, et al. 2009) (Song, et al. 2013) (Geng e Liu 2015) (Kim, Son, et al. 2015) (Medini e Boucher 2016)
Artificial Neural Network (ANN)	An artificial neural network (ANN) is a computational method based on the structure and functions of biological neural networks. Information that flows through the network affects the structure of the ANN because a neural network changes - or learns - based on that input and output.	PSS design	(Geng and Chu 2012)
Functional Analysis	Method helping in defining what PSS features (functions) should be included in a solution or not. Based on cost or customer value.	PSS Design	(Alix and Vallespir 2009) (Maussang, Zwolinski and Brissaud 2009) (Trevisan and Brissaud 2016) (Andriankaja, et al. 2016)

Method	*Description*	*Phase*	*Reference*
Service Requirement Tree (SRT)	Method belonging to functional analysis	Requirements analysis	(Pezzotta, Pinto, et al. 2014)
Service Blueprinting	Method adopted to represent the service process. It gives a cross-functional perspective of the resources involved in the process.	PSS Design	(Song, Wu, et al. 2015) (Song and Sakao 2017) (Pezzotta, Pinto, et al. 2014) (Trevisan and Brissaud 2016) (N. Morelli 2006) (Shimomura, Hara and Arai 2009) (Hara, Arai, et al. 2009) (Geum e Park 2011)
Simulation	Method consisting in the representation of a business process into a dynamic process helping in predicting process outcome	Test	(Maisenbacher, et al. 2014)(Bianchi, et al. 2009)(Pezzotta, Pinto, et al. 2014) (Alix e Zacharewicz 2012); (Garetti, Rosa and Terzi 2012) (Wrasse, Hayka e Stark 2015) (Kimita, Tateyama and Shimomura 2012) (Chalal, et al., 2015) (Medini e Boucher 2016)
SADT	SADT is a systems engineering and software engineering methodology for describing systems as a hierarchy of functions	PSS Design	(Maussang, Zwolinski and Brissaud 2009) (Trevisan and Brissaud 2016)
PSS Board	A method for visualizing a product–service system. It visualizes the PSS process in a structured and standardized manner. PSS Board can be utilized in designing, evaluating, improving, and operating a PSS.	PSS Design	(Lim, et al. 2012)
Failure Mode and Effects Analysis (FMEA)	FMEA is a structured approach to discovering potential failures that may exist within the design of a product or process	Test	(Zhang e Chu 2010) (Igba, et al. 2015)
ServQual	SERVQUAL is a multi-dimensional research instrument, designed to capture consumer expectations and perceptions of a service along the five dimensions that are believed to represent service quality.	Monitoring	(Zhang e Chu 2010)
Color coded 3D Visualization	This is a structured approach for visualizing the value of product components in relation to customer requirements	PSS Design	(Bertoni, Bertoni e Isaksson 2013)
Prototyping	This method consists in the creation of samples or models of the PSS in order to test its functionality.	PSS Design	(Exner and Stark 2015) (Exner, et al. 2014) (Tran e Park 2015) (Liedtke, et al. 2015)
		Test	(Exner and Stark 2015) (Exner, et al. 2014) (Tran e Park 2015) (Liedtke, et al. 2015)
ProVa	A structured method to analyse the provider value for each PSS.	Concept Evaluation	(Matschewsky, Sakao and Lindhal 2015)
Kano model	Method that classify customer preferences in five different categories	Requirements identification and analysis	(Van Halen, Vezzoli and Wimmer 2005) (Geng and Chu 2012)
Design-by-Analogy (DbA)	Design-by-Analogy (DbA) is a method that support the identification of solutions and examples based on connected experiences (i.e., analogies).	Idea Generation	(Moreno Grandas, Blessing and Yang 2015)
Niche Theory	Method originally adopted in ecology that is currently used to study the competition analysis of markets.	Feasibility analysis	(Lee, Geum and Park 2015)

Method	***Description***	***Phase***	***Reference***
DEA Data Envelopment analysis	Data envelopment analysis (DEA) is a nonparametric method in operations research for the estimation of optimal frontiers.	Requirements identification and analysis	(Geng, et al. 2010)
SWOT analysis	It is a structured method to identify Strengths, Weaknesses, Opportunities and Threats that can affect a project	Feasibility analysis	(Alix and Vallespir 2009)
DEMATEL	Decision Making Trial and Evaluation Laboratory (DEMATEL) is a powerful method which can deal with large problems of group decision-making by assessing the direct and indirect relationships among all elements as well as studying the direction and intensity of the relationships among already defined components at the same time.	Requirements analysis Test	(Pan and Nguyen 2015) (Geng and Chu 2012) (Shimomura and Sakao 2007)
IPA- Importance-Performance Analysis	Method adopted for visualization of customer satisfaction in relation to a service	PSS Design	(Geng and Chu 2012)
Balance Scorecard	Method for the evaluation of business based on four dimensions: financial, customer, internal process, and learning and growth perspectives.	Test	(Pan and Nguyen 2015)
Rough Set theory	It is a new mathematical method to deal with uncertain information and probability	Requirements analysis	(Song, et al. 2013)
TOPSIS (Theory of Order Preferences by Similarity to Ideal Solution)	A method designed to designate a preferred alternative according to a finite number of criteria.	Concept Evaluation	(Song and Sakao 2017)

The table discloses a broad range of methods that are used interchangeably in the same phases of the PSS engineering. For example, many different approaches were found with respect to the "requirements analysis" and to the "PSS design" steps demonstrating that the research is far from turning into a common and shared direction. Furthermore, the methods proposed by the analysed papers are *exploited in different manners and with different scopes.* QFD, for example, is largely used for "requirements analysis" but some authors also find this method beneficial for "concept development". (Song and Sakao 2017) use the approach to convert the requirements into attributes, whereas (Kim and Yoon 2012) use the same method to generate PSS concepts.

Among the analysed papers, it is also common to find *a mixture of methods*. For example (Lee, Geum and Park 2015) adopts ANP and Niche Theory to evaluate PSS concepts based on customer acceptability whereas (Pan and Nguyen 2015) aim to study the customer satisfaction with the adoption of ANP but coupled with DEMATEL. (Kim and Yoon 2012) adopt QFD together with TRIZ while (Geng, et al. 2010) focus on QFD together with ANP and DEA for rating engineering characteristics. Common patterns between methods usage and mixture cannot be found.

For what concern the most adopted or conventional methods it is possible to mention *the functional analysis, the blueprinting and* the *QFD*.

"Functional analysis" is commonly used in the product design to define the features that should (or not) be included in the product. From a PSS perspective, the value analysis, very similar to functional analysis, can be used to define the list of functions of the product-service expected by the customer (Alix 2010) or to identify the relevant activities for the service design (Van Halen, Vezzoli and Wimmer 2005) (Pezzotta, Pinto, et al. 2014). In the analysed papers, value analysis is also mentioned as a useful tool to identify customer value that can be associated to the change of the Receiver State Parameter ((Hara, Arai and Shimomura 2009) (Hara, Arai, et al. 2009)) or to the life cycle costs stating that "both customer and supplier would gain from cost reductions derived from improved resource efficiency" (Maussang, Zwolinski and Brissaud 2007).

Differently from the previous, the "Service Blueprinting" can be defined as a mapping method. (Morelli 2002) mentioned it as a possible mean to describe services in hypothetical terms. Indeed, it allows the representation of the service provision process together with the people involved in it and the relationship with the customer (Shostack 1982). (Hara, Arai and Shimomura 2009) (Hara, Arai, et al. 2009) extended this concept employing a double blueprinting (activity and behaviour) to describe service activities and product behaviour while (Pezzotta, et al. 2014) used it just to depict the service activities.

Finally, in addition to what highlighted before, QFD has been adopted to assess the impact of services, physical products on the customer RSP (T. Sakao, Y. Shimomura, et al. 2009) or to define the importance of resources in creating customer value (Pezzotta, et al. 2014)

This specific analysis of methods emphasizes the wide breath of the current research. Many methods are currently being explored. They are also used in different phases of the engineering process, but it can be noticed a higher concentration of methods in the “requirements analysis” and “PSS design” phases. As a first result emerging from the table, it can be stated that specific normative methods for each phase of the engineering process are not yet available. Furthermore, it can be highlighted that some phases are rarely studied. The next paragraph includes a cross-comparison of the methods and the engineering process showing the phases in which a scarcity of methods can be found. Based on the table main gaps in literature on engineering methods are described.

2.3 Literature GAPS on PSS engineering methods

The comprehensive analysis of literature about PSS methods and methodologies shed light on the main gaps in the PSS engineering area. Hereafter the lacunas emerged from the review are presented in connection with the extant literature. In general, a lack of common and shared terminology among the overall set or researches could be highlighted. The papers analysed and the methods suggested use different terms and definitions and, seldom, the same concept has overlapping definitions or names. This could be observed for what concern the PSS definitions but also for the methods proposed. For example, PSS is often referred as a synonym of “functional product” (Lindström, et al. 2014) , “Total care product” (Alonso-Rasgado, Thompson and Elfström 2004); “Integrated product service” (Lindahl, Sakao e Carlsson 2014).

Hereafter is a detailed list of the common gaps concerning the methods proposed in the paper reviewed is reported. They can represent possible open research questions in PSS engineering domain.

i. The first central gap, as previously highlighted, is the *lack of a standard terminology and formalism* in association to PSS research. As emerged from section 2.1.4, different studies have a different view with respect to the PSS engineering phases. As a result, existing methods refer to different phases of the engineering of PSS, but they are actually focusing on the same. The different formalism and nomenclature adopted represent a barrier to further development of methods and for future studies. This is further justified by the need for research for visualization and modularity approaches during the design phase of a PSS as suggested by (Qu, et al. 2016) in their review.

ii. A wide gap that emerged from the literature analysed is the *lack of integration of the existing methods*. Although the methods summarized in the literature analysis refer to different phases of PSS engineering, the available methods are not integrated with each other. As a result, the overall PSS engineering would result in a heterogeneous mixture of methods and approaches not interconnected with each other. Very few of the proposed methods are included into a structured and holistic methodology such as MEPSS (Van Halen, Vezzoli and Wimmer 2005) and SEEM (Pezzotta, Pinto, et al. 2014).

iii. The available methods are *mainly based on qualitative analysis*. According to the analysis of the papers summarized in the previous section, the majority of the papers are dealing with qualitative analysis and approaches. Quantitative analysis and evaluation are currently missing. The need for large scale quantitative studies that at the moment are still scarce was also reported in the literature review proposed by (Xin, Ojanen and Huiskonen 2017).

iv. The majority of the studies *focuses on the engineering phases to support the BOL of PSS.* Almost all the methods analysed are referring to specific phases of the PSS engineering development narrowly focusing only on the idea generation and initial design of the solution. This can be clearly observed in table 9 which summarizes the methods with respect to the engineering phases. Some extensive methodologies that are proposing methods for multiple phases are also lacking a long term view through the PSS lifecycle. Very few of them (Pezzotta, G., et al. 2016) (Van Halen, Vezzoli and Wimmer 2005) (Alix 2010) (Hara, Arai and Shimomura 2009) consider or at least mention the possibility to engineer methods to evaluate the PSS during the entire lifecycle of the PSS, MOL and EOL. The need to consider multiple phases of PSS engineering was also stressed by the literature review from (Xin, Ojanen and Huiskonen 2017).

v. Even only considering the engineering phases to support the PSS BOL, t*he methods proposed are not covering all the engineering phases of PSS.*

A cross-analysis of the methods with respect to the engineering phases highlights that very few methods are available for the *concept evaluation phase* (Table 9). If a vast number of methods is listed for requirements analysis, concept development and feasibility analysis, for what concern the concept evaluation methods are missing. Few authors propose methods aiming at testing the PSS itself. However this implies that the solution is implemented or a least prototyped. DEMATEL and simulation are two examples.

It is noticeable that the methods to engineer the MOL area, only one method is indicated for the monitoring and evaluation activities, ServQual. However, it is a set of Key Performance

Indicators (KPI) that can be used for the monitoring of the service provision process but not for a real assessment of the PSS.

vi. *Focus on customer perspective:* The methods analysed mainly aim at evaluating customer satisfaction or prioritizing customer requirements. The company profitability and the cost analysis are generally neglected. (Lee, Geum and Park 2015) propose a method to analyse the PSS requirements as a mean to maximize customer value, (Pan and Nguyen 2015) aims at identifying PSS that generate customer satisfaction; (Song, et al. 2013) propose an approach to evaluate customer requirements and so on. Many other papers follow the same trend. Few exceptions can be found: (Matschewsky, Sakao and Lindhal 2015) who focus on the evaluation of PSS from the provider value perspective; (Pezzotta, Pinto, et al. 2014) who use simulation to define the best solution balancing customer and company perspectives; (Kimita, Tateyama and Shimomura 2012) who analyse costs associated to a solution; (Van Halen, Vezzoli and Wimmer 2005) (Alix 2010) who analysed the PSS from a strategic point of view. This further stresses the gap identified in the literature review of (Xin, Ojanen and Huiskonen 2017) who express the need to overcome customer centricity analysing both the customer and the provider perspectives.

vii. Throughout the analysis, the methods proposed are mainly *focused on the Service component of the PSS*. The methodologies suggested explicitly focus on the design of the "service" component of the PSS neglecting the "product" and the "system" components of the PSS solution. Example of this lacuna can be seen in (Pezzotta, Pinto, et al. 2014) (Kimita, Tateyama and Shimomura 2012) (Hara, Arai, et al. 2009) (Alix 2010). In very few cases, the product and its features are included in the analysis such as in the works by (Aurich, Fuchs and Wagenknecht 2006) and (Maussang, Zwolinski and Brissaud 2007) (Maussang, Zwolinski and Brissaud 2009) (Trevisan and Brissaud 2016).

The opposite gap, only product analysis, can be instead observed in (Bertoni, Bertoni e Isaksson 2013) (Bertoni, Bertoni and Panarotto, et al. 2016).

viii. Finally, an additional gap identified is the *limited development of tools* in association with the proposed methods. As hinted before, all the described methods are mainly theoretical and are not applied in a real case, and this can be related to the lack of related tools. Apart from (Hara, Arai, et al. 2009) who develop a tool strictly connected to their methodology, the methods suggested in the works presented do not show any evidence of others tools under development.

The identification of the primary gaps concerning PSS engineering methods spurs the definition of the goal of this thesis. In the next sections, the practical requirements in association to the PSS engineering methods and assessment are presented. The joint analysis of the PSS methods gaps and the industrial needs drive the definition of the research questions that are listed in chapter 4.

Table 9 Summary of methods identified with respect to PSS engineering phases

	PSS Engineering phases	Methods											
BOL	PSS Idea Generation	TRIZ	DbA										
	Requirements identification and analysis	Persona	Actor's and System Maps	Kansei Engineering	QFD	TRIZ	Support Vector Machine	ANP	AHP	SRT	DEA	Kano model	Rough Set theory
	Feasibility analysis	Niche Theory	SWOT analysis										
	Concept development	TRIZ	QFD	Kansei Engineering	AHP								
	Concept evaluation	ProVa											
	PSS Design	Actor's and System Maps	Functional Analysis	Service Blueprinting	PSS Board	SADT	Color-coded 3D Visualization	Prototyping	IPA				
	Test	DEMATEL	Simulation	Prototyping	FMEA								
	Implementation												
MOL	Delivery/Market launch												
	Support												
	Evaluation and Monitoring	ServQual											
EOL	Product disposal/recycle												
	Service decommission/redesign												

3 The Product-Service System in industry

As hinted in the introduction, the present thesis has a two-folded objective since it aims at providing a contribution to both theory and practice. This chapter aims to summarize the advancements for what concern the product-service system in industry. In particular, it summarizes the two main studies carried out and described hereafter.

First, a Special Issue in the International Journal of Production Research (IJPR) was launched on the topic of industrial servitization and digitalization. The issue was meant at collecting good practices, concrete experiences and relevant knowledge gained in the industry about the servitization topic. The management of the special issue publications, as a guest editor allowed a comprehensive analysis on the ongoing research and practices in the industrial context, reported in section 3.1.

Second, more insights in the industrial approach toward PSS, i.e. the benefits, the challenges and the complexity of managing the new solutions, were collected through the direct participation into the everyday industrial business in ABB throughout the three years of PhD research. As a result, a general overview of the primary needs of ABB with respect to PSS engineering and development were settled. They are described in section 3.2.

3.1 Special Issue in IJPR: Service Transformation in industrial companies

Although theoretical research is moving forward for what concern the PSS development, how industry copes with all the challenges brought to the fore by the servitization has yet to be understood. While there are many cases where companies successfully made the shift to PSS, in many others situations, companies are facing severe financial damages.

A call for papers in the International Journal of Production research was launched: it was aimed at collecting valuable papers to include in a special issue dealing with “Service Transformation in industrial companies”. The final goal of the issue is the contribution to the existing know-how by exploring how manufacturing companies are mastering their service transformation in practice. It also targets the collection of lessons learned in industry regarding companies that have either benefitted or conversely suffered from their endeavour during their servitization.

In response to the call for paper, 94 extended abstracts were submitted from 27 different countries. Although the great success of the call, 42 abstracts (44 percent) were rejected by the reviewers’ panel. Among them, 21 were out of scope whereas 21 were not accepted because they lacked evidence of connection/collaboration with industry, the primary requirement of the special issue. Some of the rejected abstract were also dealing with explorative analyses showing that the collaboration between academia and industry is in an embryonic phase.

The high percentage of rejection demonstrates the misalignment between the theoretical research and the practice: even though the research on the PSS topic is quite spread and extended (see chapter 2 on literature analysis), a limited number of companies is actually experimenting the servitization and the evolution toward PSS.

These considerations are further confirmed by the statistics on the accepted abstracts. Among the 52 accepted research for full paper submission, only 12 of them were co-authored by academicians and practitioners.

For what concern the objectives of the submitted research, some common trend and interest could be observed. Figures 12 and 13 summarize the main topic of the accepted abstracts. Each one was classified based on maximum three of the categories defined.

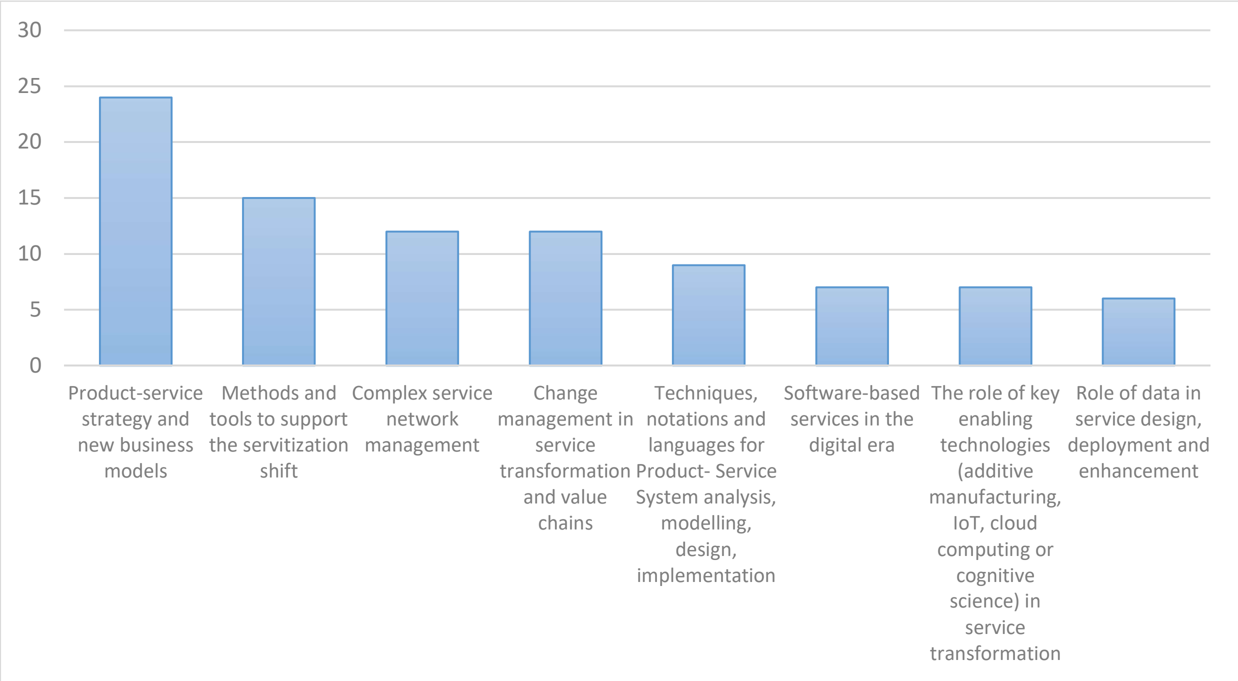


Figure 12 Classification of accepted abstracts (1/2)

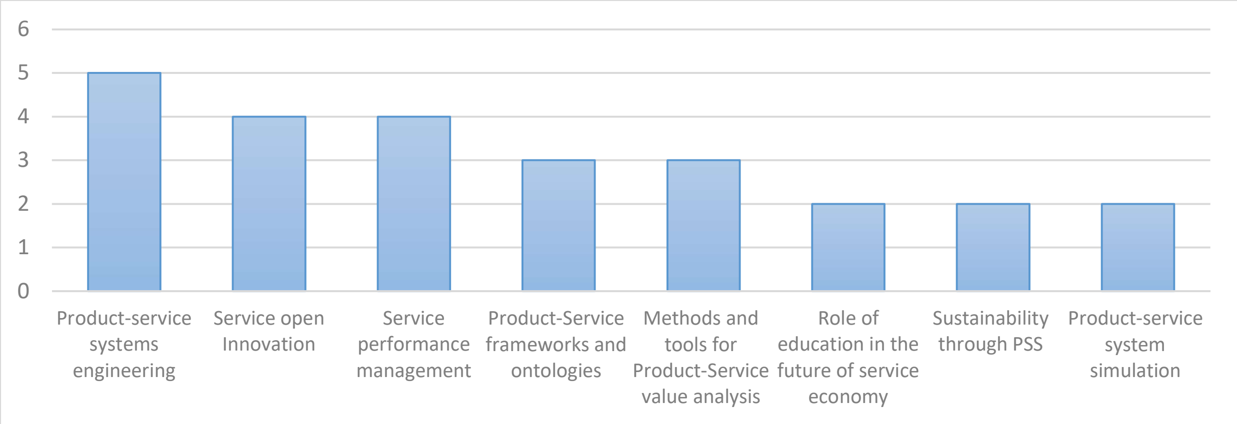


Figure 13 Classification of accepted abstracts (2/2)

As it could be observed, the majority of the abstracts proposed for the special issue are mainly related to the transition of manufacturing companies into the new business model based on the provision of PSS. The majority of researches are introducing strategies or methods to support the servitization. Some others are tackling the topic of software, key enabling technologies and data management throughout the transition. Instead, a reduced number of abstracts is advancing proposals for the PSS engineering and design (including methods and tools) to face the challenges.

According to the results, the engineering methods, tools and design approaches for PSS are not very common showing that companies are still on the way toward the change of their portfolio.

The 11 full papers finally selected for publications confirm it. Indeed, the selected researches deal with three main topics that regard the servitization.

1. *Challenges and risks in pursuing a servitized model.*

   Some of the selected papers focus their attention on the challenges of servitization identifying the *persistency of product-centred mind-set* (Coreynen, et al. 2017) (Matschewsky, Kambanou and Sakao 2017) as one of the significant complexities that manufacturing companies experienced. This also implies another common complication that is the *separation of product and service design* that makes the companies not capable of developing fully integrated solutions. The inability of being proactive (Coreynen, et al. 2017), the lack of resources and company knowledge on services (Ziaee Bigdeli, et al. 2017) and the perception of high risk concerning the servitization are basically all rooted on the two above-cited challenges that have not been overcame yet. The risk that manufacturing face during servitization is also treated by (Hou and Neely 2017) in terms of *commercial risk* and *operational risk*.

   An interesting perspective was also brought by (Lahy, et al. 2017) that describe the transition of a company through a "productization" strategy, i.e. adding services to their traditional product portfolio.

2. *Capabilities and drivers for enabling servitization*

Another relevant group of papers within the Special Issue deals with capabilities and factors influencing or supporting the service transition. Also in this stream of research, the industrial cases analysed bring to the fore the difficulties in practically adapting vocabulary and mental models to PSS (Karlsson, Larsson and Öhrwall Rönnbäck 2017). Detailed analysis concerning the capabilities required explicitly for the servitization in specific sectors are also explored (Hodges and Mo 2017). (Wagner, Jönke and Hadjiconstantinou 2017) focus on the network and the external relationship proposing guidelines to compete in the PSS market successfully.

3. *The role of key enabling technologies*

   Finally, some researches are devoted to the analysis of the industrial context in which technology is playing a leading role. Through multiple case analysis, the proposed contributions explore the remote monitoring technology (Grubic and Jennions 2017), the Internet of Things (IoT), cloud computing and predictive analytics (Ardolino, et al. 2017) and their role in facilitating service transformation in the industrial context. (Brad et al. 2017) conceptualization of smart solutions into the future manufacturing context. According to the abovementioned researches, the identification of the proper technologies to embrace a specific evolutionary path is challenging.

Concluding, the special issue lays its foundations in the identification of concrete experiences and "lessons learned" in industry. It provides an overview of the main challenges and difficulties that industry is currently facing with respect to the servitization.

According to what highlighted before, hereafter is a general summary of the results that can support the identification of relevant industrial needs.

- Although a vast number of papers were received in response to the call of papers, very few researches are proposing close connection or collaboration with industry. The majority of the reviewed abstracts are still at a theoretical level showing a poor participation of industry to the servitization and PSS debate or at least the scarcity of successful cases to be described.
- Percentage of co-written papers among the accepted abstract is quite limited confirming that even if the interest in the topic is relevant, the role of industry with respect to the servitization is mainly reactive and not proactive.
- The selected papers for the special issue are clustered in three main groups mainly dealing with the servitization challenges and capabilities. The *persistency of product-centred mind-set* and the *separation of product and service design* are the main difficulties identified and the proposed works are proposing prescriptive methods to deal with them.

Difficulties in adapting vocabulary and mental models to PSS together with the handling the "intangible aspect" are key aspects during the transition.

- Two out of eleven accepted papers bring to the fore the risk perception associated with the provision of new solutions, in particular to outcome-based contracts. According to such researches, this is one predominant factor still preventing companies to embark the servitization.
- The last topic explored is the introduction of new technologies into the servitization scenario. Four studies highlight how such digital advancements can potentially revolutionize the servitization path of manufacturing companies and how they can support the shift. The research collected are still in an exploratory phase and no practical cases and lessons learned are reported.

3.2 Direct analysis of industrial needs: the ABB case

The management of the Special Issue in the International Journal of Production Research provides an overview of the industrial practices related to PSS.

In parallel, during the three years of the PhD program, the author conducted a participant observation research that enables: i) a general understanding of the attitude of ABB toward PSS, ii) the identification of industrial practices and iii) the review of the methodologies available and used together with their features. This exploratory analysis leads to the identification of field requirements with respect to the PSS design areas that have been used to identify a research path that adequately addresses practitioners' quests while guaranteeing innovativeness.

In general, it can be confirmed that also in the ABB context, the servitization is still in its infancy. Although the company is working hard to identify new business models and opportunities, services and products are not yet integrated into a unique trend.

ABB is a pioneering technology leader in electrification products, robotics and motion, industrial automation and power grids, serving customers in utilities, industry and transport. The company operates in more than 100 countries with about 132,000 employees and infrastructure globally. It is organized in a matrix organization structure with two different reporting lines. One line depends on the division (four different divisions currently exist); the second line depends on the function to which people belong, for example, service. This implies that each employee depends on the specific division and then from the group function.

Like many multinational companies, ABB has embarked on a service transformation journey and is facing several challenges when it comes to include services into its product-oriented business. In particular, the complexity of the portfolio, the number of locations where it operates and its technology culture make the transition even harder. Hereafter a brief summary of the participant observation is reported, it could support the reader in better understanding the company requirements.

During the three years, the author regularly joined everyday business activities and frequently took part in workshops and meetings in ABB, especially in the division of electrification products. The author was regularly involved in “business life” into the low voltage business. It created a substantial knowledge about the company, its dynamics and the challenges that practitioners have to face with respect to product-service engineering and selling. During the participation to workshops, specific information was collected: focus groups and interviews were carried out periodically to gather latest updates and needs. Hereafter is a general summary of what observed during the three years.

The ABB *organization* and business strongly reflect the matrix business organization and the historical product orientation of the company. Even if during the three years, a substantial harmonization effort from headquarters has been recorded, it is still not common to observe a complete integration and collaboration among business units. This is also restrained by the frequent organizational changes taking place at a global level. Everyday operations and procedures are usually managed at a local level. Each business unit has many local units (spread in different countries), among them there could be similar practices, but local procedures are still influencing everyday operations. For what concerns the tools, common software is under implementation.

The *people* met during the participant observation represent a very heterogeneous sample: they all belong to a variety of sectors, boast a diversified background and cover different positions in the organization matrix of ABB. Even more important, the majority of the people interviewed are from a variety of countries. Some of them are people strongly in touch with their own culture and traditions whereas in some cases people are expatriate and manage to adapt to a variety of habits. Many of the interviewed people in the electrification product division were belonging to the SACE, a longest-serving company and they are doing their best to keep un with the latest innovation and technologies that are currently studied in the company.

The ABB *offer* is huge. A plethora of products and services can be observed on the global website (http://new.abb.com/). The highest share of income in ABB belong to traditional product selling. In each business unit indeed two different groups coexist, one group completely dedicated to product and one for services. The integration of the two groups is ongoing and in some cases it could happen that they have divergent goals. In this case, given the product orientation of the ABB unit analysed, the product unit has higher influence on decisions. Service units, functionally depends on a global service function that is trying to create cohesion among the services offered and the spread organization. However, such a wide variety of products implies that the service homogenization is very complex to achieve. It is also important to make the reader aware that the service units, hierarchically, are under the accountability of the product organization. On the one hand this facilitate the collaboration among people belonging to product and service. On the other hand, the distinction between the product function and the service function could make the definition of shared and common practices quite complex to achieve. Furthermore, such a distinction could partially imped the identification for the design of such integrated solutions. Traditional product design practices are not applicable in service design and a shared engineering approach is still under development. For what concern the low voltage unit of the electrification division, for example, some new solutions have been identified in the past, such as the “retrofit” and they have been developed as a product offer mainly with the support of traditional R&D.

The *customer role*. Given the product orientation of the company, new products launched in the market are usually based on “technology push” logic. The traditional product orientation and the technological leadership of the company still lead the selection of new offers and products. Customer preferences and requests are usually studied after the initial definition of new solutions in order to refine the concept. Sometimes customers’ segmentations and market research are carried out but the main preferences of customers are usually collected through direct interaction during visits. It is worth also mentioning that also top managers periodically visit customers to collect feedback about products and customer requirements. Although this direct connection with customers the KPI adopted both in product and service groups have not been updated with indicators for measuring the customer satisfaction and preferences. The Net Promoter Score (NPS) has been introduced few years ago. The results are used in everyday business and decisions but formally they are not considered as key indicators during company business review.

Specifically concerning the *PSS (or service) design methods*, during observatory research a lack of methods for the engineering of the service component of a PSS has been observed. The current service implementation process works as following:

1. A strategic decision about the introduction of a new service trigger the process. This decision could be related to the novelties in the competitors offer or to top management requirements.
2. Once the decision to implement a new service is taken, the company put all its effort to define the business model and the features of the new offer, and in organizing the service or the PSS provision. During this phase, specific tools or methods for the service and the service delivery

process are not available. In cases services are strongly related to products, product design methods are used. The development of new projects usually follows a gate model.

3. The following phase is the service implementation. Although the people experience and their knowledge of the business support the development of the project, no specific procedures or methodologies for the engineering of the service delivery process are currently available. Standard approaches are used but they are not formalized. The availability of resources to be committed in the project has a strong influence in the development process.
4. Once the service is implemented, it is monitored and evaluated, usually in terms of efficiency and profit. The Net Promoter Score (NPS) is also used to collect customer feedbacks with respect to a specific process. At this stage three different situations can happen:
    - The service is successful, customers appreciate it and the company profit is relevant. In this case, no changes are required.
    - The new service does not meet customer needs and requirements and, for this reason, it has to be re-designed in terms of service itself or in terms of business model (phase 2.). More reworks could be necessary.
    - The service (or PSS) is not delivered efficiently. In this case, the service delivery process has to be improved. Since no methods are adopted a trial and error approach is followed and the process has to be reviewed from phase iii. Two or three iterations are required.

This brief introduction gives the taste of the overall company analysis carried out during the three years of research. Whenever some questions arose, dedicated workshops and meetings were held. During the three years, many people from the different business units were interviewed and invited to workshops. The majority of them belong to the service field, but others from product management and sales departments were also interviewed. A variety of business units were involved. Importantly, the most of the participant observation was held in the low voltage unit in the electrification division.

As summary of what observed throughout the three years some difficulties, needs concerning the service (or PSS) engineering and implementation were collected.

I. One primary concern regarding the service design refers to the identification of the new services. The identification of the service is not easy and the company relies on successful services or solutions implemented by competitors and boasting good market share. Since no specific methods and tools are available, the ideation and the selection phases are quite complex to face. This is even more complex considering that ABB products, specifically the oldest one, are not designed to be serviceable and this makes the identification of new services even more complex. As previously described, this implies complexity in the decision making process and in the concept selection process that, since it is not supported by tools requires many reworks and re-design activities that are costly to the company.

II. Moreover, when doing brainstorming, some difficulties arise since the people involved are expert on the product and technicalities but do not have a service background. Understanding the customers' needs is somewhat very complex and this is further complicated by the heterogeneity of the people involved in the work (i.e. managers, R&D, marketing, sales). These differences make the selection of new solutions quite complex to achieve especially because it is complex to identify a trade-off and to select a common project to develop and to generate commitment about it.

III. Once a solution or some solutions are identified it's usually very complex to understand if the solution would work or not in practice. Usually, some interviews with the customer take place and, based on them, the new solution is delivered or not to the market. Since the exploration of customer perspective is not carried out in a structured manner it could lead to misleading information. A more organized analysis of customer perspective could be beneficial.

IV. The third main area of improvement is related to the management of the service delivery. As previously hinted, the majority of people involved have a product-oriented mind-set and they are tempted to manage service as a traditional production process. Only when they are practically involved in service delivery they can understand the problems and the peculiarity to be managed in the "intangible" service context. This could lead to either a very high responsiveness to customer with a loss in efficiency or to a high control of costs with a reduced focused on responsiveness to customers.

V. As summarized before each business unit has many local units throughout the world. One major concern of managers is the monitoring of all of them. Indeed, since all the units are different and seldom they use different tools and practices, it is very complex to monitor them in working efficiently and effectively. The need of methods to support the identification of trade-off between effectiveness and efficiency and to guide managers in taking decisions would be beneficial to support the monitoring of local units.

Similarly to what emerged from the general overview presented in the first section of this chapter, ABB is also at the beginning of its servitization evolution still trying to adapt its capabilities and skills to the PSS offer. In particular, a relevant need of structured approaches and methods to evaluate solutions before the actual implementation and launch on the market can be highlighted. This would avoid reworks of the designed solutions and a better and more structured planning of activities.

Moreover, it can be observed that there is also the urgency of guidelines or procedure for the engineering of the service delivery process that are not yet available. ABB would benefit from a structured to develop and evaluate the process of service offering before the actual implementation in order to optimize the efficiency and the efficacy of it.

4 Thesis objective and methodology

Chapter 2 illustrates the analysis on the current state of the art in PSS engineering and brings to the fore the main gaps in the research among which the lack of methods for the concept assessment phase (in the early stage of PSS design), strong orientation toward customer preferences and relevant focus on the service component of PSS. Furthermore, chapter 3 summarizes the primary needs elicited from practical observation in industry. This chapter aims at defining the thesis objective that would simultaneously cover some of the literature gaps and answer to the industrial needs. The methods followed to develop robust and valid research are also presented. Hereafter the objective of this research together with the research questions are described in section 4.1, then the research structure and methods are described in section 4.2.

4.1 Objective of the thesis and research questions

In line with the literature gaps and the industrial needs, the research in the area of PSS engineering still have some gaps to be covered. On the one hand, one significant complexity encountered by companies is the engineering of the intangible artefact of PSS, namely the service. On the other hand, even if some studies exist in that direction, methods and techniques supporting the PSS assessment prior to their actual implementation are still lacking.

Hereafter the objective of the thesis is described in order to cover the existing gaps. It is worth mentioning that it focuses on the engineering of product-oriented PSS and mainly build the knowhow considering a traditional value chain where the main stakeholders involved in the provision of PSS are the customer and the provider.

Specifically, the goal of the present research is **to develop decision making methods, applicable in industry, for the assessment of industrial Product Service System in multiple phases of the PSS engineering. The methods shall assist decision makers in considering the trade-off between the customer and the provider viewpoints during numerous engineering phases of PSS.**

It is noteworthy to stress the two main features characterizing the overall research goal:

i. The quest for the balance between the excellence in the value provided to the customer and high efficiency and productivity from provider viewpoint. This aims at covering gap vi of literature: "*Focus on customer perspective*";

ii. The applicability of the methods into the industrial context in order to ensure the practical validity of the research and to cover the lack of big scale quantitative studies identified by (Xin, Ojanen and Huiskonen 2017) (as emerged from the industrial analysis).

The proposed research objective, in particular, aims at covering two critical phases of the PSS engineering, the early concept development and the late engineering of the PSS, when the MOL should be design and assessed, that are two critical phases for the development of a successful and valuable PSS.

Keeping in mind the general features and the limitation of the scope, the thesis objective is cascaded down into two central research questions (RQs) both focusing on the assessment of PSS:

1. ***RQ1 - How to support decision makers in assessing PSS concepts in the early design phase?***

This research question aims at covering gap (v) *"lack of methods for all the engineering phases of the PSS BOL"* emerged from literature. In particular, it aims at developing an assessing method for the early stage of PSS engineering as a mean to support decision makers in identifying valuable PSS concepts to be implemented. This RQ refers to the concept generation phase when all the PSS are ideated, and few of them are selected to go through the detailed engineering phase. Figure 14 contextualizes the research with respect to the model proposed by (Wiesner, et al. 2015) . Foreseeing a holistic analysis of the PSS concepts this research question would also close the gap (vii) ("*Focus on the Service component of the PSS").*

For what concern the *industrial requirements* emerged in section 3.2, this research question aims at proposing a structured method for the evaluation of PSS alternatives that guide the team in evaluating the solutions considering multiple perspectives, especially the one from customers currently not very common. This would answer the need (II). Moreover, the definition of a method for the PSS assessment at early design stage would enable companies in having a general overview of the identified PSS prior to its implementation avoiding high investment costs and reworks. This would answer to need (III).

2. ***RQ2 -How to engineer and assess service processes to deliver the identified PSS?***

This research question focuses on gap (v) *"lack of methods for all the engineering phases of the PSS BOL"* proposing a method to support decision makers during later stages of the engineering for the BOL , i.e. detailed design. Figure 14 contextualizes the research question with respect to (Wiesner, et al. 2015) lifecycle. As it could be observed, RQ2 is focused on the service component of a PSS considering that product engineering methods are well developed and largely used and no more research is required.

Furthermore, the second research question contributes in covering gap (iv) *focuses on the engineering phases to support the BOL of PSS* since it foresees the development of an assessment method that can also be adopted in the MOL during the "support" phase in order to standardize and monitor the service delivery efficiency.

The second research question aims at responding to need IV of industry described in section 3.2. A method to assess the service delivery process prior to the implementation and also during the MOL in order to support people during the provision of the service process.

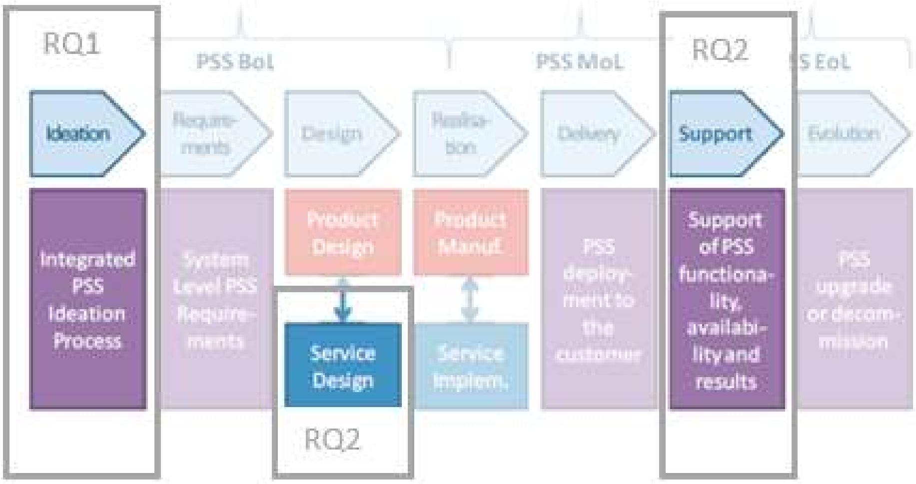


Figure 14 Positioning of the research questions with respect to the PSS lifecycle

Although the two research questions refer to different phases of the PSS engineering they both focus their attention on PSS assessment. Throughout its complete engineering, the PSS concepts have to be assessed from different perspectives and with different scopes. First, the multiple PSS solutions have to be evaluated to identify the most valuable one, while later on the selected concept has to be configured in an optimal way. Hence, both the two research questions focus on methods to be used during the PSS engineering phases. The first research question deals explicitly with the ideation phase (see figure 14) while the second would propose a method to be used during the PSS engineering in order to support both the BOL and the MOL phases of a PSS. Although they are not connected with each other, the methods foreseen by the two research questions would contribute to a unique and structured approach for the complete engineering of a PSS even if they won't be connected between each other. As previously mentioned, both the two methods can be integrated into the SEEM (Pezzotta, G., et al. 2016) (Figure 15) for PSS engineering, enhancing the assessment perspective.

The first method would support the "requirements design phase" serving to identify a PSS to be implemented while the second method would mainly guide the detailed the process prototyping allowing the process evaluation before the implementation and the monitoring during its functioning.

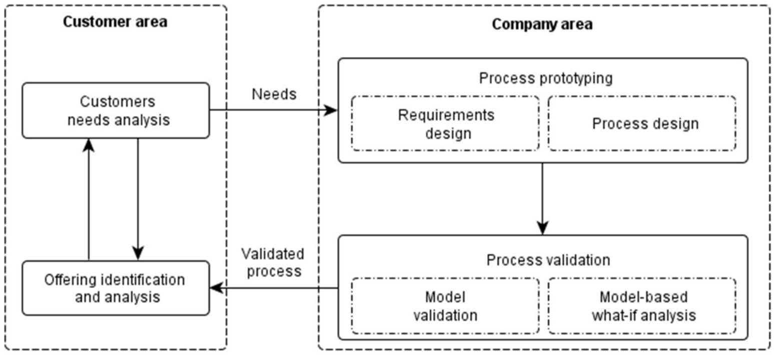


Figure 15 SEEM adapted from (Pezzotta, G., et al. 2016)

4.2 Research structure and methodologies

As many researches in operations management, this work is framed by concurrent needs for practical relevance and academic contribution. Due to this, a cluttered interaction between the practical and the conceptual worlds characterizes the overall research study and its complexity. According to Simon Croom in (Karlsson 2010) the definition of a disciplined and structure rationale could mitigate such complexity. The plan of the present research aims at guiding the research and in integrating systematically the research results into a valuable contribution to the PSS field.

The different phases of the research are carried out through the application of mixed methods, mainly belonging to quantitative research, following a *deductive "top-down"* approach.

4.2.1 Research structure

Figure 16 shows the overall structure of the research set up appreciating the main elements of a research project (Bryman 1988). Starting from a definition of a broad area of study, the project proceeds with the collection of information in industry and guides to the identification of the research questions. Then, after the formulation of possible research answers, data in practical cases are gathered, and final findings are presented.

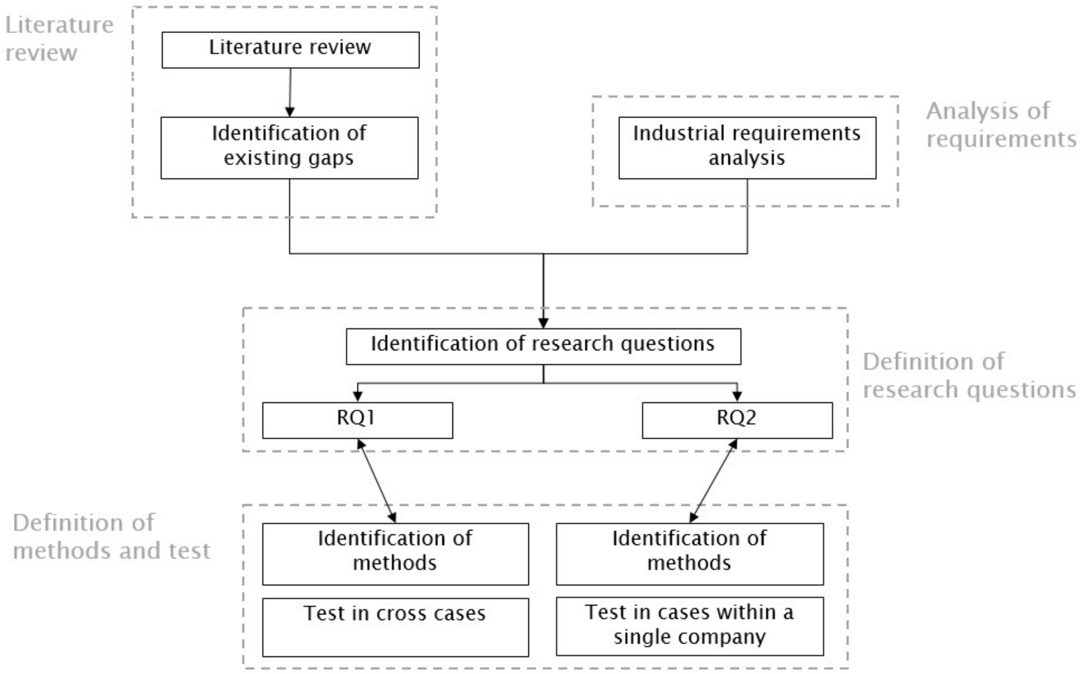


Figure 16 Research framework

The main phases can be summarized as follow:

1. *Analysis of the literature review*

   This initial phase of the research pursues the analysis of existing work in the PSS domain. This is aimed at creating awareness about models, methods and tools currently used in PSS engineering. In addition, it would clarify the existing gaps concerning the PSS and the SE disciplines. After an initial considerable review, it was continuously updated throughout the three years to find recently published works. This phase is described in chapter 2 of this manuscript.

2. *Identification of company requirements*

   Given the industrial needs that spurred the funding of this research by ABB, an analysis of company requirements is performed in parallel to the literature review. This sheds light on actual industrial needs and favours the exploitation of research results by the financing company and by similar companies with same needs. Chapter 3 reports the collection of the abovementioned information.

3. *Definition of the research questions*

   The match between the gaps of the literature and the company requirements sets the main gaps that this research aims to cover. In this phase, research objective is clarified and cascaded into two research questions. Chapter 4 summarizes this phase.

4. *Definition of PSS Design and Assessing Methods*

   According to the research questions identified, this phase is dedicated to the research on PSS engineering and assessing methods. It is aimed at covering the literature gaps while meeting the industrial needs and requirements. The advancements reached in this section are reported in chapters 5 and 6 (for RQ1) and chapters 7-10 (for RQ2).

5. *Validation of the methods in cross cases*

   In order to verify the consistency of the research results with the industrial needs and requirements, each method proposed to answer a RQ is tested in real cases. For each method, at least one of the application is carried out in ABB. Concerning RQ1; cross cases belonging to a variety of context are studied, ensuring external validity of the results. The airport and the smart city areas indeed are explored. Regarding RQ2, the cases are all belonging to ABB company but relating to multiple businesses and industry among which, robotics, motors and generators, electrification. Chapter 6 (for RQ1) and chapter10 (for RQ2) also describe the validation of the methods.

As previously suggested, the organization of the work is influenced by the tight relation to industry characterizing this research. In particular, an iterative process between phases 4 and 5 suggested by (Mingers and Brocklesby 1997) guided changes and improvement into the research. As shown by the bi-directional arrow in figure 16 the iteration includes i) the analysis of practical situation, ii) the assessment of the research in relation to the situation and, eventually iv) an action to bring desirable changes into the research. This contributes to providing feedbacks from practice to theory as well as to state the robustness of the identified methods.

4.2.2 Research methods

The research methods adopted throughout the research plan varies according to research phase and to the intended contribution of the phase to the body of research. Therefore, this thesis adopts a *multiple methods* approach.

Moreover, since this research belongs to the operations management domain, there isn't a standard and specified method to be followed (C. Karlsson 2010). However, in order to develop a research that is methodologically well done the main phases presented into the research structure (Section 4.2.1) were developed.

First, *literature review* is adopted to explore the area and to bring up the knowledge to develop new approaches (or methodologies) inside the PSS research domain. This initial analysis helped to establish the authority and the legitimacy of the research and to clarify the possible contribution of the "proposed research". The analysis of literature also supports the definition of the current research as an "original" piece of research.

In parallel, in order to highlight the close connection to practice of the research, one distinguishing feature of operations management research (C. Karlsson 2010), an empirical analysis was developed through *ethnographic research, participant observation* and *interviews* are adopted to explore the industrial requirements.

The gaps identified in literature and combined with the empirical needs constituted the starting points for the development and the analysis of the prescriptive methods to answer the RQs. The development of the two methods followed the same procedure. First, a specific literature analysis was developed to collect greater awareness about existing knowledge in the specific field. Then, based on the specific limitations identified and on the existing literature, two possible methods were identified. The methods were set mainly considering the empirical needs and the gaps emerged from the detailed literature analysis. Then in order to grant the method validity and to make it relevant to the operations management research, the methods were validated in real case(s) to ensure their usability and their connection to practice. The validation was in line with the deductive approach to research. In this phase, the quantitative model-based research (Meredith, et al. 1989) is followed. Such approach "is based on the assumption that we can build objective models […] or that can capture (part of) the decision making problems that are faced by managers in real life operational processes" (Karlsson

2010). In this step, theoretical methods are developed and the validated into practical cases to demonstrate industrial validity. Validation in real cases is achieved through meetings with people directly involved in the practical case in a workshop based setting. Data regarding the cases were also collected through interviews and *workshops.* The cases carried out in collaboration with ABB were held during the participant observation. More details about the specific development of the method and about the cases are described in the specific sections were methods and validation cases are described.

For each of the case presented, both regarding RQ1 and RQ2, the validation case was used in order to understand how the method worked in a real case and what were the results of the method application. Whenever the final goal of the case was achieved the validation case was considered complete. In each case, weaknesses, improvements and strengths of each method were also collected. Hereafter is a more detailed description of the most relevant and rigorous methods adopted in the thesis.

4.2.3 Literature review

Literature reviews were conducted throughout the entire plan of the research, each with a differing extent.

An initial and general review was performed to review the existing academic literature in the PSS field. Being an initial search, it was framed with a wide scope to be sensitive to pertinent literature across different research approaches in the PSS context. The summary of this analysis was collected in a rigorous manner both in the searching and in the mapping phases. As described in chapter 2 of this thesis, all the material retrieved from the search was catalogued and summarized through tables to facilitate information codification and results analysis.

The structured literature review supported the analysis of the latest progress in the PSS domain, creating a knowledge frame for further steps of the research and guiding the identification of a possible contribution to the current project. The analysis of the state of knowledge featured the identification of common approaches and practices and brought considerable insights concerning the most common research methods in the field. More than ensuring that the PhD research meet the criterion of "original" piece of work, the critical evaluation of the available literature supported the definition of scope boundaries and constraints of the analysis. Last but not the least, the rigorous approach helped in developing skills and capabilities for critical evaluation of scientific research.

With reference to each research question, more *narrow-focused literature reviews* were carried out. As the general review, they were based on a rigorous search approach, but they were aimed at exploring the specific areas of interest around the RQ. The scope of this kind of research was wider and was focused on the analysis of the topic in other disciplines and domains that could bring interesting understating about a topic.

The specific literature reviews carried out for each research question and for each specific subsection of the research questions are reported in the chapters dedicated to RQ1 and RQ2 respectively chapters 5 and 6 and 7-10.

4.2.4 Ethnographic research, participant observation and interviews

During both company requirements collection phase and the data verification, the research exploited the adoption of ethnographic research and interviews. In particular, ethnographic research was adopted to explore peculiarities and mindset of ABB where the author of this thesis was hosted for 3 years.

It is noticeable that the level of participation was quite high given the large amount of time that the researcher spent in the company. Moreover, the presence at many internal meetings and workshops led to a large collection of information.

Crucial in ethnography research is a long residence and participant observation during which the researcher becomes part of the organization, learn how situations are usually managed and decisions are taken. As described by Denzin (N. Denzin 1989) a participant observation is "[…] defined as a field strategy that simultaneously combines document analysis, interviewing of respondents and informants, direct participation and observation […]." During the participant observation data were collected and verified through triangulation with different people in the organization to ensure that the data collected in the participant observation were correctly interpreted. Additional data, both internal and publically available was also scrutinized to ensure a comprehensive understanding of the company. These data regards, in particular, the existing engineering process for service and PSS, and the internal procedures of the companies.

On the other hand, interviews with peoples from other organizations were carried out to extend the research to a broader domain and to analyse different requirements. Interviews were also held to collect data for the method testing. Generally, interviews were managed as semi-structured interviews following a specific set of questions that change according to the goal. In many cases, the research team reviewed the results of the interviews in order to increase confidence in the finding as suggested by (Eisenhardt 1989).

Part I - Discussion

The first part of this thesis represents a general introduction to the topic of PSS. First, a summary of the literature is reported in Chapter 2 with the identification of the current gaps. The results of a three-year participant observation held in ABB was also described to summarize the industrial practices in PSS engineering. The findings were further supported by the analysis of the papers collected in a special issue about "service transformation in industrial companies". In the light of literature gaps and industrial needs, this thesis goal is to develop methods, applicable in industry, for the assessment of industrial Product Service System that shall assist decision makers in considering the trade-off between the customer and the provider viewpoints during two critical phases of the PSS engineering. Two different research questions are identified in relation to the assessment of PSS. Although the two research questions refer to different phases of the PSS engineering they are both focusing on the assessment and the evaluation of PSS, a critical activity to be carried out to engineer valuable PSS.

The next two parts of the thesis discuss the research advancements regarding RQ1 and RQ2 respectively and show the benefits of the proposed methods.

Part II

The second part of this thesis is aimed at presenting the outcome of the research concerning RQ1. It deals with the identification of a method for the PSS assessment during the early stage of engineering, specially during the concept assessment phase. On the one hand, this phase is critical since it can determine the superiority or the failure of the final design solution. On the other hand, it is characterized by a scarcity of information about the features of the PSS solution. In order to introduce the reader to the topic a summary on the state of the art in the area of the early stage PSS assessment is provided. It includes an analysis of the available methods and on the criteria adopted to pursue the assessment. As a first outcome, it emerges that the existing methods have a strong orientation toward customer preferences and that the provider value associated to the analyzed PSS is somehow neglected. Moreover, some of the existing methods require a considerable amount of data and information that could not be retrieved in the early development phase. For what concern the evaluation criteria proposed in literature for the assessment of PSS a variety of criteria are presented. However, they are very heterogeneous and characterized by different levels of granularity.

In the light of the state of the art, the remaining part of chapter 5 presents the Engineering Value Assessment (EVA) method proposed in this thesis. The EVA method supports the evaluation of PSS alternatives from both the customer and the provider perspectives and guides the identification of a trade-off between the two. The EVA assessment lays on two set of homogeneous evaluation criteria.

In order to validate the EVA method and its features, Chapter 6 summarizes four different validation cases that refer to four different contexts and solutions spanning from product-oriented PSS to service-oriented PSS. The cases highlight the benefits of the EVA method especially related to its capability of pushing the discussion among team members and in the immediate visualization of the PSS value perceived by the involved decision makers.

5 The Engineering Value Assessment (EVA) method for PSS

This chapter introduces the first primary outcome of this thesis: the Engineering Value Assessment method that pursues an assessment approach for the early stage of engineering. The first section is dedicated to the description of the main features of the early engineering phase (section 5.1). Then a specific literature analysis is presented concerning the available methods (section 5.2). Finally, a detailed description of the EVA method is reported in section 5.3.

5.1 Main features of the early stage of engineering

The early stage of engineering phase, indeed, is a critical phase during which the PSS concepts that would be implemented into the company offer are ideated and selected. In this phase, engineers must identify PSS that ensure a good 'fit' with the firm's existing unique competencies, experience and reputation (De Brentani 2001). Many authors recognize the early stage development phase as a critical phase for the subsequent development. (Chen, Chu and Yang, et al. 2015) explain that "*insufficient evaluation of the PSS solutions allows poor design alternatives to operate in practice, and causes damage which can rarely be compensated at the later stages*". (Lagerstedt, Luttropp and Lindfors 2003) argue that "*early development phases, so-called re-think phases, are considered to have the influence on major changes in products in general.*" (Meuris, et al. 2014) suggest that "*Key properties of the design solution and its architecture*" are defined during the early stage design phase that turns out to be very critical. Finally (Mourtzis, Doukas and Fotia 2016) stresses the relevance of the early design phase *"…which is utterly important for the subsequent success of the offering since it can determine the superiority of the final design solution*". However, even if it is considered advantageous to make changes in an early design stage when relatively little capital is committed (Alam and Perry 2002), this opportunity is normally accompanied by limited knowledge about problems and solutions (Figure 17). Conversely, when the development team has established a more developed knowledge base in the later stages, major decisions have already been made, capital has already been committed, and it is, therefore, costlier and time-consuming to make changes. The 'design process paradox' (Ullman 1992) is well known in product development literature and is further exacerbated when dealing with the development of PSS. Therefore, the early design stage is a very critical phase that has strong impact on the future PSS development and is characterized by the scarcity of information and knowledge about the identified concepts.

Although this prominent role, literature lacks ad-hoc methods to deal with this phase and specifically with the assessment of concepts, as emerged from the literature analysis. The goal of this chapter is to propose the Engineering Value Assessment (EVA) method for the assessment of PSS during the early stage phases of PSS engineering. First, an overview of literature regarding the available methods for the early design stage is summarized in section 5.2. Then, a general overview of the EVA method developed to support the initial stage assessment is reported.

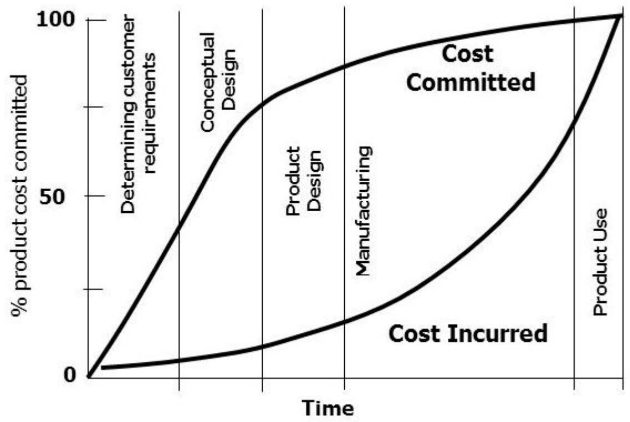


Figure 17 Engineering cost commitment, adapted from Ullman (1997)

5.2 Literature analysis on methods for early assessment of PSS

5.2.1 Methods for the assessment of PSS concepts

A major concern in literature is the lack of established methods and metrics to systematically assess and evaluate PSS concepts (Chen, Chu and Yang, et al. 2015) (Exner and Stark 2015).

A broad overview of literature discloses that the majority of existing assessment techniques (Mourtzis, Doukas and Fotia 2016) (Cavalieri and Pezzotta 2012) are hardly applicable in an early design stage, mainly because they are data intensive to be applied in situations where information with regards to costs, markets, prices and processes is unstable. Besides, they often "*pay little attention to producer and cost perspectives, which are also crucial in the process of PSS evaluation and operation*" (Qu, et al. 2016). These gaps are also highlighted by existing contributions on the topic. Literature dealing with the early assessment of PSS was retrieved from Scopus and ISI Web of Knowledge databases. The search included 3 sets of keywords as shown in table 10, to emphasize both the early stage of the PSS development and the concept assessment phase.

Initially, the three sets were searched together using the Boolean operator "AND" (Search #1), but this rendered few results. Therefore, sets 2 and 3 were searched independently according to search #2 and #3. The final list of retrieved papers contained 607 items that after a screening of the papers in the engineering area and the removal of duplicates lead to 340 papers. The abstract screening was focused on the removal of papers that did not explicitly deal with assessment methods and approaches for PSS design, and it further reduced the number of relevant publications to 97. Further filtering on the full text allowed the selection of manuscripts based on an assessment of PSS concepts reaching a final set of papers (47). During this filtering, literature review manuscripts were used for the snowballing process (Wohlin 2014) and then discharged. In order to include all the relevant papers into the analysis the most known PSS development methods were also analyzed. Among them

Lifecycle oriented PSS approach of Matzen and Tan (Tan, et al. 2009) Methodology for PSS (MEPSS) (Van Halen, Vezzoli and Wimmer 2005)Service Engineering of Sakao, Shimomura and Tomiyama (Sakao and Shimomura 2007) (Shimomura and Tomiyama 2005). The snowballing exercise also contributed in including relevant work in the area rendering a list of 31 papers specifically addressing the topic of concept assessment in early design stage.

Table 10 Summary of literature analysis in early design assessment

Search #	Search string	Scopus	ISI Web of knowledge	Total
1	"Product- Service System" OR "Functional Products" OR "integrated Product Service" **AND** "Assessment" OR "Evaluation" OR "Selection" **AND** "Early stage design" OR "Early stage" OR "Preliminary design"	5	1	
2	"Product- Service System" OR "Functional Products" OR "integrated Product Service" **AND** "Assessment" OR "Evaluation" OR "Selection"	387	171	
3	"Product- Service System" OR "Functional Products" OR "integrated Product Service" **AND** "Early stage design" OR "Early stage" OR "Preliminary design"	36	7	
	Total number of papers retrieved	428	179	607
	Selection of Engineering subject area			446
	Duplicate removal			340
	Title and abstract filtering			97
	Full text screening			47
	Snowballing			52
	Final set of papers on PSS early design phase			**31**

The 31 papers were then analyzed to explore their contribution to the early stage assessment. Out of 31, only 17 were relevant for the goal of this research. Some of the retrieved papers indeed are proposing assessment approaches, but they seem more suited for detailed engineering assessment. Indeed, many of them focus on lifecycle assessment and lifecycle cost assessment, such as the approaches proposed by (Sousa-Zomer, Cauchick and Paulo 2015) or by (Chou, Chen and Conley 2015). (Xing, Wang and Qian 2013) proposed a method based on lifecycle thinking that allows evaluating life-cycle performance, life-cycle cost, and life-cycle environmental impact of a PSS for value assessment. (Doualle, et al. 2016) propose different steps to evaluate PSS environmental sustainability throughout all the PSS design process. (Sun, et al., 2012) and (Lee, Geum and Lee, et al. 2012) suggest two different evaluation method for PSS during the running time. Finally, (Shimomura, Hara and Arai 2008) (Kimita, Shimomura and Arai 2009) (Lee, et al. 2012) recommend concept assessment methods focused only on the service component considering just the customer satisfaction. These approaches are not suitable as they require plenty of information about concepts that, as previously hinted, are not available in the early stage of engineering that is the focus of this RQ.

Table 11 summarizes the final set of papers analyzed. It reports the reference, a short description of the study and the main perspective that is considered during the assessment of the analyzed paper, either the customer or the provider. The main method adopted in the research is also provided.

According to what emerged in the literature analysis and summarized in table 11, it could be observed that there is a small group of research dealing with early design assessment. The analyzed papers are all suggesting possible approaches for the evaluation of PSS but considering different objectives. Some of them focus on the sustainability (Hu, et al. 2012) (Kim, et al. 2016) (Chen, Chu and Yang, et al. 2015) goal whereas some others are more concerned with customer satisfaction (Geng and Chu 2012). It is noticeable that the majority of the proposed approaches assess the PSS solutions from the viewpoint of customer evaluating the solutions only considering the fitting with the customer requirements. This implies that the listed concepts are not analyzed with regard to their profitability and convenience from the viewpoint of the provider. Among those analyzed, only one paper supports explicitly the assessment of the solutions considering the provider performance associated with the solution. The method, proposed by (Matschewsky, Sakao and Lindhal 2015) is called “ProVA” and is aimed at the assessment of the provider benefits. As could be deducted from the table, some other researches consider the costs and the effort to develop a PSS solution but only inside a more holistic approach.

It is also noticeable that, while all methods deal either with the customer (CV) or with provider (PV) perspectives, they often fail in integrating the two and in guiding the identification of a proper trade-off. The result could be that the solutions would be effective in meeting customer requirements or efficient for the provider implementation.

The existing researches were also screened specifically referring to the methods proposed for the early stage assessment were reviewed. In particular, some of the papers reviewed are not proposing a specific method for the assessment. For example (Yoon, Kim and Rhee 2012) propose a model for PSS assessment but no methods are proposed and (Kim, et al. 2016) or (Cho, Kim and Lee 2010) suggest a set of evaluation criteria but how to use them is not explained either coupled with a procedure or a method. (Hu, et al. 2012) also identify a set of criteria for the PSS assessment without a structured method.

Table 11 Summary of literature analysis

#	Reference	Paper goal	Method proposed	Customer Value	Provider Value
1	(Yoon, Kim and Rhee 2012)	Propose an evaluation model of PSS that considers both customer and provider perspectives. (no method proposed)	No method	y	y
2	(Chen, Chu and Yang, et al. 2015)	An integrated PSS solutions evaluation approach based on sustainability criteria is proposed. The approach is based on axiomatic design and the main outcomes is the analysis of a single PSS considering the impact that the sustainability criteria has on it.	Axiomatic design	y	n
3	(Akasaka, et al. 2012)	They proposed a method for PSS concept generation and assessment. They suggest the adoption of view model to support the concept generation and then they suggest an assessment method,(based on view model) to evaluate customer satisfaction while minimizing the costs.	Service design methodology and view model	y	only resource constraints
4	(Chen, Chu e Xiwu, et al. 2015)	A new evaluation approach integrating Information Axiom and the theory of Fuzzy Random Variable is developed. Firstly, according to fuzziness and randomness, the evaluation criteria are classified into four categories. Secondly, Information Axiom is used to evaluate the PSS alternatives.	Information Axiom and Fuzzy random variable	y	n
5	(Lee, Geum and Park 2015)	Propose a method for evaluating PSS concepts that focuses on customer acceptability. Analytic Network process (ANP) is adopted to define the importance and the interrelations among different value criteria and customer experience cycle. Then Niche theory adopted to capture whole market segment by customer survey.	ANP and Niche Theory	y	n
6	(Sakao and Lindahl 2012)	The article proposes a new method for evaluating PSS. The evaluation is achieved based on the importance of various customer value and each offering's contribution to the value as well as the customer's budget.	Ad-hoc method No Name	y	n
7	(Matschewsky, Sakao and Lindhal 2015)	The paper proposes a method to evaluate the Provider value during the evaluation of product service systems	ProVa method	n	y
8	(Hu, et al. 2012)	A 32 criteria evaluation framework of sustainable performance to implement PSS.	No method	indirectly	indirectly
9	(Geng, Chu and Xue, et al. 2011)	A systematic decision-making approach to determine the optimal fulfillment levels of Engineering Characteristics.	Systematic decision making and Kano model	y	only costs
10	(Geng, Chu, et al. 2010)	A method to rate the Engineering characteristics according to the value of the customers.	QFD, ANP, DEA	y	only costs
11	(Rondini, Pezzotta, et al. 2016)	Proposes a method to design and assess PSS concepts based on the SErvice Engineering Methodology (SEEM). The assessment is easy to adopt and few data are required.	SEEM	n	y
12	(Cho, Kim and Lee 2010)	In this paper, the E3 concept composed of economical, ecological, and experience values is proposed so that the PSS concept design and evaluation can be conducted with E3 values viewpoints.	No method, just evaluation criteria	y	y
13	(Dewberry, et al. 2013)	This paper focuses on a design experiment that sought to introduce alternative resource consumption pathways in the form of product service systems (PSS) to satisfy household demand and reduce consumer durable household waste.	No method	y	n
14	(Geng and Chu 2012)	Evaluate customer satisfaction associated to a PSS solution	Kano model, ANN, DEMATEL, IPA	y	n
15	(Kim, et al. 2016)	This research proposes an evaluation scheme for PSS models. The PSS model evaluation scheme consists of evaluation criteria and methods. The set of evaluation criteria has a four-layered hierarchical structure which has 2 perspectives, 5 dimensions, 21 categories, and 94 items in total.	No method but only evaluation criteria	y	indirectly
16	(Lagerstedt, Luttropp and Lindfors 2003)	This paper discusses an extended functional representation in design for environment methods to evaluate sustainable design solutions, especially in early (re-think) phases of product design.	LCA	n	n
17	(Shimomura and Sakao 2007)	The paper proposes a method for evaluating service solutions conducted from a provider perspective during the design process. The approach is based on Quality Function Deployment (QFD).	QFD	y	y

Among the other researches, some methods could be highlighted such as the QFD (Shimomura and Sakao 2007), ANP, Niche theory (Lee, Geum and Park 2015) or information axiom theory (Chen, Chu e Xiwu, et al. 2015). However, these methods are all very complex approaches that require relevant engineering knowledge or background (Geng, Chu and Xue, et al. 2011) or that requires detailed data to be computed. This makes them poorly applicable in practice.

As a result it could be stated that a method supporting the evaluation of PSS concepts and the identification of a balance between customer and provider perspective is not yet available. Since this is one key aspect that this thesis aims at covering by defining the EVA method.

5.2.2 PSS value criteria

In parallel to the review of the existing PSS assessment methods, further research was carried out in order to understand the key relevant criteria to be analyzed during the assessment of PSS.

Indeed, while literature agrees on the pivotal role of 'value' as a proxy for 'design goodness', it is less aligned when it comes to cascade this notion down to measurable indicators able to support the early stage assessment exercise. While value is interpreted as the ability to generate new revenue streams, to increase operational performances, (Mathieu 2001), social well-being and environmental sustainability (Vezzoli, et al. 2015), a universal taxonomy of "drivers" or "factors" influencing PSS value is not established in the PSS community.

The literature analysis was carried out in the form of keyword search in the Scopus and ISI Web-of-Science databases. In order to include nearby terms (i.e., 'measure' and 'measurement'), the search used abbreviations and the search operator (*), as summarized in Table 12 . As it could be observed from the table, the terms "criteria", "factor", "metric", "measure", "indicator" and "driver" were all used during the search since they are all used in literature to define the variable used for the analysis and evaluation of PSS. The first filter on title and abstract considering 'relevancy of the described metrics for PSS design', and 'applicability to early design stage decision making' was performed. The list was then filtered on a full-text base, eliminating entries not explicitly referring to 'value metrics for customers, stakeholders or provider'. Redundant items were removed, and the remaining ones were complemented with relevant contributions through backwards and forward snowballing (Wohlin 2014). The final paper list was composed of 64 manuscripts as summarized in Table 12.

Table 12 Summary of literature on PSS value metrics.

Search string	Scopus	ISI Web of knowledge	Total
("criteri*" OR "factor*" OR "metric*" OR "measure*" OR "indicator*" OR "driver*") AND ("product service systems" OR "functional product")	99	15	
Title based filtering	22	12	
Abstract based filtering	18	12	
Full text based filtering	8	9	
Redundancy analysis			16
Snowballing			48
Final paper list			**64**

As the number of contributions was quite relevant, a systematic framework to categorize all the contributions and the proposed criteria were identified. It was inspired by the equation proposed by Lindstedt and Burenius (Lindstedt and Burenius 2003) that defines customer value in the broader perspective of "perceived customer benefit", then divided by the "use of customer resources", intended as money, time and effort as reported by equation 1.

$$Value = \frac{Benefits}{Expenditure} \qquad [1]$$

This equation was used as a reference to set two comprehensive families of value metrics for the literature categorization: 'Total Functionality' and 'Total expenditure'. Moreover, since the innovation of this work is the concurrent analysis of CV and PV the two families were then doubled as suggested by (Xing, Wang and Qian 2013), to collect relevant indicators addressing i) customer and ii) provider viewpoints. The groups were further broken down into more specific value categories to take design decisions (e.g., selection of features that shall be included in the PSS offer) on concrete needs and opportunities. The categories were mainly developed during the analysis of the collected set of manuscripts and considering the Design Thinking (Leavy 2010)concepts of "feasibility", "viability" and "desirability" ("what can be done" - "what you can do successfully within a business" – "what people want or will come to want"). Table 13 shows the final framework adopted for the analysis of literature.

Table 14 summarizes the literature review results. All the contributions identified are mapped against the value categories defined in Table 13. The mapping highlights the categories for which the contribution is proposing a set of drivers (or metrics) (✓) (the metrics identified are not reported in the table but are available upon request). Papers that implicitly or partially mention possible metrics are marked with (*p*) whereas in case the reviewed metrics did not find a direct mapping into the proposed categories, they were classified as 'uncategorized' (U). Examples of such metrics include several criteria for environmental sustainability, health and other social-related aspects.

Table 13 Classification framework based on Lindstedt 2003

Customer Value (CV)		Provider Value (PV)	
TOTAL FUNCTIONALITY	**TOTAL EXPENDITURE**	**TOTAL FUNCTIONALITY**	**TOTAL EXPENDITURE**
(C1) Product/ service value in use	(C8) Ownership cost	(P1) Business opportunity and ROI	(P6) Product/ service lifecycle cost
(C2) Business opportunity and ROI	(C9) Operational cost	(P2) Brand strategy	(P7) System/ infrastructure cost
(C3) System convenience	(C10) Financial and opportunity cost	(P3) Customer and Stakeholder relationship	(P8) Financial and opportunity cost
(C4) Intangibles	(C11) Effort	(P4) Capability creation and retention	(P9) Effort
(C5) Capability creation and retention		(P5) Uncertainty/ risk	
(C6) Brand/ strategy			
(C7) Uncertainty/ risk			

Overall, the first classification of literature highlights that, similarly to what observed in relation to methods, in decision making customer value metrics are given more importance than provider value metrics. Indeed, only 23% of contributions mentioned at the same time customer and provider value. The majority (47%) focus their attention on customer value. It is also noticeable that none of the reviewed contributions captures all categories of value defined in Table 13 demonstrating that a holistic set of metrics for capturing value associated to PSS is not yet available. Concerning the categories adopted for the classification, it is surprising to find a general lack of focus on metrics that capture the opportunity of leveraging customer's brand and strategy (C6) through PSS provision. Most contributions assess PSS goodness from a 'system convenience' (C3) and cost perspective (C8-C9-C10), but only a few shift the focus towards a customer-of-customer perspective (C2).

From a provider viewpoint, a more homogeneous distribution is observed. Still, only a few contributions highlight the organizational effort (P9) linked with the provision of PSSs.

As previously hinted, all the value metrics proposed by each paper analyzed were also listed inside each category from C1 to P9. As a result, a total of 122 indicators for customer value in the 11 CV categories, and 146 indicators for PV were identified. This former list of metrics includes very heterogeneous metrics that are characterized by notable differences in terms of granularity and taxonomy. According to what emerged from this analysis of literature, a comprehensive set of value criteria associated to PSS is lacking.

In order to cover the gaps identified in literature, in the next section a method for the assessment of PSS during the early design phase is described (Section 5.3). Moreover, a complete set of evaluation criteria for a holistic value assessment is proposed (section 5.3.4).

Table 14 Literature review results

Reference	CV	C1	C2	C3	C4	C5	C6	C7	C8	C9	C 10	C 11	PV	P1	P2	P3	P4	P5	P6	P7	P8	P9	U
(Akasaka, et al. 2012)	✓	✓		✓				✓	*p*	*p*													
(Alix and Vallespir 2009)	✓	✓							*p*	*p*			✓	✓	✓	✓	✓				✓		
(Bertoni, Eres, and Isaksson 2011)	✓	✓		✓	✓				✓	✓	✓		✓		*p*	*p*	✓		✓	✓	✓		
(Ceschin 2013)	✓							*p*		*p*		*p*	✓	✓				✓	✓	✓	✓	✓	
(Chen, Chu e Yang, et al. 2015)	✓	✓		✓					*p*	*p*													✓
(Cherubini, Iasevoli and Michelini 2015)	✓	✓		✓		*p*			*p*		*p*												✓
(Chirumalla, et al. 2013)													✓			✓	✓				*p*		✓
(Chou, Chen and Conley 2015)	✓	✓		*p*	✓	✓			✓	✓	✓	✓	✓				✓		✓	✓			✓
(Chun, et al. 2011)	✓								✓	✓	*p*												
(Estrada and Romero 2016)	✓	✓																					
(Everhartz, Maiwald e Wieseke 2014)	✓	*p*		*p*	*p*	✓		✓			✓	*p*											
(Felber and JK. 2015)	✓		*p*	*p*	✓								✓	✓	✓		✓		✓	*p*	*p*		
(Geng and Chu 2013)	✓	✓		*p*	*p*				✓	✓		✓											
(X. Geng, X. Chu, et al. 2010)	✓	✓							✓	✓													
(Goncalves e Kokkolaras 2015)	✓	*p*		*p*				✓		✓	*p*												
(Hu, et al. 2012)	✓	✓				✓			✓	✓	✓	*p*	✓	✓	✓	✓	✓	*p*	*p*		✓	*p*	✓
(Khumboon, Kara e Ibbotson 2011)	✓	✓		✓				*p*		✓			✓					*p*	*p*	*p*			
(Kim, et al. 2011)	✓	✓							✓	✓			✓	✓	*p*	✓	✓	*p*	✓	✓			✓
(Kim, et al. 2016)	✓	✓		✓					✓	✓			✓	✓		*p*	✓		✓	✓			✓
(Kim, et al. 2011)	✓	*p*			✓				✓	✓			✓	✓	✓				✓	✓			
(Kimita, Shimomura and Arai 2009)	✓	*p*		✓				*p*		✓													
(Kimita e Shimomura 2013)	✓	✓																					
(Kuntzky e Herrmann 2013)	✓	✓											✓	✓					*p*	✓			✓
(Kurita, et al. 2013)													✓						✓	✓			
(Lagemann and Meier 2014)													✓	*p*			✓	*p*	*p*	*p*			
(Lee, et al. 2012)													✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
(Lee, Geum and Park 2015)	✓	✓		✓	✓		✓			✓		✓											
(Lindström, et al. 2014)	✓	✓		*p*	*p*				✓	✓	*p*		✓		✓	✓	✓	✓					
(Long e Wang 2011)]	✓	✓		*p*				✓	*p*														
(Matschewsky, Sakao and Lindhal 2015)													✓		*p*	✓		✓	✓	✓			
(Mattes, Bollhöfer e Miller 2013)													✓	✓	✓	*p*	✓		*p*		✓		
(Mazo e Borsato 2014)	✓	✓		*p*	✓			*p*				*p*											✓
(Mert, Waltemode e Aurich 2014)	✓	✓		✓		✓																	
(Mourtzis, Doukas e Fotia 2016)	✓	✓		*p*					*p*	✓			✓				✓	✓	✓	✓	*p*		✓
(Mourtzis, Fotia e Doukas 2015)	✓	✓		✓	✓			*p*	✓	✓			✓	✓		✓	✓	✓	✓	✓	*p*		
(Müller, Schulz e Stark 2010)	✓	✓	✓	✓	*p*	✓				✓		✓											
(Nemoto, Akasaka e Shimomura 2013)	✓	✓		✓	✓			✓	*p*	*p*		✓											
(Neugebauer, et al. 2013)													✓	✓	✓	✓	✓	✓		*p*		*p*	✓
(Ng, Harding e Rosamond 2013)	✓	✓		✓	✓		*p*		✓	*p*													
(Pan e Nguyen 2015)													✓	✓	✓	✓	✓	*p*	*p*	✓			✓
(Peruzzini, Marilungo e Germani 2015)	✓	✓		*p*	*p*				*p*	*p*		✓											
(Reim, Parida e Sjödin 2016)													✓			✓	✓	✓					
(Rodrigues, Pigosso and McAloone 2016)													✓	✓		✓	✓	✓	✓	*p*			✓
(Roy and Cheruvu 2009)	✓		✓						*p*				✓	✓				✓	✓	✓			✓
(Sakao and Lindahl 2012)	✓	✓		✓																			
(Sakao, Paulsson and Müller 2011)	✓	✓		✓		*p*			✓	✓		*p*											
(Schenkl, Rösch e Mörtl 2014)	✓	*p*		✓	✓			✓	✓		*p*												
(Shimada, et al. 2013)	✓	*p*																					
(Shimada, Taira, et al. 2011)	✓	*p*																					
(Shimomura, Hara and Arai 2009)	✓	✓																					
(Shimomura, Watanabe, et al. 2011)	✓	✓		✓	✓																		
(Song, Ming, et al. 2013)	✓	*p*								✓			✓	✓				*p*					✓
(Song and Sakao 2017)	✓	✓		✓					✓		✓												✓
(Stefano, et al. 2015)													✓	*p*		*p*	*p*	*p*	*p*	*p*			✓
(Storey e Easingwood 1998)													✓	✓	✓	✓		✓		*p*	✓	*p*	✓
(Sundin, Nässlander e Lelah 2015)													✓						✓				✓
(Taabodi and Sakao 2011)	✓	✓																					
(Tan, et al. 2011)	✓	✓		✓	*p*		✓		✓	✓													
(Van Ostaeyen, et al. 2013)	✓	✓																					
(Weißfloch e Geldermann 2016)													✓	✓	✓	✓	*p*	✓	*p*		✓	✓	
(Williams 2006)													✓	✓	✓								✓
(Xiao-rong, Sui-cheng e Lang 2009)	✓	*p*		✓	✓								✓			✓	✓						
(Yang 2009)	✓		✓	✓	✓	✓		✓	✓	✓			✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
(Yoon, Kim and Rhee 2012)	✓	*p*		*p*									✓		✓		*p*	✓	✓	✓	*p*		✓

5.3 The EVA method

According to the specific analysis, the extant literature does not propose any method for the early concept assessment capable of jointly considering both customer and provider value. In order to overcome this gap, a specific method is proposed. It was specifically developed to answer RQ1 and lays on existing multi-criteria decision-making approaches. It aims at defining a specific procedure to guide the identification of valuable PSS concepts and to assess the value associated with a PSS in a structured manner. It includes the definition of specific methods and value criteria that should be adopted during the evaluation phase. For these reasons, it is called Engineering Value Assessment (EVA) method.

The EVA method is composed of two different steps that enable the assessment and the recombination of PSS solutions.

The first step uses as input a previously predefined list of PSS for a high level evaluation of the concepts. It enables the analysis of the main features of the identified concepts. The output of this phase is a prioritization of the concepts and the identification of the more valuable features of each of them. This output of this first step would lead to possible recombination of the concepts features in order to identify new PSS concepts with high customer value and provider value.

Since the first step of the evaluation does not allow high differentiation between the concept during the assessment and since it could lead to changes into the initial PSS concepts, a second and more detailed assessment phase is foreseen. The latter considers a wider variety of value criteria and, the method adopted in this second step and presented hereafter enables more differentiation of the concepts during the assessment. The final output of this second step that is also the output of the overall EVA method, is the ranking of the PSS concepts analysed that can be either the initial ones or new concepts defined after step 1.

In order to comply with the scope of the research question, the evaluations carried out at each step are two, one from the customer perspective and one from the provider perspective. At the end of each step a match between the two is also foreseen by the EVA method to propose a trade-off between the two and to identify a unique positioning of the concepts.

Figure 18 summarizes the overall structure of the EVA method. The EVA is a mixture of existing methods either already used in PSS engineering or belonging to others fields such as the engineering design (Frey, Herder, et al. 2009, Frey, Herder, et al. 2010) or multi-criteria decision making (MCDM) methods (Zavadskas and Turskis 2011).

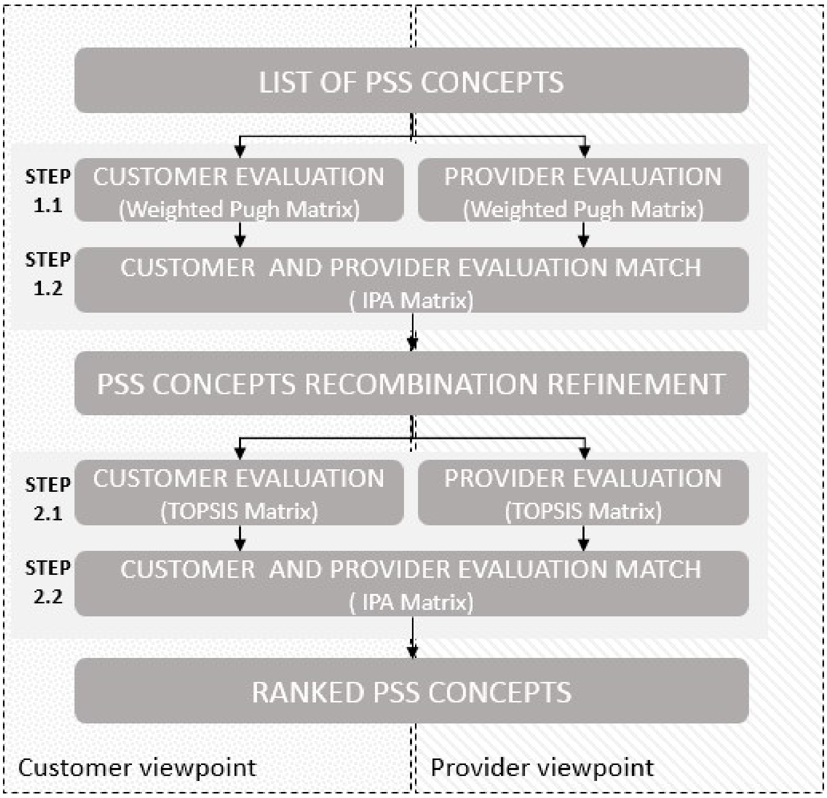


Figure 18 EVA method structure

The two steps that compose the EVA exploit different methods. At each step, ad-hoc evaluation criteria to be coupled with the proposed method are also specified.

Table 15 summarizes the main motivations behind the methods selection at each step. In general, based on the main requirements collected during industrial meetings, methods characterized by high ease of use and understanding were prized.

Indeed, as suggested by (Frey, Herder, et al. 2010) "*Engineering design has to be carried out under deadline, and budget constraints and engineers must decide how to make decisions based partly on how much time and energy the available methods require*... *Engineers must seek the most efficient approaches to complete their work under realistic constraints, and these are particularly valued in the early stages of design*" (Frey, Herder, et al. 2010).

As the EVA method aims at guiding decision makers in finding a proper tradeoff between the customer and the provider value associated to each PSS solution, the assessment at each step is carried out twice: one from the viewpoint of customer and one from the viewpoint of provider. Moreover, at the end of each evaluation step (Figure 18) the EVA method foresees the adoption of the Importance Performance Analysis (IPA) matrix to combine the evaluation score of the two actors involved.

Overall, the method is meant to be followed during focus groups in a workshop-like setting, involving participants from different organizational functions (mainly R&D, marketing, sales and finance), and, when possible, customers. An expert facilitator from academia could also support in speeding up the process and better explain the activities inside each step of the method.

The process kicks-off by requesting the workshop participants to generate a first list of PSS concepts, which are defined as a product enabling a series of services processes, activities and service resources (adapted from (Song and Sakao 2017)).

Table 15 Rationale for method selection in the EVA method

Method selected	Rationale for selection
PUGH (Cervone 2009) (Frey, Herder, et al. 2009, Frey, Herder, et al. 2010)	Commonly used in the product concept selection. No detailed data are required Well-known method that is good in "concept recombination" during early stage ensures convergence toward an "optimal" concept.
TOPSIS (Chang and Tseng 2008) (Behzadian, et al. 2012) (Song and Sakao 2017)	Good in handle human decision making Algorithm easy to use and implement Best and worst solutions are compared quantitatively Do not require attribute preferences to be independent (Chen and Hwang 1992) Most common MCDM method used in PSS literature
IPA (Martilla and James 1977) (Geng and Chu 2012)	Origins related to the definition of strategic decisions for the company Integration of two perspectives and immediate and clear visualization of the provider/customer trade-off.

Hereafter a detailed description of the two phases and of the IPA matrix representation is reported.

5.3.1 Step 1: Pugh method

In the EVA method, the main purpose of Step 1 is to guide a first evaluation of the PSS concepts and to identify opportunities for improvement, recombination and refinement of them. Step 1 of the EVA method is designed to manage PSS concepts that are very heterogeneous in nature, spanning from pure products to pure services (A. Tukker 2004) or concepts that are still rough and poor information are available about them. Given the participation of people with different background and education, assessment methods at this stage need to be flexible, simple and intuitive; all characteristics that point for the adoption of Pugh matrixes (see rationale in Table 15).

Pugh enables comparison of new concepts based on multiple criteria with respect to an existing concept, called baseline, defined by the provider, which by definition scores "0" in all chosen evaluation criteria that for the specific method are presented in section 5.3.4. All the concepts under evaluation are then assigned a (+), (-) or (0) if they are, respectively, better, worse or equal to the baseline with respect to a single evaluation criterion. Each criterion is weighted by the engineering team, team to stress (or not) its relevance. Once the matrix is completed, concepts are given a total score by summing up all "+", "-" or "0" obtained. The Pugh assessment is repeated twice, firstly with a focus on the customer criteria, then on the provider ones. Table 16 shows an example of Pugh Matrix. The criteria to be adopted in this step of the method are reported in section 5.3.4.

Table 16 Example of Pugh matrix

Criteria	Weight	Baseline	Concept 1	Concept 2	Concept 2
Criteria 1	3	0	-	-	+
Criteria 2	5	0	-	+	+
Criteria 3	7	0	-	-	+
Criteria 4	5	0	-	+	-
Criteria 5	4	0	+	+	-

It is worth noticing that step one could be performed iteratively until concepts features are well established and refined.

Once the concepts are improved or more detailed, they are forwarded to Step 2, where the assessment is more specific and based on a more detailed set of evaluation criteria.

5.3.2 Step 2: TOPSIS method

Since the first step of the EVA method allows the evaluation of solutions only through "+" or "-" and it is aimed at providing suggestions regarding possible improvements. Hence, at the end of step 1, PSS concepts should be recombined and reviewed in order to propose solutions with a higher value. Hence, to the end of PSS concepts prioritization and evaluation, a second step is foreseen by the EVA method. The second step aims at a more detailed evaluation of PSS concepts considering a wider and more complete number of criteria. To do so, this step is exploited through the TOPSIS technique (Chang and Tseng 2008) (Behzadian, et al. 2012).

Similarly to other MCDM methods, TOPSIS is based on a mathematical algorithm. In detail, it measures the shortest distance from a positive ideal solution and the farthest distance from a negative-ideal solution. The first maximizes the benefit criteria and minimizes the cost criteria, whereas the second maximizes the cost criteria and minimizes the benefit criteria. Among the methods proposed by (Zavadskas and Turskis 2011) it has been selected because the algorithm is quite easy to understand and because it provides as output a cardinal ranking of alternatives, without requiring attribute preferences to be independent (Chen and Hwang 1992). Also in this step, the TOPSIS assessment is repeated to evaluate the value from a double perspective: customer and provider.

In details, the TOPSIS process is carried out through the following six steps.

Step 1. Evaluation of the concepts

The evaluation of the alternatives is considering the features of the concepts. Two different approaches can be used to assign scores. If available specific data associated with the evaluation criteria could be included. If, as in the majority of cases during the early design assessment, specific data are not available, scores based on a Likert scale can be used to judge the concepts. An ad-hoc scoring was identified for the EVA method as in the following table (table 17). Hence, a score ranging between 0 and 5 is assigned to each concept respect to each criterion. “0” means that the concept does not provide any value associated with the criteria while “5” indicates that the solution contributes in an excellent way in providing the value. Conversely, for the criteria recognised as costs, negative scores are assigned.

Table 17 Likert suggested for the EVA method evaluation

Score	**Label**	**Explanation**
0	None	This category of Value may be omitted for the evaluation of this concept
1	Inadequate	Benefits regarding the Value yielded by the concept are negligible.
2	Acceptable	Very slight benefits regarding the Value can be expected from the concept
3	Satisfactory	Benefit to Value is on par with expectations for this concept.
4	Good	Benefits regarding the Value notably exceeding expectations on this concept
5	Optimal	Best performance in terms of Value for the respective concept

At the conclusion of the first step, a matrix composed of m criteria (rows) and n alternatives (columns) is obtained:

$$X = \left(x_{ij}\right)_{m\times n}, \text{with i } = \text{ } 1, 2, \dots, \text{m and j } = \text{ } 1, 2, \dots, \text{n} \quad [2]$$

Step 2. Normalisation of the matrix

The second step consists in normalizing each element of the evaluation matrix to obtain the normalised evaluation matrix:

$$N = \left(n_{ij}\right)_{m\times n} \text{where } n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \quad [3]$$

Step 3. Calculation of the weighted normalised matrix

Before performing the third step, the importance of each criterion needs to be stated assigning to each metric the respective weights on a whole of one hundred percent (w_i, with i = 1, 2, ..., m). After having decided the relevance of the criteria, it is possible to calculate the weighted normalised matrix:

$$T = \left(t_{ij}\right)_{m\times n} \text{ where } t_{ij} = r_{ij} \times w_i. \quad [4]$$

Step 4. Identification of the ideal and the negative solution

To calculate the distance from the ideal and the worst solution, it is before necessary to identify them. First of all, the criteria are divided into two different sets:

$$I_+ = \{i = 1,2, \dots, m | i \text{ associated with the positive criteria}\};$$

$$I_- = \{ i = 1,2, \dots, m | i \text{ associated with the negative criteria}\}.$$

Then, the ideal solution is defined as:

$$A_b = \{ \langle \min(t_{ij} | j = 1,2, \dots, n | i \in I_- \rangle, \langle \max(t_{ij} | j = 1,2, \dots, n | i \in I_+ \rangle \} \equiv \{ t_{ib} | i = 1,2, \dots, m\}.$$

While the negative solution is:

$$A_w = \{ \langle \max(t_{ij} | j = 1,2, \dots, n | i \in I_- \rangle, \langle \min(t_{ij} | j = 1,2, \dots, n | i \in I_+ \rangle \} \equiv \{ t_{iw} | i = 1,2, \dots, m\}.$$

Step 5. Distance calculation from the best and worst solution

The fifth step consists in calculating the distance between the alternative j and the best (worst) condition A_b (A_w). Respectively, the distances from the ideal and the worst solution are:

$$d_{bj} = \sqrt{\sum_{i=1}^{m} (t_{ij} - t_{ib})^2}, \text{with } j = 1, 2, \dots, n ; \quad [5]$$

$$d_{wj} = \sqrt{\sum_{i=1}^{m} (t_{ij} - t_{iw})^2}, \text{with } j = 1, 2, \dots, n. \quad [6]$$

Step 6. Similarity to the worst condition calculation

Conclusively, in the last step, in order to rank the alternatives under evaluations, the similarity with the worst condition is calculated.

$$s_{wj} = \frac{d_{wj}}{(d_{wj} + d_{bj})}, \qquad 0 \leq s_{wj} \leq 1, \qquad \text{with } i = 1, 2, \dots, m \quad [7]$$

Where s_{wj} =1 corresponds to the ideal solution while $s_{wj} = 0$ corresponds to the worst solution.

5.3.3 The IPA matrix

The results of both Step 1.1 and 2.1 render a score for both the CV and the PV. Such scores, however, are independent one from the other. In order to facilitate the design team in visualizing the value of each concept and to find a tradeoff between the customer and the provider, these scores are positioned on a 2-dimensional map (steps 1.2 and 2.2). This is adapted from the IPA method (Martilla and James 1977) that was originally developed to support the synchronous analysis of services considering the importance of the solution for the customer and the performance of the provider with respect to them. Instead, the proposed IPA features an “importance” axis that displays the CV results and a “performance” axis that displays the expected PV. (Figure 19).

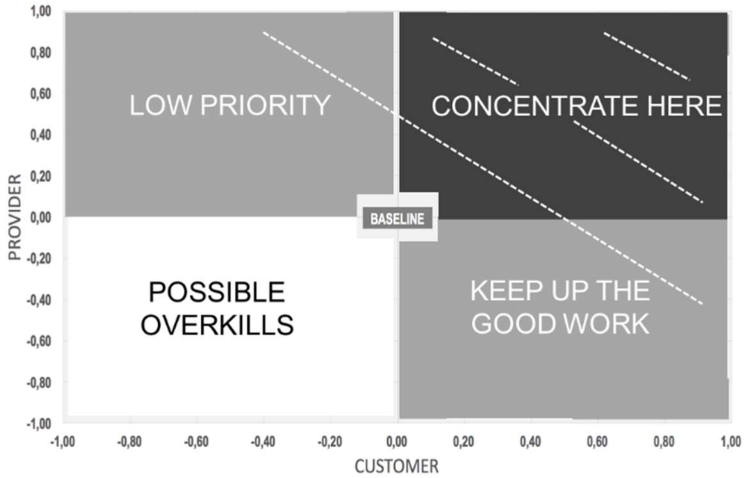


Figure 19 IPA matrix structure

Given point (0,0), which represents the baseline, the map can be divided into four quadrants:

I. PSS concepts in Quadrant I (QI – Concentrate here) boast high value. In general, they could be moved to the second step assessment.

II. PSS concepts in Quadrant II (QII – Low priority) generate additional value only for the provider. Improvements could be advised considering the criteria where the concepts scored "-" in step 1. In Step 2, concepts in this quadrant should be discarded.

III. PSS concepts in Quadrant III (QIII – Possible Overkills) have a lower value for both the actors analyzed. As a consequence, it is suggested to kill their development already in Step 1.

IV. PSS concepts in Quadrant IV (QIV – Keep up the good work) have high value only for the customer. In Step 1 (as for QII), these concepts are worth additional analysis and can be further modified to be increased later.

The main purpose of the proposed IPA method in Step 1 is to facilitate the communication and the knowledge sharing inside the design team about possible refinement of the concepts. In Step 2 its role is fundamentally different, that is to support the design team in terminating the process by selecting one (or few) PSS concepts for the detailed design stage, ideally, the one(s) that gets closer to the top-right corner of Figure 19.

The overall method is aimed at supporting the design team from the very beginning of the ideation phase, through the refinement, until the selection of a PSS concept to be designed in detail. Considering the difference in scope of the two steps, however, they could be adopted independently for the analysis and/or the prioritization of alternatives. In figure 20, a flowchart meant to support companies in adopting the EVA method by selecting the most suitable step to follow considering the kind of information already available at the PSS concepts stage.

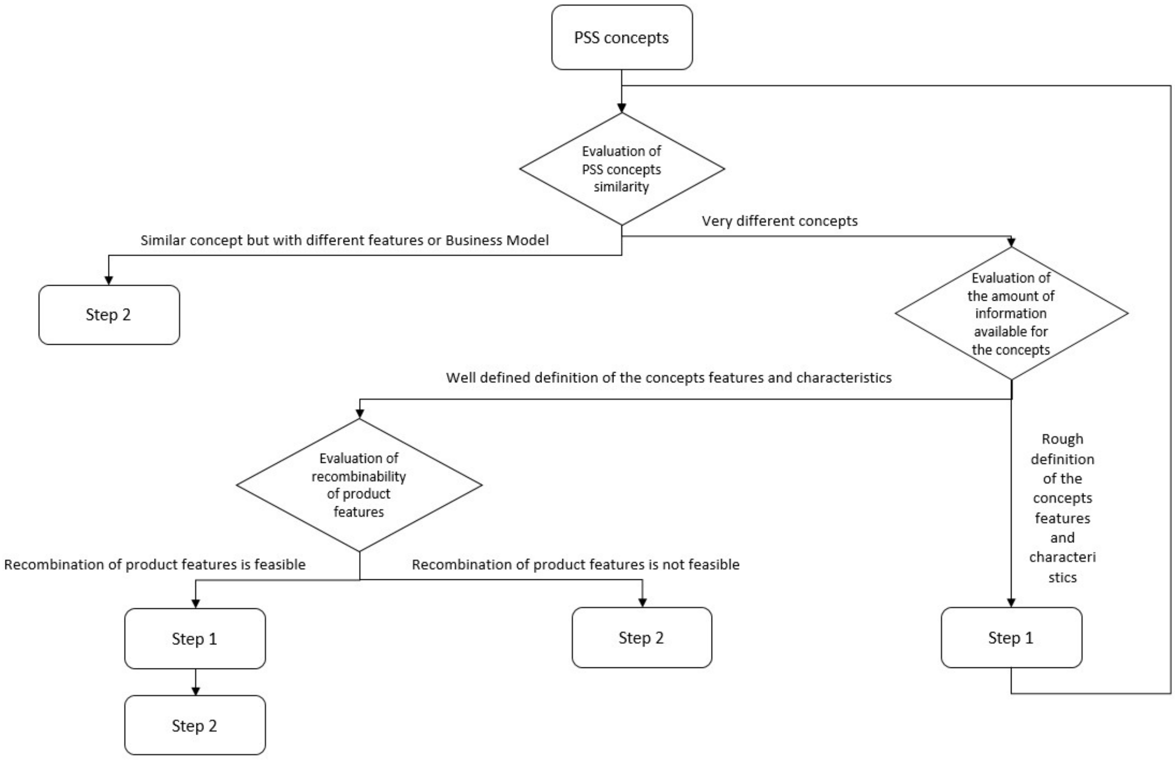


Figure 20 EVA method guidance flowchart

5.3.4 The evaluation criteria

As it could be observed from the description of the EVA method and described in the previous paragraph, both the two steps are based on multiple criteria decision-making methods. Hence it is of utmost importance to provide a complete set of exhaustive and holistic criteria to be used. The EVA method also includes a list of criteria according to which the PSS concepts should be evaluated. A criterion is defined as "A principle or standard by which something may be judged or decided" (Oxford Dictionaries. 2018). Regarding the EVA steps, Step 1 enables the first screening of the PSS concepts and requires high level criteria that allow grasping the value of PSS concepts from a high level. On the other hand, step 2 would require a more detailed set of criteria that enable the analysis and assessment of PSS considering a wider list of value facets. Please notice that the word "indicator" is used as a synonym of criteria in the following sections.

In the light of what emerged from the literature analysis, it was decided to use the *value categories* as the general criteria to be used in Step 1 whereas a more detailed list of *criteria* belonging to the category was identified to be used in Step 2. Figure 21 schematize the adoption of value categories and detailed criteria with respect to the EVA method.

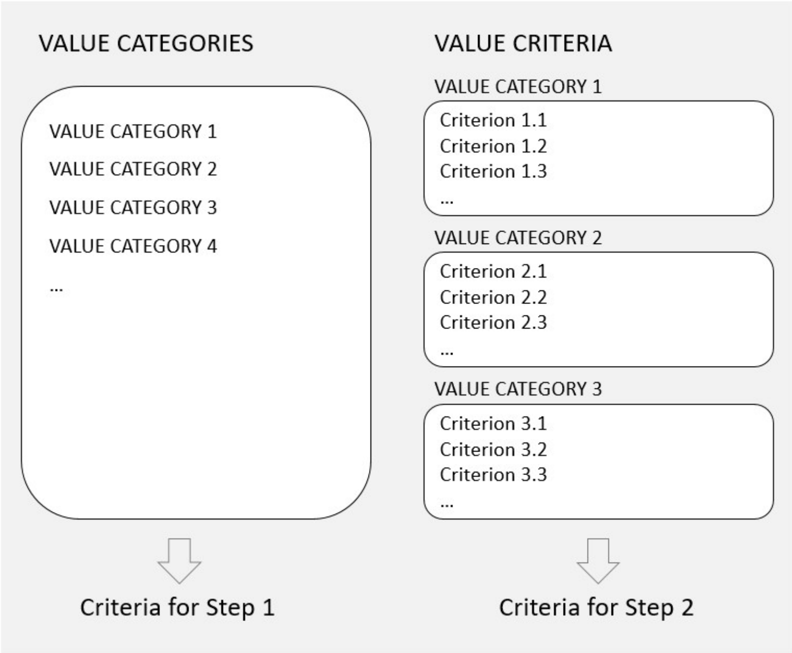


Figure 21 Evaluation categories and criteria schema

According to the schema presented in Figure 21, the EVA method adopts value categories as a general criterion for the evaluation, whereas it further split them into more detailed criteria whenever a higher level of detail is required. The value categories are meant to be used with the Pugh method in Step 1 of the EVA method (Figure 22). They are summarized in Table 18 and Table 19 under the " value categories" column. Then, a more detailed list of indicators to be used in connection with the TOPSIS method in the second step of the EVA method is composed of the specific criteria belonging to each value category. Indeed, the indicators proposed represent are cascaded down from the value categories proposed for the first step. They are included in Table 18 and Table 19 and are summarized in the "Value criteria" column. As it could be observed from the tables, they belong to the more general category that it is used in the first step.

In line with the double-sided EVA method two lists of value categories are available (one for the customer and one for the provider) and two for value criteria (one for the customer and one for the provider). They are summarized in Table 18 and Table 19.

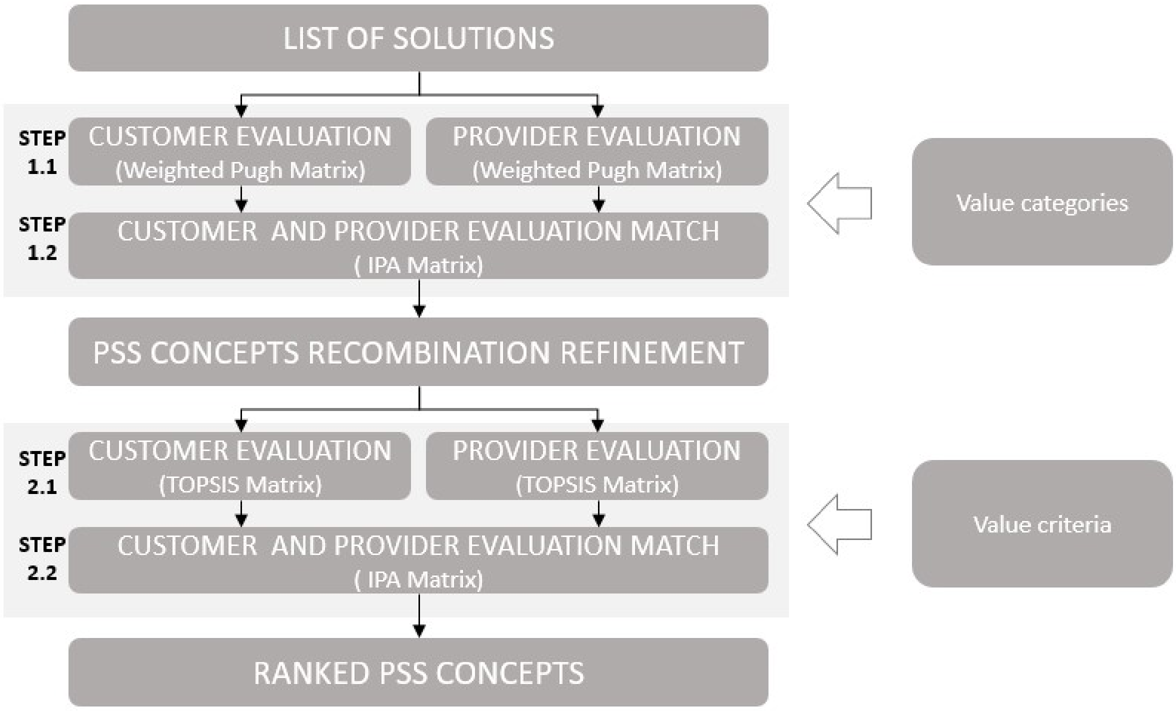


Figure 22 EVA method and the evaluation criteria

Hereafter, a detailed description of the main phases followed to reach the final list of value category and criteria summarized in Table 18 and Table 19 is reported.

5.3.4.1 Criteria identification

The first analysis of the literature on the PSS value criteria shows that literature does not propose any holistic and complete set of evaluation criteria. In order to identify them, the initial list of criteria identified was used as a starting point. It was firstly analysed considering the industrial viewpoint collected through interviews. The interviews were aimed at collecting the extant indicators that are (un)consciously considered while making decisions about new PSS.

From the provider perspective the most important criteria taken into account is the "profit" associated with the new solution. The technical feasibility and the readiness for the company in developing and in producing the new solution is also one relevant indicator that emerged during the participant observation held in ABB together with the relevance of the company image. It particularly refers to the analysis and the alignment of the PSS in relation to existing offer and to the image that the company has with its products. For what concern the provider perspective, the key factors influencing decisions are:

- The market and the volumes that could be exploited through the service. This is the key point highlighted by all the participants

- The investment and R&D expenditure in some cases are leading the decisions. It was mentioned that *"If the expenditure is high, and we don't have the budget to do it we can't implement the solution"*
- The relevance of the service in the contingent scenario is critical, for example with respect to competitors or emerging technologies. One manager states that *"In some cases a solution is selected because it is aligned with the overall company business in a specific period. Currently, all the solutions involving digital technologies and monitoring are really welcome whereas more basic solutions are not well appreciated from a global level".* Another one stresses the relevance of the other brands "*If some of our competitors are offering specific solutions, for sure we have more incentives to move in the same direction".*
- Customer requirements with respect to a solution also play a relevant role. The sales responsible for a company pointed out that "*Usually we also consider what would be the customer perception of the new solution. Of course, we are not interested in solutions that customers do not want.*"

The investment and the costs for the implementation of the new solution are also relevant criteria that ABB considers while taking decisions. Other indicators emerged from literature such as environmental sustainability, the positioning with respect to other value chain actors are not currently given prominent importance.

Regarding the customer evaluation criteria, the participant observation in ABB highlight that in the low voltage unit the analysis of customer perspective is not very common. However, during specific interviews, a list of the important factor that, according to the people interviewed, are considered by the customers while selecting a solution was collected. Here is a detailed list:

- *"Customers are always focused on the proper functioning of their assets".* According to all the interviewees, this is the key value that a company can bring to customers.
- The price of the solutions is also one of the most critical aspects to be evaluated by the customers. The following comment summarizes the relevance: "*Nowadays customers are really sensitive to prices. Even if we are leader in our market they are not willing to pay a price premium for the brand."*
- The quality of the solutions that customers are buying, of course, strongly influence customers' decisions. This is testified by the participants "*Customers take care about the quality of the goods and the services provided.*"
- The relationship established between customers and providers was also mentioned as an essential condition to conclude positively the deal with the customer. In this regard, provider

reliability is key topic.

Based on the analysis of relevant factors obtained through interviews and considering the results of the literature (Section 5.2.2) it is possible to state that there exist an extensive set of heterogeneous metrics (or factors) focusing on different goals. In order to pursue a coherent and comprehensive set of evaluation criteria to support the EVA method, three main phases were developed:

1. Structured analysis of the literature categories and drivers through system thinking
2. Validation of the identified categories and drivers through interviews in industry

5.3.4.2 Criteria analysis through system thinking

Given the relevant amount of criteria identified in literature and their high heterogeneity, the robustness of the proposed set of criteria has been analyzed through a focus group of researchers and academics.

During the meeting, people were asked to analyze all the mapped value categories and criteria and to provide any feedback/suggestion about them. Here are the main criticalities emerged concerning the value categories:

- Inside the "uncategorized" list of criteria, many of them are concerned with the evaluation of environmental impact and sustainability are included suggesting that the categories analyzed were not comprehensive of such value dimension.
- Some of the categories proposed are associated to a variety of criteria (e.g. "system convenience") According to the expert this could indicate that this category is very general and thus that it has to be further split into more categories.

For what concerns the specific criteria (to be adopted in step 2) here are the weaknesses emerged:

- The indicators proposed inside each category are characterized by a different level of detail creating a strong discrepancy in the final set. E.g., "ROI" and "shorten sales delay".
- Some of the criteria identified are linked by a direct cause-effect relationship. For e.g. "ROI" and "profit". They cannot be included in the same group of criteria since they can generate a double effect in the final value assessment.
- The criteria collected among the "benefit" family are somehow very specific E.g. "optimize transportation network" whereas the criteria suggested for the "cost" family are very general E.g. "fixed costs".
- It is also noticeable that a plethora of benefits has been mentioned but that the cost in which the customer and/or provider has to incur to obtain such benefit is not mentioned at all.

In order to extract a common level of detail and to avoid the pitfalls just described, the list of evaluation criteria extracted from literature analysis (Section 5.2.2) was mapped. The main concept of system thinking was used a as a reference in order to represent and "*communicate dynamic complexities and interdependencies*" (Anderson and Lauren 1997). The maps were adopted to characterize the so-called "big picture" of the system.

Considering the value categories and criteria identified, four different maps were created: two for customers (benefits and costs) and two for the provider (benefits and costs). On each map, the criteria were placed in the map based on their similarity and on the topic to which they were referring.

According to this first classification and analysis, quite clear categories emerged in all the four maps. As emerged during the focus group, the two maps of the benefits were populated by more criteria and propose a more extensive analysis of PSS solutions with respect to the costs maps. Cost criteria indeed are very similar to each other and refer to categories of costs that are common and well known (e.g. resources consumption, process, resources skills and disassembly costs). On the other hand, the identified benefit criteria refer to different fields and bring up many possible advantages that can be associated to a PSS (e.g. safety, competitiveness on the market, empathy, knowledge sharing…)

On this first "big picture", the synonyms and the similar criteria collected from literature were merged together.

Moreover, the relationships among the indicators were analyzed. Whenever a dependency relationship was detected, one single criterion was selected to avoid the double effect. For example, the following list of criteria was identified from literature:

- Improve retention of existing customers
- Improve customer loyalty
- Improve customer involvement and commitment
- Customer relationship stability
- Customer dependency

All these five criteria were collected in one single category "Improve retention of existing customers" since all the others were considered as part of this criteria.

Particular mention is worth for the criteria "Profit Increase" and "Revenue increase" that in the final list of evaluation criteria are not mentioned. The increase in revenues indeed is an effect of two other indicators "new customer acquisition" and, eventually, of "generation of a new market". Analogue evaluation was defined as "Profit increase" being it a result of cost reduction that could be associated with the change in "efficiency of asset/employee" and to "natural resources consumption".

For what concern nomenclature and taxonomy all the criteria names were homogenized and all the adjectives such as "increase" and "reduce" were deleted.

Regarding the two maps referring to costs, it can be noticed that the definition of cost categories and specific criteria was critical since, as mentioned in the previous paragraph, cost indicators are scarce in literature. In order to identify a robust and well established structured of value categories existing researches were used. Concerning the provider categories, the value delivery stages proposed by (Brax and Visintin 2017) were adopted. The main cost categories are: production, design, implementation, operations, support and disposal. For what concern the identification of the categories for the customer, the study proposed by (Roda and Garetti 2015) was adopted as main reference. The study focuses on the total cost of ownership and proposes multiple stages that were adopted for the customer categories classification.

Finally, the benefit and the cost maps were merged together to verify that for each benefit an associated cost exists. The main rationale for considering both aspects of early design PSS assessment is that decision makers need to realize that any design decision always affects multiple value types at the same time.

The next figures display the two maps of the value criteria and value drivers one for the customer (Figure 23) and one for the provider (Figure 24). As it is possible to observe, each map shows the list of the criteria identified throughout the analysis. The criteria are further split into benefits (black ink) and costs (coloured ink). Both of them are then grouped into categories: the dotted squares represent the value categories classified as benefits whereas the value categories representing the costs are distinguished by a different colour.

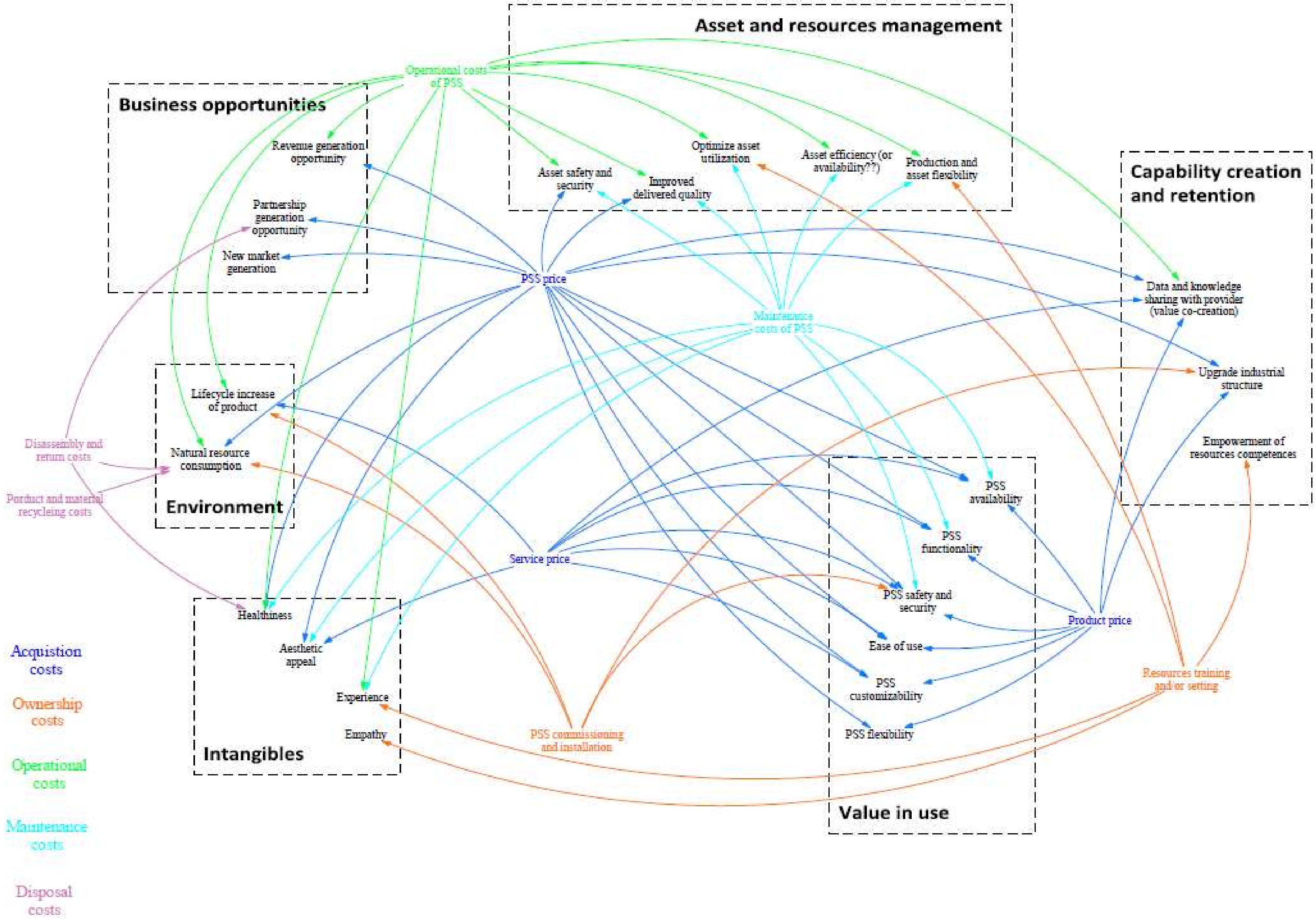


Figure 23 Analysis of customer value categories and criteria

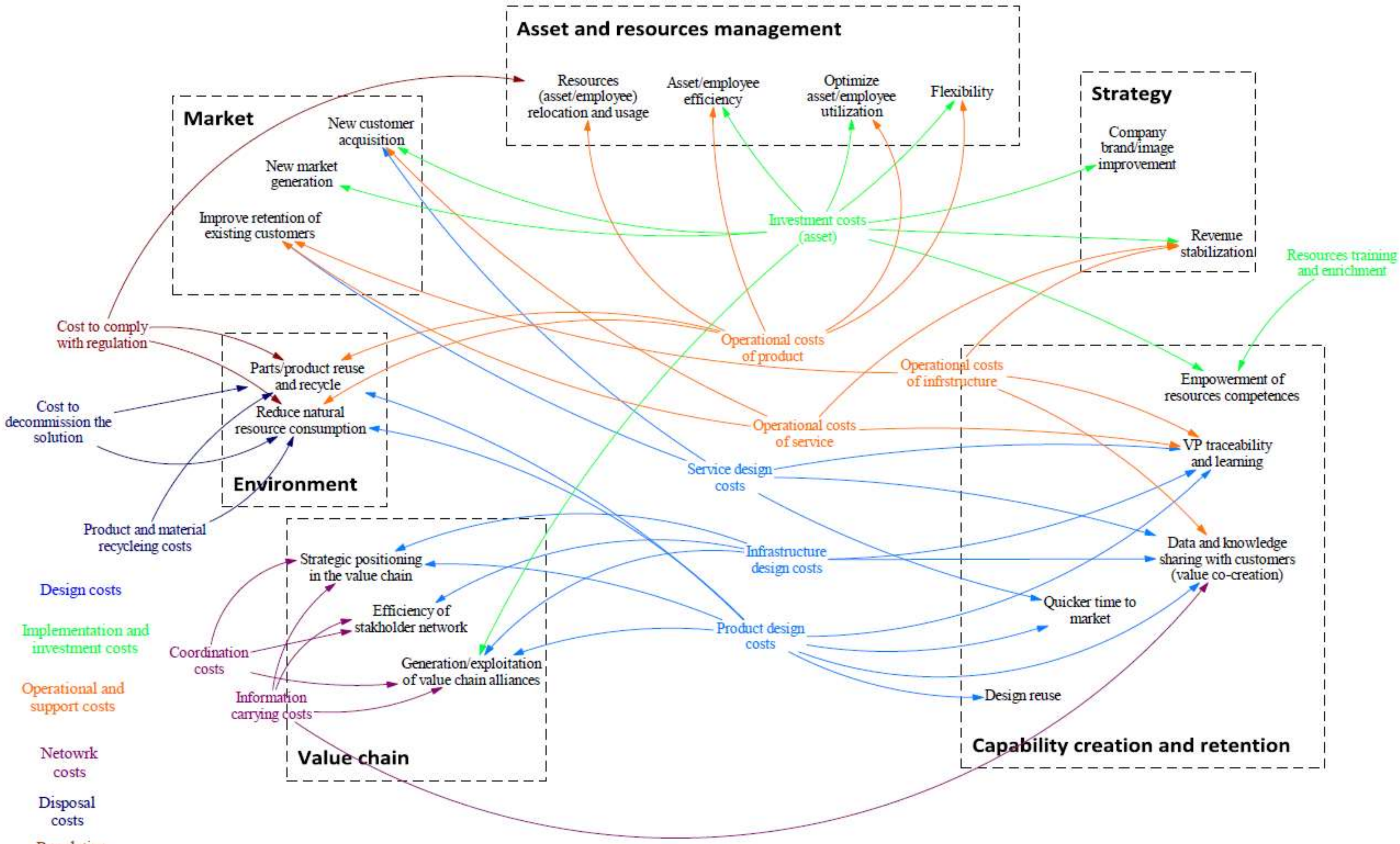


Figure 24 Analysis of provider value categories and criteria

5.3.4.3 Criteria validation

Once the final sets of criteria were defined through the system mapping additional interviews with industrial people were held to validate the final list of criteria.

After an introduction to the EVA method, participants were then asked to review the identified list of criteria and to comment on it. Six different people in ABB were involved in this validation phase. During the interviews, some key aspects of decision making in early stage of design were highlighted. Hereafter a summary of the discussion is reported.

In relation to the specific list of evaluation criteria for the provider perspective, emerged from the system thinking maps, the interviews suggest the following improvements. ABB service manager pointed out on the aspect that has been neglected in the definition of value categories and criteria: "innovation". Indeed, at the moment of decision, the company usually consider the *innovation* level of a solution. The higher is the innovativeness the higher is the appealing of it. Based on this, the criterion was added to the list. In the same direction, two people pointed out that it could be useful to include in the analysis the *company readiness* to implement a solution. This is directly related to the investment required for the company. Therefore, this was not included in the final list.

Additional comments were related to "Cost to comply with regulation" that according to the companies interviewed are cost already included in the design costs of a solution. This could be easily considered into the EVA method assigning a weight of zero to the criterion that is not considered in the analysis, therefore, it was decided not to delete this category. The same works for the detailed criteria "Service design costs" and "product design costs" that, according to practitioners, are somehow complex to distinguish.

Furthermore, it emerged that the company brand image is important to be discussed. Since this is not reported in the general value categories (those adopted in step 1) it has been decided to modify the name of the category to "Brand and strategy".

In the detailed criteria, under the strategy category, it was highlighted that strategy alignment is not included but this is relevant. This criterion was added to the list.

For what concern the list proposed for the evaluation of customer value, it emerged that the category "value in use" and "asset and resources management" are somehow overlapping because the value is used in many cases is also the value that the solution has on the overall asset management. Categories "Operational costs" and "maintenance and repair costs" could also be merged. As previously, in case one category has not required a weight equal to zero can be assigned.

An additional detailed criterion that was mentioned is the “time to market” of the customer. This was added to the list. In tables 18 and 19 the final list of value categories and criteria are reported.

Table 18 Provider value categories and criteria for value evaluation

		Value Categories		Value Criteria
BENEFITS	B1	Strategy *& Brand image*	1	Company brand/image
			2	Revenue stabilization
			3	*Alignment with strategy*
	B2	Capability creation and retention	3	Empowerment of resources competences
			4	VP traceability and learning
			5	Data and knowledge sharing with customer (value co-creation)
			6	Time to market
			7	Design reuse
	B3	Asset and resources management	8	Resources (asset/employee) relocation and usage
			9	Asset/employee efficiency
			10	Resources (asset/employee) Flexibility
			11	(Optimization) Asset/employee utilization
	B4	Market	12	New customer acquisition
			13	New market generation
			14	Improve retention of existing customers
	B5	Environment	15	Natural resources consumption
			16	Parts /products reuse and recycle
	B6	Value chain	17	Generation/exploitation of value chain alliances
			18	Strategic positioning in the value chain
			19	Efficiency of stakeholders network
	B7	*Innovation*	*20*	*Innovation*
COSTS	C1	Design costs	1	Service design costs
			2	Product design costs
			3	Infrastructure design costs
	C2	Implementation costs /investment	4	Implementation costs
			5	Resources training and enrichment
	C3	Operational and support costs	6	Operational costs of service
			7	Operational costs of product
			8	Operational costs of infrastructure
	C4	Disposal costs	9	Products and material recycling costs
			10	Cost to decommission the solution
	C5	Costs to comply with regulation	11	Costs to comply with regulation
	C6	Network costs	12	coordination costs
			13	information carrying costs

Table 19 Customer value categories and criteria for value evaluation

		Value Categories		Value criteria
BENEFITS	B1	Capability creation and retention	1	Data and knowledge sharing with provider (value co-creation)
			2	Upgrade industrial structure
			3	Empowerment of resources competences
			4	*Time to market*
	B2	Asset and resources management	4	Asset safety and security
			5	Improved delivered quality
			6	(Optimization) Asset utilization
			7	Asset efficiency
			8	Asset Flexibility
	B3	Business opportunity	9	Revenue generation opportunity
			10	Partnership generation opportunity
			11	New market generation
	B4	Environment	12	Lifecycle increase of product
			13	Natural resources consumption
	B5	Intangibles	14	Healthiness
			15	Aesthetic appeal
			16	Experience
			17	Empathy
	B6	Value in use	18	PSS availability
			19	PSS functionality
			20	PSS safety and security
			21	Ease of use
			22	PSs customizability
			23	PSS flexibility
COSTS	C1	Acquisition costs	1	Service Price
			2	Product price
			3	PSS price
	C2	Ownership costs	4	PSS commissioning and installation
			5	Resources training and/or setting
	C3	Operational costs	6	Operational costs of PSS
	C4	Maintenance and repair costs	7	Maintenance and repair costs of PSS
	C5	Disposal costs	8	Disassembly and return costs
			9	Products and material recycling costs

6 Validation of the EVA Method

This chapter represents the second main contribution to the research concerning the first research question. It summarizes the validation activities carried out in relation to the EVA method. First, an overview of the analysed cases and the procedure to apply the method is provided in section 6.1, then the four specific cases are presented in the following sections.

6.1 Validation cases

The cases were selected considering the industry, the type of PSS (spanning from pure product to PSS until pure service solutions) and the number of stakeholders involved as shown in figure 25.

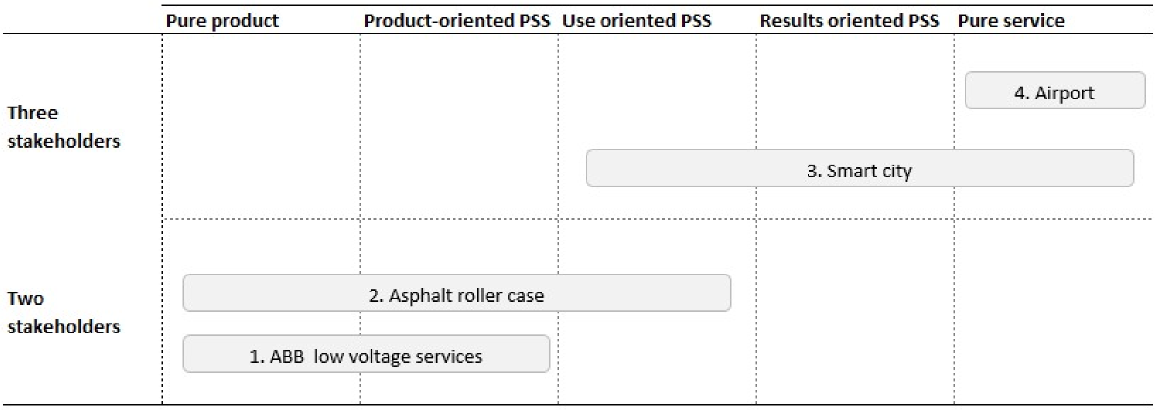


Figure 25 Positioning of the cases selected for validation.

In the first validation case, the solutions considered are mainly product oriented PSS or pure product advancements, summarizing the current offer of ABB low voltage unit (section 6.2). The second validation case shows the application of the method in the construction industry. Two possible sets of early design concepts are shown; they refer to the improvements of an asphalt roller. One set of concepts collects product concepts whereas the second refers to possible PSS solutions (or business model) associated to the asphalt roller such as use-oriented or result-oriented. The case is described in section 6.3. Then, in order to verify the applicability of the EVA method in in more complex contexts, two validation cases are set up including a third stakeholder interested in the PSS selection. The first case refers to the analysis of pure PSS solutions in the smart city context. A bunch of solutions for the improvement of the lifestyle and the wellbeing in the city of Bergamo are evaluated through the EVA method. Instead of just considering two stakeholders (i.e. provider and customer), the peculiarity of this case is the inclusion of a third actor during the examination of the solutions: the smart city stakeholders. More details are reported in section 6.4. Finally, a case in a pure service environment is described in section 6.5. In this last case, the solutions identified are “pure” services to be implemented at the airport. Also in this case, three different stakeholders were consulted in the analysis.

All the validation cases followed a common procedure during the EVA adoption. The cases were developed through workshops where people from different company functions were involved. At least four people were usually involved. In all the cases, apart from the one about the Bergamo smart city, it was not possible to directly involve customers into the workshop. Therefore at least one person from the sales department and/or in direct connection with the final user of the solution was required. One researcher from the university, well acquainted with the EVA method and the evaluation criteria lead the workshop.

The first step of the workshop was the collection of the PSS concepts to be analysed. People involved in the case were asked to identify and describe the concepts to be evaluated during the workshop. During this phase, all the ideas and all the possible improvements to the current offer were taken into account. The initial description of the concepts enables the definition of steps to be pursued according to the flowchart shown in Figure 20. In three out of four cases analysed, the people were prone to identify new solutions and/or features therefore both the two steps of the EVA were applied. In the last case, the PSS solutions for the self-check-in at the airport were well defined and only the second step was followed for the final prioritization of concepts.

Apart from the abovementioned difference, all the validation cases followed a similar sequence of activities summarized in Figure 26.

For each, first, the people involved in the workshop were asked to define a set of PSS concepts to be evaluated. An initial clarification of their features was also discussed among the team members to have a common understanding of them.

Then the first step toward the adoption of the EVA was the assignments of the criteria weights. Since it is quite complex to assign weights, the people were required to set an importance level of the criteria from 1 to 10. The percentage, i.e. the weight was then calculated considering the sum of the scores and the relevance of each criterion.

The second phase of the EVA application was the assignment of scores. The people involved were required to define a score for each concept with respect to a specific criterion according to the Pugh method. Hence they were required to compare each concept with respect to the baseline concepts concerning each criterion. Usually the people involved discussed among each other regarding concepts features before providing the final score. Seldom the participants have divergent opinions about the concept, but after discussion, they agree on the final score. The scores about the concepts were included in an excel file, prepared in advance by the university researcher, that directly apply the Pugh method algorithm and shows the analysis of the evaluation into the IPA map. The definition of weights and scores was also performed from the customer perspective or from the perspective of additional stakeholders. The predefined excel file directly included all the evaluations into the IPA map.

After the scores assignments, the results in the IPA were shown to the participants in order to verify if the results were coherent with their judgment and with their opinion (Figure 26). It happened that some concepts were positioned in strange areas of the map and for this reasons the scores assigned were reviewed.

At the end of the first step, improvements and recombination possibilities were discussed into the team. The university researcher usually leads the discussion suggesting possible hints of change. At the end of the discussion new and improved PSS solutions were identified. They were used as input for the second step.

The second step, based on TOPSIS was applied following the same steps presented before but considering the TOPSIS algorithm reported in section 5.3.2.

Hereafter is a detailed description of the validation cases.

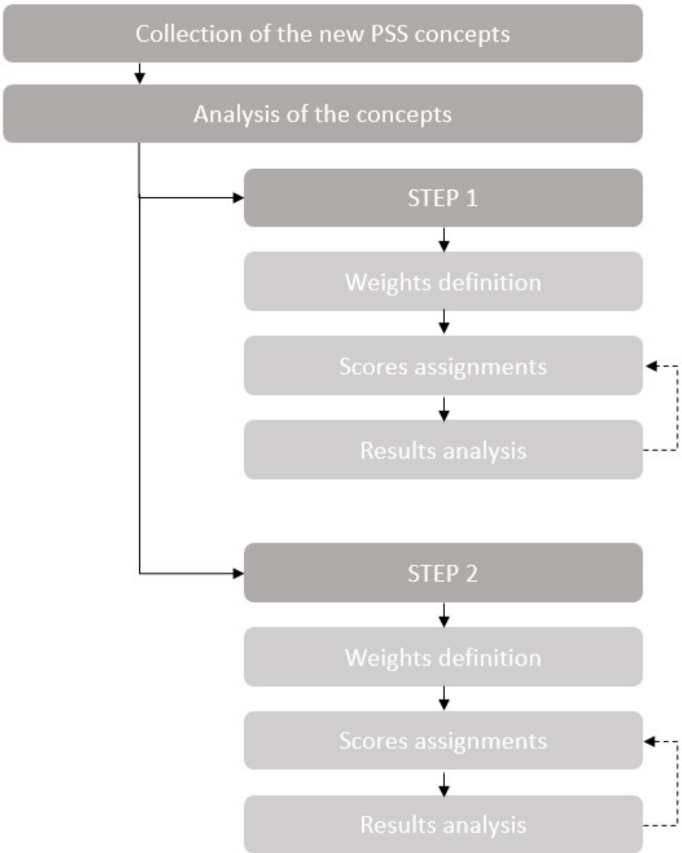


Figure 26 Process followed during validation cases

6.2 Validation in an industrial context: the ABB case

The first practical verification of the EVA method was carried out in collaboration with ABB, in particular with the low voltage products unit. At the moment of the study, the PSS portfolio of such unit was well developed, and the EVA method was adopted for the assessment of the existing offer to verify its relevancy and to identify a possible area of improvements or change. From a theoretical perspective, the application to existing solutions could be beneficial since the comparison between the actual offer positioning and the results obtained could display similarities and discrepancies.

During the test case analysis, five different PSS offers were analyzed:

- *Concept 1 - A modular service contract agreement.* This solution offers many types of services and the customer based on his actual needs could decide what could be the pattern of services that better suit his situation.
- *Concept 2- Extended Warranty.* It refers to the provision of extended warranty on new or replaced products. This could allow the customer to avoid unexpected cost in the first year of the product lifecycle.
- *Concept 3 - The installation and commissioning service*.

- *Concept 4 - Predictive maintenance.* A new digital service providing information to the customer via the cloud and proposing predictive maintenance on products.
- *Concept 5- Maintenance.* Traditional preventive and corrective maintenance delivered by high skilled technicians.

The case was conducted as a workshop with five different people responsible for the development of new services in the specific unit of the company: global service manager, service sale manager, two services "product" manager and service operations manager. One researcher well acquainted with the method and the evaluation criteria lead the workshop.

First, the expert provided a general description of the method and the steps. Then, the overall list of drivers was described and contextualized to create a shared understanding among the participants. Following, the team was asked to contextualize the method metrics to capture value generation for both the provider and the customers, as well as to define the rank weights for such dimensions. Tables 20 and 21 reports the Pugh matrix developed for the provider value assessment. All the other tables including those used for the provider evaluations are reported in the appendix. The "retrofit" service was selected as a reference concept for the analysis. It consists in the replacement of an old product with the newest product with a specific kit that enables quick installation without structural modifications of the plant.

Table 20 Pugh Matrix for the ABB case (provider)

Provider	WEIGHT	Modular Service contract	Extended warranty	Installation and commissioning	Predictive maintenance	Maintenance	Baseline - Retrofit
Strategy brand & image	14%	1	1	0	1	0	0
Capability creation and retention	10%	1	-1	1	1	0	0
Asset and resources management	5%	1	-1	0	1	0	0
Market	17%	-1	-1	-1	0	-1	0
Environment	2%	0	0	0	1	0	0
Value chain	12%	1	1	0	1	0	0
Innovation	10%	1	-1	-1	1	0	0
Design costs	5%	1	1	1	-1	1	0
Implementation costs /investment	9%	-1	1	1	0	1	0
Operational and support costs	12%	-1	0	-1	-1	-1	0
Disposal costs	0%						0
Costs to comply with regulation	0%						0
Network costs	3%	-1	0	0	-1	0	0
	100%	**2**	**0**	**0**	**3**	**0**	**0**

Table 21 Weighted Pugh matrix for the ABB case (provider)

Customer	WEIGHT	Modular Service contract	Extended warranty	Installation and commissioning	Predictive maintenance	Maintenance	Baseline - Retrofit
Strategy brand & image	14%	0.14	0.14	0.00	0.14	0.00	0.00
Capability creation and retention	10%	0.10	-0.10	0.10	0.10	0.00	0.00
Asset and resources management	5%	0.05	-0.05	0.00	0.05	0.00	0.00
Market	17%	-0.17	-0.17	-0.17	0.00	-0.17	0.00
Environment	2%	0.00	0.00	0.00	0.02	0.00	0.00
Value chain	12%	0.12	0.12	0.00	0.12	0.00	0.00
Innovation	10%	0.10	-0.10	-0.10	0.10	0.00	0.00
Design costs	5%	0.05	0.05	0.05	-0.05	0.05	0.00
Implementation costs /investment	9%	-0.09	0.09	0.09	0.00	0.09	0.00
Operational and support costs	12%	-0.12	0.00	-0.12	-0.12	-0.12	0.00
Disposal costs	0%	0.00	0.00	0.00	0.00	0.00	0.00
Costs to comply with regulation	0%	0.00	0.00	0.00	0.00	0.00	0.00
Network costs	3%	-0.03	0.00	0.00	-0.03	0.00	0.00
	100%	**0.05**	**0.07**	**-0.05**	**0.22**	**-0.16**	**0.00**

Figure 27 shows the results of the first step of the EVA method through the IPA map.

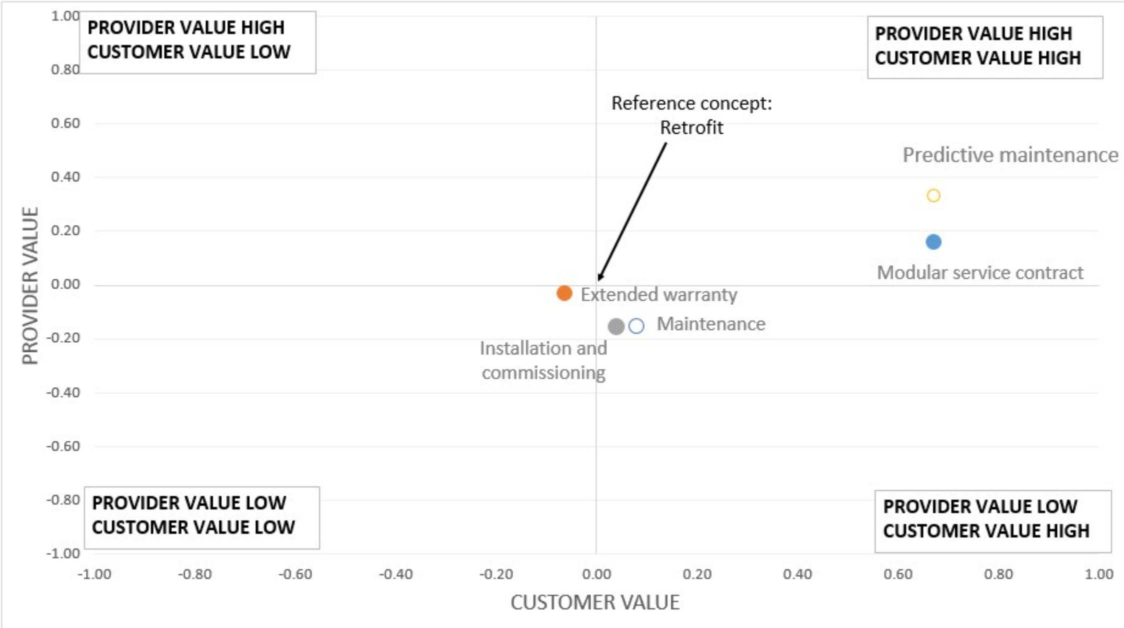


Figure 27 IPA matrix for the first step assessment

Since the "retrofit" service is quite relevant for the current business, from a provider perspective, few of the concepts analyzed could boast more relevance than the reference concept positioned in the origin of the axes. "Predictive maintenance" and "modular service contract" are in the "concentrate here" area given their high innovativeness and the strong commitment of the company to them.

Concerning the customer side, again "Predictive maintenance" and "modular service contract" have high relevance. "Modular service contract" can be heavily customized whereas "Predictive maintenance is an innovative service that attracts customers.

"Maintenance" and "Installation and commissioning" could be defined as "order qualifiers" in this kind of market and this can explain their positioning in the IPA matrix: customers appreciate them, but the value is quite limited.

The "extended warranty" concept shows limited value from both the two decision makers given the relatively low complexity and innovativeness. For this reason, this concept was not part of the analysis in the second step of the EVA method.

As EVA method structure, the most relevant concepts were analyzed in the second step considering more detailed value drivers. After the score assignments, the TOPSIS method was used to calculate the ranking of the solutions from both provider and customer perspectives. Results of step 2.2 are collected in Figure 28.

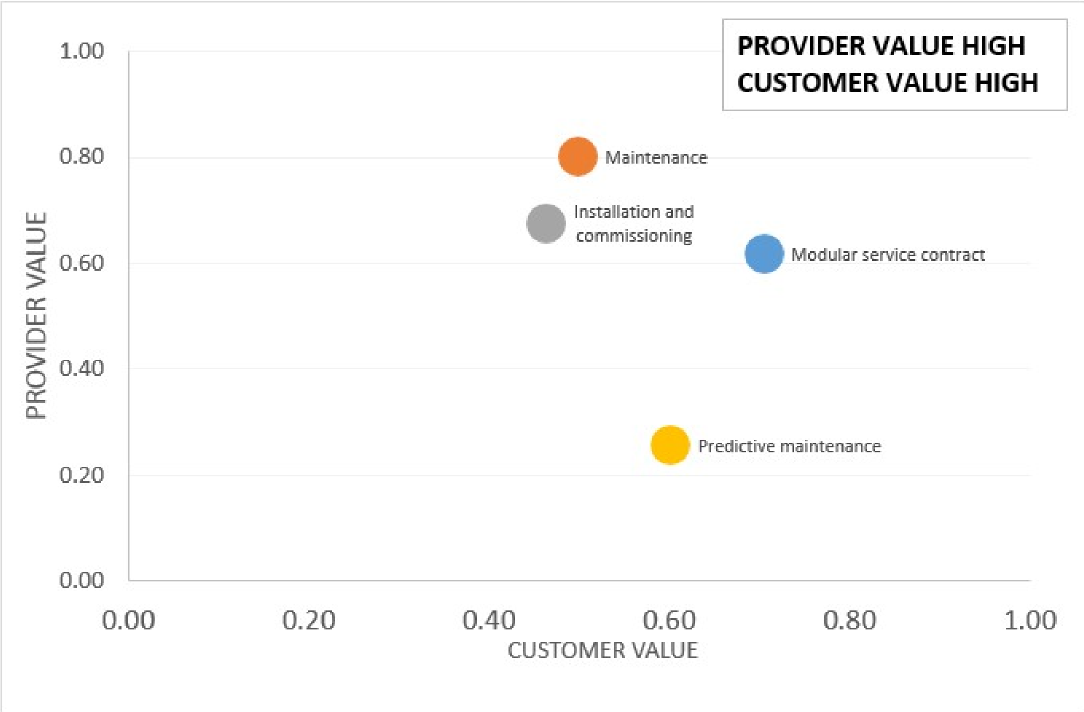


Figure 28 IPA matrix for the second step assessment

As it could be observed from the matrix, “maintenance” and “installation and commissioning” are very similar to each other. The relatively small advantage of maintenance is related to the possibility to monitor assets that, from the provider perspective, implies the additional business and long term relationship with the customer, while, from the customer side, means high reliability of assets. They are also valuable for the provider since they allow better utilization and optimization of resources.

The “predictive maintenance” service based on cloud is extremely innovative but it is costly for both the customer and the provider whereas the “modular service agreement” could represent the proper solution to deal with the customer that can select the solution most suitable to his needs.

In the light of improvements, the results obtained can support the identification of strengths and weaknesses of the solutions. The predictive maintenance solution, indeed, is not completely satisfactory for the customer (at least less than the modular service contract) due to the costs associated to the product add-ons required for the enabling of service. The reduction of this cost could push the solution toward the right-hand area of the matrix.

“Predictive maintenance” and “modular service agreement” are also not positioned optimally in the provider value scale. The analysis of detailed scoring evidences the high operational cost of the solutions. Making the support processes and operations more efficient and flexible could support the reduction of such cost pushing the solutions in the upper part of the map.

A first outcome of the EVA method validation case in ABB is the positive feedback collected from the study. The managers agreed that the IPA representation of the analyzed solutions actually depicts the current positioning of the products. Therefore, the results are meaningful and capture the actual value associated with the solutions.

6.3 Validation in an industrial context: The asphalt roller case

The second validation case of the EVA method was developed in relation to the design of an innovative solution for asphalt compaction. In this case, the test was conducted in the form of a student project. A group of five students from the Master Program in Mechanical Engineering was tasked with the development of solution concepts for the next generation asphalt compaction machines. The activity was executed in close collaboration with an asphalt equipment manufacturer that pushed the development, the selection and the prototyping of new products as well as PSS solutions.

At the end of the ideation phase, the team generated 13 solutions. They could be classified into 2 families by adopting the PSS categorization proposed by (A. Tukker 2004) : 6 concepts belong to the 'product' category (i.e., Pure product or Product oriented PSS), while 7 belong to the 'service' category (i.e., Use oriented PSS, Result oriented PSS and Pure service).

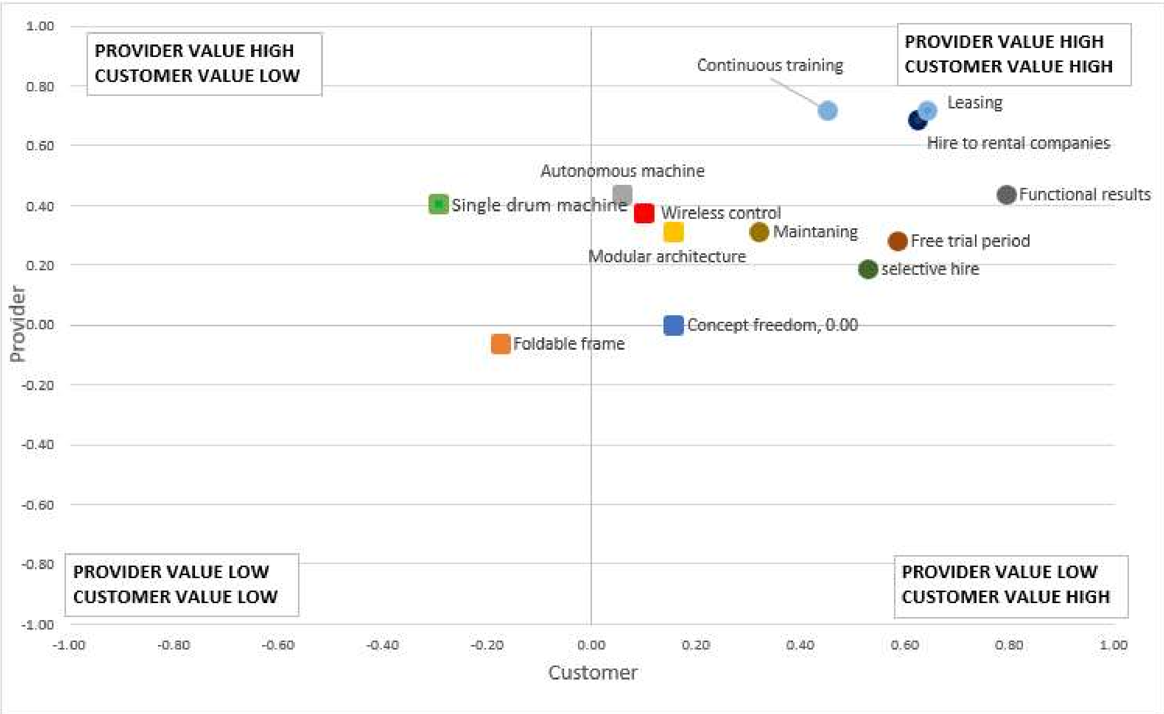


Figure 29 IPA matrix for the first step assessment

According to the EVA method structure, all the 13 solutions were evaluated through the Pugh Matrix considering the value categories identified, from both the customer and the provider perspective. Also in this second case, direct customers were not available for the discussion and the people belonging to the company were asked to provide input from customer perspective. The evaluation tables for both the customer and the provider are reported in the appendix. The reference concept adopted in

this validation case is the current offer of the company producing the asphalt roller, i.e. the traditional asphalt roller.
The results of step 1.1 are represented in Figure 29. Solutions classified as 'products' are represented by squared markers, while solution classified as 'service' is represented with circle markers. According to IPA map in the figure, the PSS solutions (circle markers) are, in general, more valuable than pure product concepts. This is mainly due to the long-term sustainability associated with the PSS concepts and business model such as renting or leasing. The representation, showing the differences between the pure product concepts and the PSS concepts was used as main reference by the team to identify opportunities for recombining the initial concept descriptions, mostly with the aim to merge product- and service-oriented ideas into a more coherent and exhaustive PSS description.
As a result, the 13 concepts were reduced to four PSS solutions to be further assessed in Step 2. These final concepts were evaluated based on a selection of the 2nd step set of value criteria through the TOPSIS method. Since no specific data was available, a 5 point Likert scale was set to include experts' judgments into the TOPSIS matrix.
The tables including the evaluations are summarizing reported in the appendix. The results of Step 2.2 that integrates the results obtained from customer and provider evaluations are displayed in Figure 30.

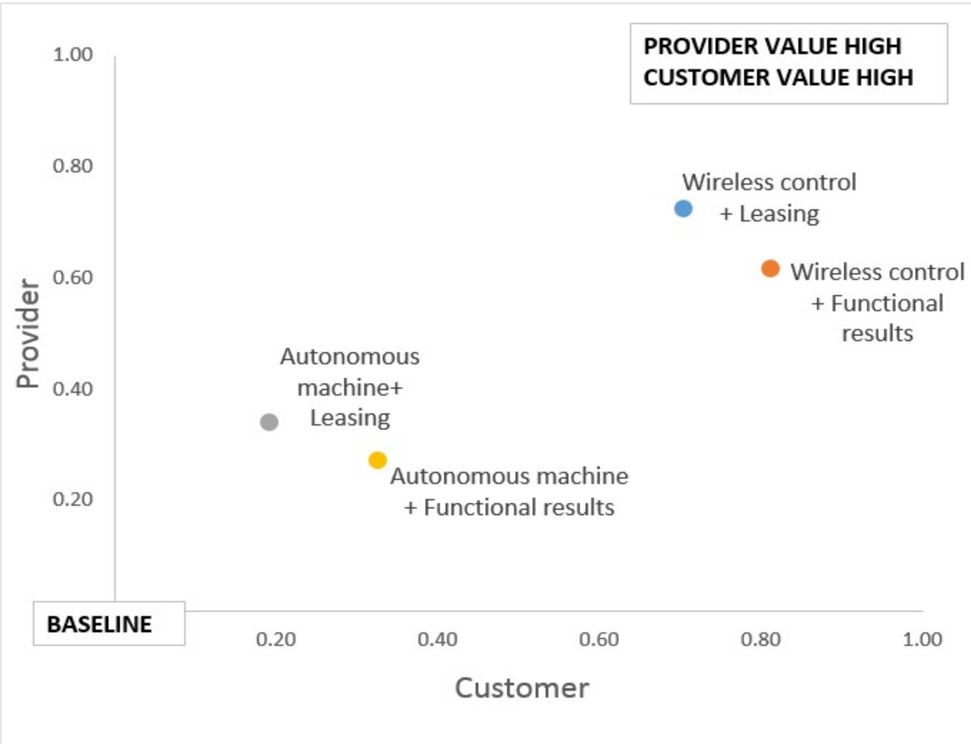


Figure 30 IPA matrix for the second step assessment

As a result, it emerges that the wireless design (meaning that the roller can be driven by a remote controller) is the solution that better satisfy customers and provider needs. For what concerns the business model associated with it, the company considers the pay-per structure (functional results) as preferred by the customers whereas the leasing is the preferred solution. The final choice is up to the provider that can decide if to prioritize the customers' preferences or the provider's one.

6.4 Validation in the smart city context: The case of Bergamo

In order to broaden the verification of the EVA method, an additional case was developed in the context of smart city and smart PSS. Many municipalities indeed are moving toward the identification of new solutions "able to optimize the use and exploitation of both tangible (e.g. transport infrastructures, energy distribution networks, natural resources) and intangible assets (e.g. human capital).

The practical validation in a pure PSS context was developed through the Bergamo 2.035 research program on smart cities. The project started in 2013, is led by the University of Bergamo in collaboration with the Municipality of Bergamo, Harvard GSD and a private investor, Italcementi Foundation. The main goal of this research project is to find solutions able to improve the urban community life in all the main pillars of the smart city indicated by the European community: i) *smart economy* (e.g. private-public cooperation, development of social incubators); ii) *smart mobility* (e.g. Intelligent Transport System to improve urban mobility, decreasing of environmental impacts); iii) *smart environment* (e.g. reducing pollutants emissions, promoting the use of renewable source, monitoring energy consumption); iv) s*mart people* (e.g. networking and communication, sharing data, security and protection of sources, initiatives to overcome digital divide); v) *smart living* (e.g. co-working spaces, living-lab, cultural initiatives, crowdsourcing co-design); and vi) *smart governance* (e.g. involving citizens on topics of public relevance, on-line document).

As a major outcome of the project, many ideas and solutions have been proposed (table 22), each characterized by different investments, advantages, complexity and scope. In this context, the EVA method was applied since a "one shot" implementation of all the solution was not economically feasible and municipality and stakeholders find difficult the comparison and the analysis of the solutions characterized by different degrees of feasibility and impact. Moreover, given the different level of technology and the involvement of stakeholders required by each solution, it was also difficult to understand which could be the less expensive solutions in terms of capital and efforts and which could be the easiest to implement.

The method, as in the previous validation cases, was applied in a workshop setting with experts in different domains from the University of Bergamo. During the focus group, three key perspectives were considered:

- Customers, i.e. Bergamo citizens
- Provider, i.e. the Bergamo municipality

- Stakeholders, i.e. all the people influenced by the smart PSS solutions. It is worth highlighting that the stakeholders considered were the shop owners, the only ones with interest in all the proposed solutions.

Table 22 Summary of the Smart city PSS solutions identified for the Bergamo smart city project

Smart City Pillars	Solutions proposed	Description
Smart Mobility	01. Smart parking management	Possibility to remotely find an available parking space and pay for it through an app. In this way, some problems are solved both on the citizens-side (i.e., extending the park remotely, not wasting time looking for parking in areas with stalls already occupied) and municipality-side problems (i.e., abusive parking controls).
	02. Electric buses	Introduction of buses with electrical engine in the local public transportation fleet, with a particular attention to create an electrical buses network in the most polluted areas in the city centre.
	03. Smart sensors installation	Smart sensors for controlling traffic flow in the city centre in order to better manage traffic movements in the city and eventually adequate regulations in real time (i.e. traffic lights).
	04. Smart loading and unloading areas	Possibility to equip the loading-unloading areas with sensors and a management system that allows the remote booking by the carriers. This to optimize the loading and unloading operations, speed up the process and discourage drivers' incorrect behaviours.
	05. Airport Shuttle	An additional service linking directly Bergamo airport with the train station, without intermediate stops.
	06. Improved bike sharing	An improved version of the already existing bike sharing system in order to both extend the bike sharing network to new areas of the city and make easier the access to the bike sharing service for tourists.
Smart Environment	07. Smart lightening	Convert the traditional city lighting system to a smart lightening system, with low-power lamps and people's detection sensors in order to cut costs and energy consumption.
Smart People	08. Smart ageing service	Services that increase the city liveability for elderly (e.g. benches, anti-slip sidewalks, places for socialization, home deliveries and at medical at home services).
Smart Living	09. Wellness paths	Paths specifically designed for citizens who wish to play outdoor sports activities in the city with the installation of some sports gear along the way to transform the city into an open-air gym.
Smart Governance	10. Online municipality portal	A municipality internet portal that allows the citizens to obtain most of the available documents on-line by avoiding physical visits to municipality offices.
Smart Economy	11. Bergamo tourist card	A tourist card that lets access all the museums and city attractions, and gets discounts at cafés, restaurants and shops as happens in lots of European cities.
	12. Interactive tour	Realization of an app for smartphones that allows access to additional tourist information through the QR codes located in major tourists' sites, and the viewing of some monuments with the Augmented Reality.

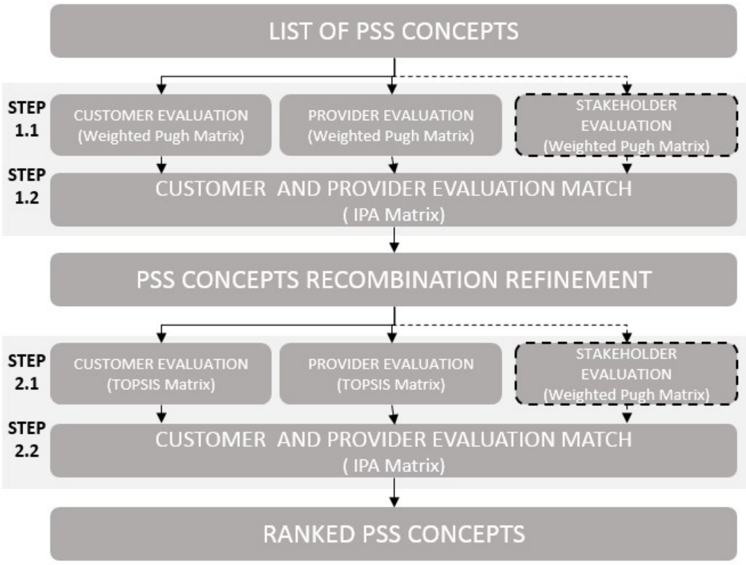


Figure 31 EVA method adapted for three stakeholders

In the light of the context and the third party included in the analysis (the stakeholders), the overall EVA method structure and the evaluation criteria proposed were adapted. A complete set of metrics for the assessment of the solutions from the stakeholders' perspective was also identified. Figure 31 shows the EVA method structure reviewed in order to include a third actor in the evaluation: stakeholders. Table 23 summarizes the specific set of drivers adopted for the evaluation of stakeholders' value. They are a mixture between the provider and the customer benefits. Intuitively, no costs are included in the list because the stakeholders have no expenditure in association with the smart city PSS. According to the analysis carried out, the drivers identified for the customers and the provider (Section 5.3.4) can be adopted for the analysis of stakeholder value. In addition, some additional metrics turned out to be relevant for the specific perspective. They are written in italic in the table.

The first step analysis was carried out through the Pugh method. The detailed matrixes are reported in Appendix A. Figure 32 summarizes the results based on the IPA map. In this case, the solution selected as reference concept is the city Wi-Fi. Wi-Fi indeed can be considered as a basic service inside the smart city context. All the major cities, indeed, are organized with proper infrastructure to grant this functionality to the citizens and to the tourists.

Table 23 Value drivers for stakeholders' perspective

		Value category	Specific drivers
BENEFITS	B1	Capability creation and retention	Data and knowledge sharing with municipality, citizens and other stakeholders (value co-creation)
			Empowerment of resources competencies
			Time to market
	B2	Strategy	Company brand/image
			Improve communications
	B3	Asset and resources management	Asset safety and security
			Improved delivered quality
			(Optimization) Asset utilization
			Resources (asset/employee) relocation and usage
	B4	*Innovation*	*Improvement of technological standards*
			Innovativeness
			Connectivity
	B5	Market	New customer acquisition
			New market generation
			Improve retention of existing customers
	B6	Environment	Lifecycle increase of product
			Natural resources consumption
	B7	Value chain	Generation/exploitation of value chain alliances
			Strategic positioning in the value chain
			Efficiency of stakeholders network
			Public-private partnership possibilities

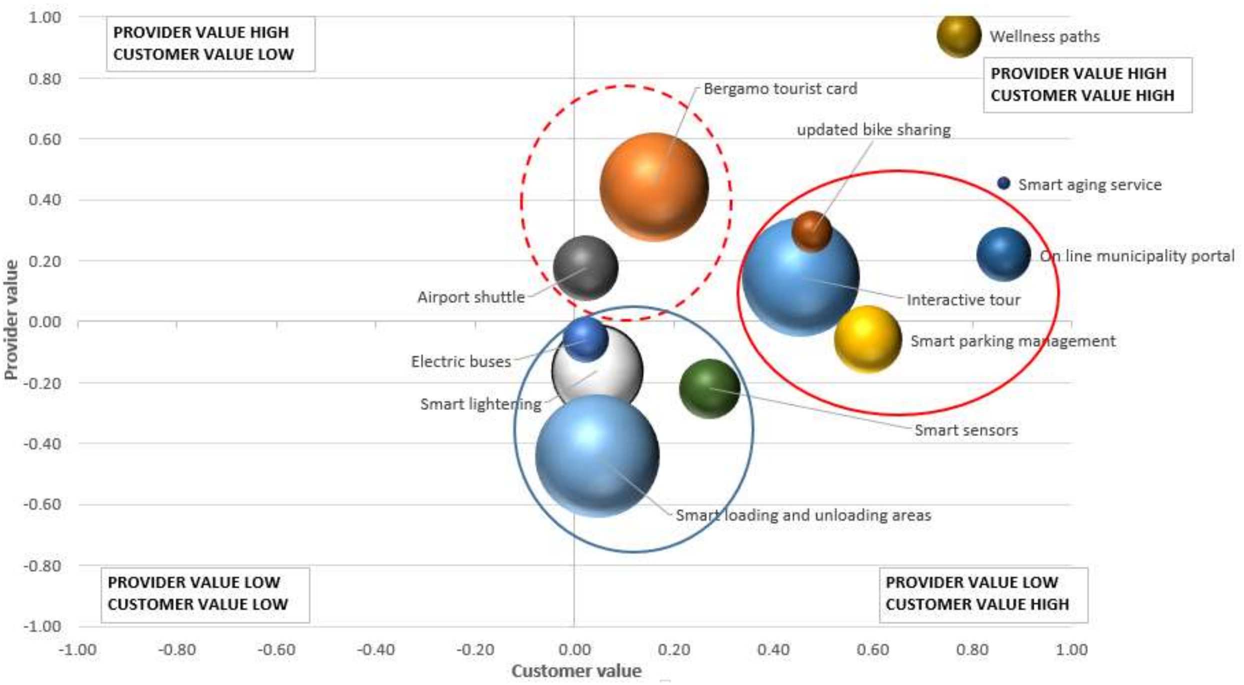


Figure 32 IPA matrix for the first step assessment - Smart city case

As could be observed from the figure 32, all the smart city PSS concepts show at least equal or higher value with respect to the reference concept. Given that the Wi-Fi solution is quite basic in the current smart cities scenario, it is not surprising that no solutions with lower value than the selected reference concept could be found. The solutions could split into four main categories as follow:

- *Optimal.* One solution lays in the optimal area providing high value for both the customers and the provider with the average value in association to stakeholders (medium size of the point). "Wellness path" is indeed considered a high-value added service for the citizens being a healthy and sustainable hobby provided, free, by the city. For the municipality, this solution is convenient since it requires relatively low investment and maintenance costs at the same time being instrumental in bringing Bergamo to a more sustainable lifestyle.
- *Low provider value (blue circle).* This includes the solutions that from customer perspective can be compared to Wi-Fi whereas for the provider are not satisfactory. "Smart lightening", "electric buses", "smart loading and unloading areas" and "smart sensors" are placed here. The commonality among them is the high investment required by the municipality for their implementation. Even if they could support the city in reducing pollution and traffic congestion, they are not really appreciated by the customers. Stakeholders report high interest in the "smart loading and unloading areas" given the possibility to have a timely refurbishment. For them, "Smart lightening" is very negative (the black border of the point shows negative value) since it is not increasing business at all. Considering the limited value of the solutions for two out of three actors involved, these solutions are not considered interesting for further analysis.
- *Medium provider value (dotted circle*). "Airport shuttle" and "Bergamo tourist card" are borderline from customer perspective. The shuttle is quite a basic solution, therefore similar to Wi-Fi whereas the tourist card does not really affect Bergamo citizens. Both of these solutions however are quite relevant for the stakeholders because they can potentially increase the number of tourist in Bergamo increasing the shops' revenues. As it can be observed, this is particularly true for "Tourist Card". According to such relevance for stakeholders, this PSS solution is further analysed in Step 2.
- *Borderline solutions (red circle*). Some of the solutions are in a borderline position for the provider with medium relevance for customers. "Interactive tour" "Updated bike sharing" "online municipality portal" "Smart parking management" and "smart aging services". Among them, it could be possible to observe the relevance of "interactive tour" and "municipality portal" from the stakeholders' perspective as well. This implies quick contact and more efficient relationship with municipality. "smart parking management" even if quite

relevant for the citizens is quite expensive and not convenient for the municipality, again in relation to the huge investment required. It could be noticeable the "smart ageing service" that even though it does not require high effort from Bergamo and could be potentially highly appreciated by the citizens, it not appreciated by the stakeholders.

Based on the above considerations, the solutions located in the top-right area of the map that is also showing some relevance for the stakeholder were selected for further analysis. The only solution not selected is the "smart ageing services" since it has very limited relevance for the stakeholders (small size of the point). "Bergamo tourist card" and "Interactive tour" having many similar and complementary features were joined together in a single PSS solution. Finally, it should be pointed out that almost all solutions are already in or near the first quadrant. This is because the solutions taken into consideration are smart city solutions, so they are already trying to meet the needs of the citizen and the public administration. The selected solutions were further analysed with the TOPSIS method. Evaluation tables are reported in appendix A. The results of the second step are represented in Figure 33.

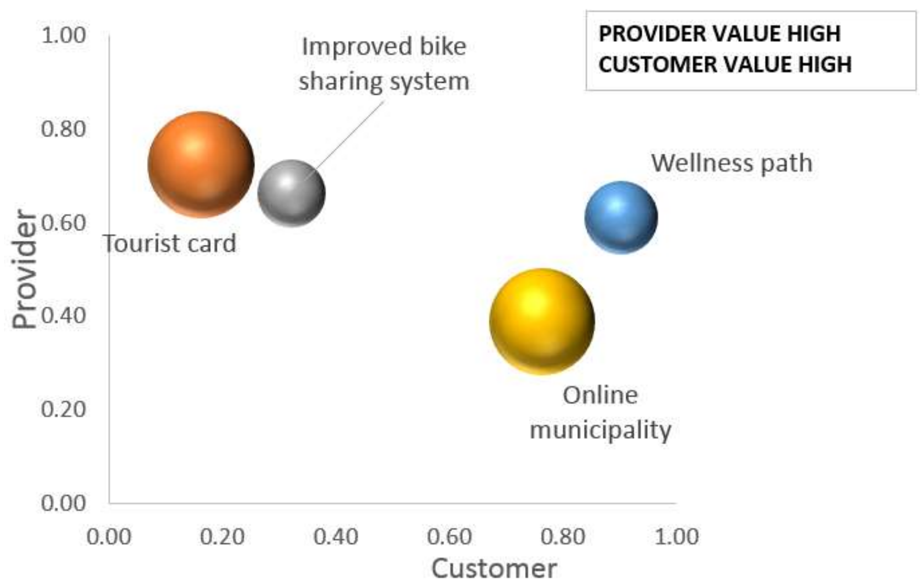


Figure 33 IPA matrix for the second step assessment - Smart city case

As displayed in the graph, the solutions are split into two main groups. "Wellness path" and "online municipality portal" are the solutions that provide greater benefits to customers proposing new services for their lifestyle and for their contact with the municipality. The improvement of bike sharing is not evaluated very positively given the fact that the service is already in place and they do not perceive high value from its improvement. On the contrary, this is much more appreciated by the municipality of Bergamo together with the introduction of a "tourist card allowing interactive tour in the city". These two solutions would strongly influence Bergamo image attracting a variety of tourists.

The possibility to increase their revenues from tourist is also the main motivation behind the high influence of "tourist card" on stakeholder value. The "Bergamo tourist card" seems the preferred solution. It offers quite relevant value to all the actors considered in the exercise.
According to the results, the decision about new PSS implementation strongly depends on the priority of the city. In case the priority would be given to resident citizens, the "online municipality portal" could also provide some gains for the stakeholders. In case more tourist-oriented solutions would be implemented, the "tourist card" could be a good trade-off between citizens and stakeholders.
Finally, if the stakeholders are not very relevant in the Bergamo context, the priority would be given to the wellness path that shows similar provider value to "improved bike sharing" and "tourist card" but that can definitely boast higher value for customers, namely Bergamo citizens.

6.5 Validation in the airport context: The case of Orio al Serio.

The last practical validation of the EVA method was performed in a pure service context: the airport. In particular, a case related to the design of an innovative solution for check-in process was analysed. Similarly to the case in the smart city, three main stakeholders interested to the airport services were identified: i) the customers (also called passengers), ii) the airport management and iii) the airlines that operate in the specific airport.

According to the possible self-check in currently available in the market, four possible concepts were analysed. They are characterized by two main characteristics: the structure and the process. The *structure* outlines how the counters are physically shaped while the *process* describes how the sequence of the activities necessary to perform the check-in, are delivered. Concerning the structure, two possible options are available: *retro fit* or *new fit*. The retro fit design can be installed overnight onto existing airport check-in desks while the new fit is a structure designed to be disruptive to the traditional paradigm of check-in counters. Regarding the process, the main activities to be performed can be summarized as follows: (1) verify the passenger's boarding pass; (2) weigh the baggage; (3) issue the baggage check-in tag; (4) accept the baggage; (5) deliver the baggage. These activities can be performed in *one step* or *in two-step*. For the two-step design, two different interfaces are required. The first three activities are performed through the so-called kiosks while the bag is injected into the baggage system (fourth and fifth activity) thanks to a different interface.

Hence, the combination of the two alternatives of each feature (structure and process) results in four main concepts:

- *concept 1*: retro fit – one step;
- *concept 2*: retro fit – two-step;
- *concept 3*: new fit – one step;

- *concept 4*: new fit – two-step

These four alternatives are the concepts selected for the application of the EVA method. Considering that all the selected concepts refer to a single service (i.e. the self-check-in) and that their design is clearly defined (there is not any possible refinement of the design concepts), only the second step of the EVA method has been applied as suggested into to the map in Figure 20. Hence, the perspectives of the three stakeholders about the engineering concepts were analysed in relation to the final set of metrics using only the TOPSIS technique.

In detail, the test case has been contextualized into Orio al Serio International airport. Il Caravaggio airport, it is located in Bergamo, in the north of Italy. The airport, managed by SACBO S.p.A, served 11,159,631 passengers in 2016 and it is ranked as the third busiest airport in Italy after Roma Fiumicino and Milano Malpensa.

For the specific case, ad-hoc evaluation criteria were studied with people responsible for the check in implementation project. Concerning *customer viewpoint*, the major criteria contributing to value generation are the accessibility of the service, the employee kindness, the service convenience and the image of the service. The cost is also contributing to the overall value creation. *The airport value*, on the other hand, is mainly built upon the revenue generated by the service, its reliability and safety, its positioning with respect to the strategy and the cost for the implementation. Finally, the *airline* categories of value are mainly related to the associated revenues, the image and the impact on operations. The evaluation tables collecting the metrics used for the evaluation could be consulted in appendix A.

Hereafter is the summary of the results obtained from the method application. Figure 34 shows the IPA map resulting from the application of the second step of the EVA method.

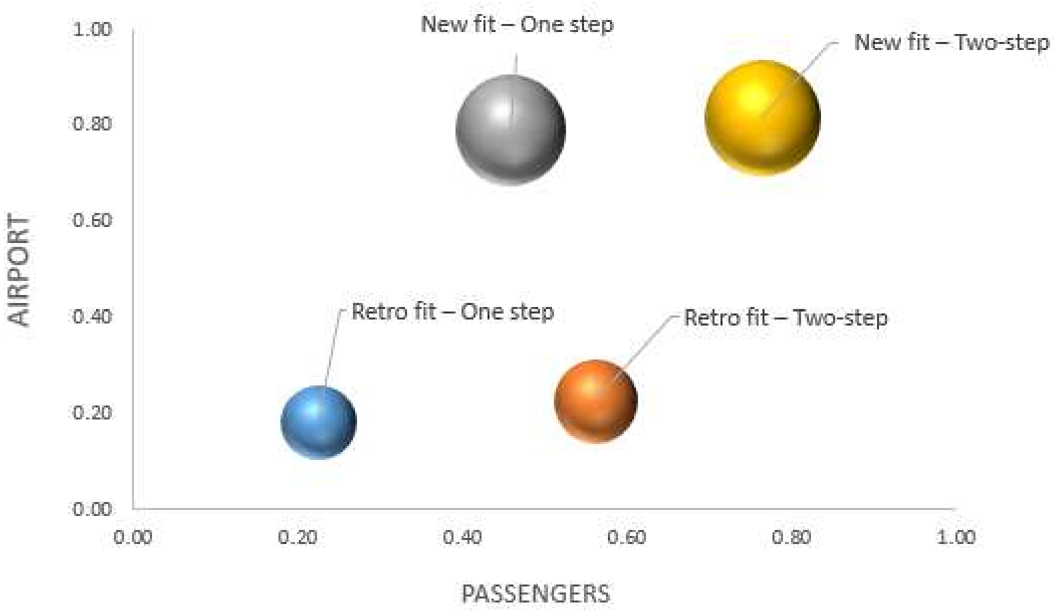


Figure 34 IPA matrix for the second step assessment - Airport case

Definitely, *the passengers* prefer the two-step solutions even if the one-step could be thought as the favourite one. Indeed, the two-step design got higher scores in relation to efficiency, service time, responsiveness and ease of use. In addition, the two-step design offers higher schedule flexibility during the check-in process and more accurate and timely information, both values considered very relevant for the air travellers. For what concern the structure the air travellers recognise the degree of novelty and innovation as a relevant value driver thus prizing the new fit structure.

Regarding *the airport* perspective, the new fit solutions (grey and orange points) are those less distant from the ideal solution (top of the map) even if they require higher investment cost. Indeed, the new fit solutions allow to better satisfy the necessity of appearing a technological innovator to attract more airlines and passengers increasing both the aeronautical and non-aeronautical revenue. In addition, the new fit designs allow the airport to rethink the terminal layout dulling the current congestion level of the areas.

Dealing with the third stakeholder, the airlines, it could be observed that they are also pleased by the new fit solutions. As for the airport's perspective, the airlines are interested in using advanced technologies to enhance their images and to save operational costs. In addition, no noticeable difference between the two process alternatives designs (one-step or two steps) is visualised.

Concluding the analysis, the optimal solution that maximizes the three stakeholders' perspectives is the "new fit – two-step" concept. Indeed, this alternative has obtained the highest score from all the stakeholders.

This validation in pure service context demonstrates the validity of the method in supporting decision-making and trade off identification also in the specific context, far from traditional manufacturing. Even though the evaluation criteria were specifically defined for the case, the method showed advantages in prioritizing solutions based on multiple perspectives.

Part II - Discussion

In this second part of the thesis, the EVA method for the early stage assessment of PSS is proposed. The method wants to provide a support structure for the cross-functional PSS engineering team to fully capture the value contribution of PSS concepts since the early engineering phases, from multiple viewpoints (i.e. customer, provider and other stakeholders).

Chapter 5 summarizes the method whereas chapter 6 includes four validation cases that provided some hints about the weaknesses of the method. Regarding the main advantages and the positive feedback from the cases, the variety of industries and contexts where the EVA was applied, shows the flexibility and the wide applicability of the EVA method.
Furthermore, the alternatives analyzed in the four cases differ in type and features, demonstrating that the method can support the assessment of solutions spanning from pure product engineering concepts (asphalt roller case) to PSS solutions (ABB and smart city case), till pure service concepts (airport case).
The cases (from 6.2 to 6.5) also highlight the flexibility of the method in dealing with both two and three stakeholders. While increasing the actors involved in the decision making the EVA method still perform properly providing meaningful information for decision makers.

From what concern the method implication, the feedbacks collected from the practical validation, generating consensus and pushing the discussion among team members could be highlighted as one relevant advantage of the EVA method. The immediate visualization of the value perceived by the involved decision makers is another major benefit of the method. The quick value visualization enables the creation of a general understanding of the value contribution of concepts, their features, their benefits and their costs. The method easiness of use and applicability reported by the people involved in the validation cases constitutes an additional value added motivation for the method validity.

As regards the evaluation criteria proposed to be coupled with the EVA method, the people involved in the validation studies describe them as complete and exhaustive. The validation cases highlight that they are generally valid for the assessment of product-oriented and pure PSSs. Even if for a specific case they could be too wide, considering the different cases they were able to guide the evaluation and to manage the plethora of value dimensions associated to PSS. Therefore, they could be considered as general guidelines among which the specific criteria can be selected according to case specificity. Regarding the pure service concepts evaluation, the proposed drivers are not effective in capturing the value associated with the solutions and in the specific case the value drivers are tightly related to the specific context.

Some drawbacks of the EVA method shall be pointed out. First, the complexity in involving real customers during the evaluation is a major limitation since, being the provider, retrieving customer preferences and choices are complex, and the evaluation could not be exhaustive. Another major complexity refers to step 1 -Pugh method. Although the pairwise comparison facilitates the value assessment, the selection of a reference concept in the PSS context is complex. In some cases, (see for example the ABB case), the solutions compared are extremely different among each other's and the selection of the baseline concept is very critical because it can influence the overall results of the approach.

The time required for the application of the method was also pointed out as a possible weakness of the method. Especially for what concerns the second step, the evaluation of multiple PSS concepts considering the high number of proposed criteria is very time to consume and could be not feasible due to the relevant amount of time required.

Part III

The third and last part of the thesis includes all the advancements with respect to RQ2. It focuses on the development of a method to engineer and assess the service delivery process during the PSS engineering phase. The method is meant to be used in the both in the BOL of PSS, to evaluate the identified design and in the MOL phase in order to monitor the implemented PSS. The first chapter of this part summarizes the existing literature and researches concerning the process assessment. Through the chapter, simulation and analytical solutions are identified as the two most suitable approaches to reach the goal of RQ2. After the identification of their main features and their comparison with respect to service delivery process assessment, discrete event simulation emerged as the most suitable method, and it is applied in multiple cases, also described in chapter 7. However, the cases highlighted some complexities of the discrete event simulation for the assessment of service delivery process due to the high amount of time required for model design and to the complexity in modelling heterogeneous customer behaviours. The intensive activity of data collection also emerged as a critical point to be faced. To cope with the two issues, two possible area of interest are identified and discussed in chapter 8 and 9, as showed in Figure 35.

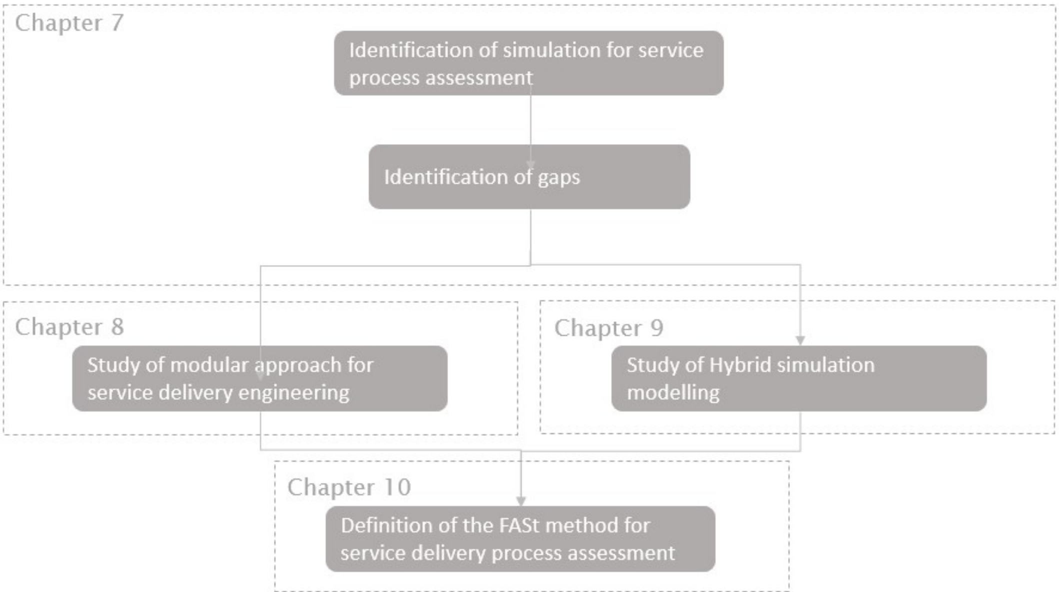


Figure 35 Structure of Part III of the thesis

First, the study of a modular approach to engineer the service delivery process is studied. A specific structure and a procedure for service delivery process engineering are proposed at the end of chapter 8. Such an approach would facilitate process modelling and consequent replication into a simulation model. Second, the analysis of hybrid simulation is developed in chapter 9. It studies the exploitation of agent based modelling for the simulation of heterogeneous customers. A validation case at the end of chapter 9 highlights the benefits of hybrid modelling with respect to pure discrete event simulation. In the light of the advancements in the two areas, a final proposal of a method for service delivery process assessment is presented: the FASt method. Chapter 10 describes the FASt method, the specific modelling procedure and the steps for the adoption of hybrid simulation and reports a full scale validation case in collaboration with ABB.

7 Assessing of the service delivery process

This chapter constitutes the initial analysis of the research concerning the second research question. After introducing the assessment in the context of service delivery process (section7.1), section 7.2 summarizes the analysis of the methods available for business process assessment and the identification of the one that best fits with the service delivery features of a PSS: discrete event simulation.

Section 7.3 describes the application of the selected method in multiple cases and reports the main gaps and difficulties to be faced during the application in services. Limitations and further improvements of the method are illustrated section 7.4 in order to introduce the following chapters.

7.1 The assessment of the service delivery process

As for the first area of investigation, also the second fundamental research of this thesis focuses on the assessment of PSS. During this phase, the topic of assessment was further explored with respect to later stages of engineering, once the PSS concepts are selected and engineered. However, considering that methods and tools for the final product design assessment are well known and largely adopted in industry, the exploitation of methods for the assessment of the service component of a PSS is the focal point of the study. Indeed, service constituents introduce engineering requirements that, as explained before, are profoundly different from product ones, thus necessitating an ad-hoc approach going beyond the mere transposition of product-engineering methodologies to the service domain. Unlike a product, indeed, service is a combination of processes, people skills, and materials that must be appropriately integrated to result in the ‘planned’ or ‘engineered’ service (Goldstein, et al. 2002).

Particularly relevant to the current discussion – and for the identification of a method for assessing the service component of PSS– is the possibility to consider the service as a business process (Ponsignon, et al., 2012) composed of coordinated activities and tasks, performed by available resources. The definition of services, by itself, supports this conjecture. IBM describes service as *“a provider/client interaction in which both parties participate and both parties obtain some benefit from the relationship […]. A service is a form of activity, consumed at the point of production*.” (Katzan 2011). In the same direction, (L. Berry 1980) and (Zeithaml and Bitner 1996) define service as “*deeds, acts or* *performance*", whereas (Gronroos, 2000) presents a service as "*an activity or series of activities provided as a solution to customer problems*". Finally, (Edwardsson, et al., 2005) emphasizes the process nature of a service delivery process and the benefits that can be obtained by the customers. These statements describe how services have been traditionally perceived and defined as something intangible, and their nature viewed as an activity or process (Johns 1999). According to this, this thesis argues that the assessment of a service delivery process could be achieved adopting (or partially adapting) commonly used modelling approaches, methods and paradigms to (re-)engineering and analyse business processes.

7.2 Literature analysis on methods for service process assessment

As a first step to identify a possible method for the service delivery process assessment, literature on the two most known and adopted quantitative methods for business process (re)engineering: a*nalytical solutions and simulation* (Jonkers and Franken 1996) was screened. The analysis was aimed at: i) identifying in literature the available methods inside the two categories and ii) selecting the most suitable considering the peculiarities of the service delivery process of a PSS.

Literature in the area of "business process engineering" and "assessment" joined with "simulation" and "analytical solutions" was searched in the two main peer-reviewed databases, Scopus and ISI Web of knowledge. Among the proposed papers, those analysing the existing approaches (or methods) and describing advantages and disadvantages were selected. Literature reviews were also preferred to other types of documents. A final refinement of the search was also completed with the support of Google Scholar and following the snowballing method (Wohlin 2014). Articles dealing with PSS and service were given the priority with respect to others papers.

The papers collected were analysed and classified according to the method to which they refer. Regarding the simulation modelling method, different approaches were found in the analysed literature, in particular:

- *Discrete Event Simulation (DES).* It is arguably the most used technique in practice (Brailsford and Hilton 2001). It is process-centric and focuses on the tactical/operational dimension, based on entity flows, resource sharing and sequences of activities: entities can only have a passive behaviour. This approach, rooting to 1960s (Gordon 1961), is based on entities that travel through the blocks of the flowchart where they stay in queues, are delayed, processed, seize and release resources, split, combined, etc. It supports a medium-low abstraction (Borshchev and Filippov 2004) (Hirth, et al. 2015) (Weidmann, et al. 2015).
- *System Dynamic (SD)* dates back to 1950, and is largely used to analyse the dynamics of a system (Sterman 2000). In SD, the real-world processes are represented in terms of stocks,

flows between these stocks, and information that determines the values of the flows. Interaction and system behaviour is represented by feedback loops and the overall structure is based on a set of differential equations (Borshchev and Filippov 2004). It supports the highest level of abstraction.

- *Agent-based modelling (ABM)* is a recent approach that is more effective in modelling individuals' behaviour, from a bottom-up perspective. In ABM, agents have their own rules and become active elements of the model (Maisenbacher, et al. 2014) so that the global system behaviour is not defined but emerges from their behaviour (Borshchev and Filippov 2004).
- *Life-Cycle simulation* is a quantitative method that is used in order to perform analysis on the entire life cycle of a product. It is generally used to create knowledge and to forecast different product life cycle scenarios (Garetti, Rosa and Terzi 2012).
- *Petri-net simulation* method was developed in 1962 as a new model to describe the information flow in systems, and it was further expanded in order to be used in synchronization process, asynchronous events, concurrent operations, and conflicts or resource sharing for a variety of industrial automated systems at the discrete-event level (Zhou 1998).
- *Monte Carlo simulation* is a mathematical model used to support the risk analysis and the decision-making process in a quantitative way. It grounds on a parametric simulation approach to model the system. Indeed, through MC simulation is possible to suppose parameters characterized by a probability distribution function for each variable that could represent uncertainty within the model (Nilakantan 2015).

In addition to these most common simulation methods, literature discusses other approaches with limited use such as *Ontological representation, intelligent simulation, Distributed Simulation* and *Simulation Gaming*. Given their limited spread, these last approaches were not analysed in detail.

The following tables (Table 24, 25, 26, 27) summarize the analysis of literature. They recap the main objectives and the applications of the previously mentioned simulation methods.
The analysis of available literature allowed the identification of the methods and their limitation and strengths for business process analysis. In order to understand which of them could be applicable in the context of PSS for the assessment of the service delivery process, the main limitations and strengths of each method were also analysed. Tables 28 and 29 provide a summary of them.

Table 24 Discrete Event Simulation main objectives and application fields

	Application field	Objective
Discrete Event Simulation	- manufacturing (Babulak and Wang 2007) (Jahangirian, et al. 2010)	- process and organizational design (Babulak and Wang 2007) (Jahangirian, et al. 2010)
	- Banking and finance services (Babulak and Wang 2007)	- production planning control (Babulak and Wang 2007)
	- Healthcare (Babulak and Wang 2007) (Viana, et al. 2014) (Brailsford, et al. 2013)	- scheduling (Jahangirian, et al. 2010)
	- logistics and transportation (Tako e Robinson 2009) (Babulak and Wang 2007) (Jahangirian, et al. 2010)	- inventory management and control (Jahangirian, et al. 2010)
	- Public sector (Babulak and Wang 2007) (Jahangirian, et al. 2010)	- SCM (Tako e Robinson 2009) (Jahangirian, et al. 2010)
	- Automotive (Jahangirian, et al. 2010)	- quality management (Jahangirian, et al. 2010)
	- Service industries (Jahangirian, et al. 2010)	- financial management (Babulak and Wang 2007)
	- Pharmaceutical (Jahangirian, et al. 2010)	- manpower, capacity and facility planning (Babulak and Wang 2007) (Jahangirian, et al. 2010)
	- Consulting (Jahangirian, et al. 2010)	- strategy (Babulak and Wang 2007) (Jahangirian, et al. 2010)
	- Energy (Jahangirian, et al. 2010)	- project management (Jahangirian, et al. 2010)
	- Airlines (Jahangirian, et al. 2010)	- transportation management (Jahangirian, et al. 2010)
	- Software development (Jahangirian, et al. 2010)	- maintenance management (Jahangirian, et al. 2010)
	- Oil and gas (Jahangirian, et al. 2010)	- knowledge management (Jahangirian, et al. 2010)
	- Agricultural (Mesabbah, et al. 2016)	- shipping strategy analysis (Babulak and Wang 2007)
	- Policy (Varol and Gunal 2015)	- material handling system (Babulak and Wang 2007)
		- modelling of police emergency response (Babulak and Wang 2007)
		- optimization of armed response vehicle deployment (Babulak and Wang 2007)
		- re-engineering criminal investigation process (Babulak and Wang 2007)

Table 25 System Dynamic main objectives and application fields

	Application field	Objective
System Dynamic	- Healthcare (Viana, et al. 2014) (Brailsford, et al. 2013)	- production planning and control (Jahangirian, et al. 2010)
	- Software development (Jahangirian, et al. 2010) (Lättilä, Hilletofth and Lin 2010)	- strategy (Jahangirian, et al. 2010)
	- urban (Borshchev and Filippov 2004)	- policies analysis (Tako e Robinson 2009) (Jahangirian, et al. 2010)
	- social (Borshchev and Filippov 2004)	- project management (Jahangirian, et al. 2010)
	- ecological (Borshchev and Filippov 2004) (Lättilä, Hilletofth and Lin 2010)	- knowledge management (Jahangirian, et al. 2010)
	- economics (Lättilä, Hilletofth and Lin 2010)	- forecasting (Jahangirian, et al. 2010)
	- innovation diffusions (Lättilä, Hilletofth and Lin 2010)	- management training and education (Jahangirian, et al. 2010)
	- workforce management (Lättilä, Hilletofth and Lin 2010)	- quality management (Jahangirian, et al. 2010)
	- food (Jahangirian, et al. 2010)	- SCM (Jahangirian, et al. 2010) (Lättilä, Hilletofth and Lin 2010) (Tako e Robinson 2009)
	- aircraft manufacturing (Jahangirian, et al. 2010)	
	- semi-conductor manufacturing (Jahangirian, et al. 2010)	
	- automotive (Jahangirian, et al. 2010)	
	- logistics (Jahangirian, et al. 2010) (Tako e Robinson 2009)	
	- pharmaceuticals (Jahangirian, et al. 2010)	
	- electronics (Jahangirian, et al. 2010)	
	- utility companies (Jahangirian, et al. 2010)	
	- generic part manufacturing (Jahangirian, et al. 2010)	
	- education (Jahangirian, et al. 2010)	
	- Insurance (Jahangirian, et al. 2010)	
	- computer hardware (Jahangirian, et al. 2010)	
	- construction (Jahangirian, et al. 2010)	
	- consulting (Jahangirian, et al. 2010)	

Table 26 Agent Based Modelling main objectives and application fields

	Application field	Objective
Agent Based Modelling	- healthcare (Varol and Gunal 2015) (Borshchev and Filippov 2004)	- SCM (Jahangirian, et al. 2010) (Zhang e Zhang 2007) (Bonabeau 2002)
	- manufacturing (Lättilä, Hilletofth and Lin 2010) (Jahangirian, et al. 2010)	- Marketing (Zhang e Zhang 2007)
	- maintenance and supply chain - management (Lättilä, Hilletofth and Lin 2010)	- evaluate the influence of governmental economic policies on business (Zhang e Zhang 2007)
	- e-commerce (Lättilä, Hilletofth and Lin 2010)	- production planning and (Jahangirian, et al. 2010)
	- banking (Lättilä, Hilletofth and Lin 2010)	- Flows of individual entities (Maisenbacher, et al. 2014)
	- transportation (Jahangirian, et al. 2010) (Varol and Gunal 2015)	- Markets and their dynamics (Maisenbacher, et al. 2014)
	- shipping terminals (Jahangirian, et al. 2010)	- Organizations in terms of organizational design or operational risk and success (Maisenbacher, et al. 2014)
	- ICT (Jahangirian, et al. 2010)	- Diffusion of information flows in social networks or diffusion of innovation and adoption (Maisenbacher, et al. 2014)
	- electricity (Jahangirian, et al. 2010)	- transport management (Jahangirian, et al. 2010)
	- pharmaceutical (Varol and Gunal 2015)	- inventory control (Jahangirian, et al. 2010)
	- social science (Varol and Gunal 2015)	- resource allocation (Jahangirian, et al. 2010)
	- PSS (Maisenbacher, et al. 2014)	- scheduling (Jahangirian, et al. 2010)
	- energy (Kremers 2013)	- strategy (Jahangirian, et al. 2010)
	- policy (Varol and Gunal 2015)	- organizational design (Jahangirian, et al. 2010)
		- decision making (Zhang e Zhang 2007)

Table 27 Life cycle simulation and Petri Net main objectives and application fields

	Application field	Objective
Life Cycle Simulation	- industrial robot manufacturing (Garetti, Rosa and Terzi 2012)	- facility management (Garetti, Rosa and Terzi 2012)
	- navy industry (Garetti, Rosa and Terzi 2012)	- life cycle assessment (Wang, Brême and Moon 2014)
	- cement manufacturing (Garetti, Rosa and Terzi 2012)	- evaluate product cost (Garetti, Rosa and Terzi 2012)
		- reverse logistics or closed-loop supply chains (Komoto, et al. 2005)
		- simulating environmental and, product performances (Garetti, Rosa and Terzi 2012)
PETRI NET	- generic part manufacturing (Jahangirian, et al. 2010)	- scheduling (Jahangirian, et al. 2010) (Zhou 1998)
	- food (Jahangirian, et al. 2010)	- project management (Jahangirian, et al. 2010)
	-construction (Jahangirian, et al. 2010)	- SCM (Jahangirian, et al. 2010)
	- semiconductor manufacturing (Zhou 1998)	- transportation management (Jahangirian, et al. 2010)
	- manufacturing (Kaid, et al. 2015)	- semiconductor testing plant (Zhou 1998)
		- semiconductor fabrication processes (Zhou 1998)
		- diffusion cell controller in an IC CIM System (Zhou 1998)
MONTE CARLO SIMULATION	- Investment & Finance (Nilakantan 2015) (Loizou e French 2012)	- risk analysis (Loizou e French 2012) (Nilakantan 2015)
	- energy (Nilakantan 2015) (Jahangirian, et al. 2010)	- sensitivity analysis (Nilakantan 2015)
	- pharmaceutical industry (Bonate 2001)	- forecasting analysis (Nilakantan 2015)
	- property (Jahangirian, et al. 2010)	- financial management (Jahangirian, et al. 2010)
	- accountancy (Jahangirian, et al. 2010)	- project management (Jahangirian, et al. 2010)
	- software development (Jahangirian, et al. 2010)	- maintenance management (Jahangirian, et al. 2010)
	- construction (Jahangirian, et al. 2010)	- strategy (Jahangirian, et al. 2010)
	- manufacturing (Jahangirian, et al. 2010)	- scheduling (Jahangirian, et al. 2010)
	- electronics (Jahangirian, et al. 2010)	- resource allocation (Jahangirian, et al. 2010)
	- jet engine repair (Jahangirian, et al. 2010)	- process engineering manufacturing (Jahangirian, et al. 2010)
	- nuclear and spacecraft (Jahangirian, et al. 2010)	- inventory management (Jahangirian, et al. 2010)
	- defence (Nilakantan 2015)	- capacity planning (Jahangirian, et al. 2010)
	- banking (Nilakantan 2015)	
	- retirement (Nilakantan 2015)	

- portfolio planning (Nilakantan 2015)

Table 28 Discrete Event Simulation, System Dynamic and Agent Based Modelling advantages and disadvantages

	Advantages	Disadvantages
Discrete Event Simulation	- flexible approach: able to code almost anything (Viana, et al. 2014) (Brailsford, et al. 2013) (Jeon e Kim 2016)	- no holistic view of the system (Tako e Robinson 2009) (Viana, et al. 2014) (Chahal 2010)
	- micro level analysis (Tako e Robinson 2009) (Viana, et al. 2014) (Chahal 2010) (Brailsford, et al. 2013)	- huge data requirement (Viana, et al. 2014) (Brailsford, et al. 2013) (Jeon e Kim 2016) (Jahangirian, et al. 2010)
	- detects and models complexity (Tako e Robinson 2009) (Brailsford, et al. 2013) (Chahal 2010) (Mesabbah, et al. 2016)	- long run time (Viana, et al. 2014) (Brailsford, et al. 2013) (Jahangirian, et al. 2010)
	- interactive - ease to use (Tako e Robinson 2009) (Brailsford, et al. 2013)	- multiple replications needed (Viana, et al. 2014) (Tako e Robinson 2009) (Jahangirian, et al. 2010) (Brailsford, et al. 2013)
	- capture stochastic behaviour (Mesabbah, et al. 2016)	- no stakeholder engagement (Jahangirian, et al. 2010)
		- statistical analysis and interpretation of the output (Viana, et al. 2014) (Brailsford, et al. 2013) (Tako e Robinson 2009)
		- difficulty in capturing dynamic complexity (Chahal 2010)
System Dynamic	- holistic view of the system (Tako e Robinson 2009) (Kremers 2013) (Jeon e Kim 2016)	- Less flexibility compared to DES (Brailsford, et al. 2013) (Lättilä, Hilletofth and Lin 2010)
	- feedback loops (cause-effect relationship) (Tako e Robinson 2009) (Chahal 2010)	- tricky validation (Brailsford, et al. 2013)
	- comprehend dynamic complexity (Tako e Robinson 2009) (Chahal 2010)	- do not capture individual variability (Brailsford, et al. 2013) (Viana, et al. 2014)
	- user friendly (Tako e Robinson 2009) (Brailsford, et al. 2013)	- no interactive (Brailsford, et al. 2013) (Tako e Robinson 2009)
	- minimal data requirement (Tako e Robinson 2009) (Brailsford, et al. 2013)	- no detailed (general view of the system) (Jeon e Kim 2016) (Lättilä, Hilletofth and Lin 2010) (Chahal 2010) (Tako e Robinson 2009)
	- quick to run (no multiple replications) (Brailsford, et al. 2013) (Jeon e Kim 2016)	- less reliance on hard data when compared with DES (Jahangirian, et al. 2010)
	- ease of modelling (Jeon e Kim 2016)	- do not detect system complexity (Lättilä, Hilletofth and Lin 2010)
Agent Based Modelling	- detailed and realistic representation of complex system (Bonabeau 2002) (Maisenbacher, et al. 2014) (Kremers 2013)	- difficult to understand interactions among people (Maisenbacher, et al. 2014) (Kremers 2013)
	- flexibility: allows changes during the simulation (Maisenbacher, et al. 2014) (Kremers 2013) (Bonabeau 2002) (Jeon e Kim 2016)	- difficult interpretations of the outcome (Kremers 2013) (Bonabeau 2002)
	- capture emergent phenomena (Bonabeau 2002) (Kremers 2013) (Borshchev and Filippov 2004) (Lättilä, Hilletofth and Lin 2010)	- long-time run (Bonabeau 2002) (Lättilä, Hilletofth and Lin 2010)
	- easy to build/implement (Jeon e Kim 2016) (Lättilä, Hilletofth and Lin 2010)	- high computational requirement for modelling large system (Bonabeau 2002)

- interactions among business functions (Lättilä, Hilletofth and Lin 2010)	- huge data requirement (Lättilä, Hilletofth and Lin 2010) (Kremers 2013)

Table 29 Life cycle Simulation and Petri Net and Monte Carlo simulation advantages and disadvantages

	Advantages	Disadvantages
Life Cycle Simulation	- permits to cover the whole life cycle perspective (Contaldo et al.,2014)	- static viewpoint and no dynamic response of the system (Wang, Brême and Moon 2014) - uncertainty in the decision process (Wang, Brême and Moon 2014) - do not capture the uniqueness of the system (Wang, Brême and Moon 2014) - limited availability of information to describe the product model and its life cycle (Komoto, et al. 2005) - not efficient in coping with the behaviour of multiple actors (Phumbua and Tjahjono 2010)
PETRI NET	- easy visualization of complex system (Kaid, et al. 2015) - can model a system hierarchically (a top-down fashion at various levels of abstraction and detail) (Kaid, et al. 2015) - analyses qualitative and quantitative aspects of the system (Kaid, et al. 2015) - Flexible: thanks to its graphical and mathematical notation are able to analyse and amend the models of a process without losing the model identity (Aldin e de Cesare 2009) - Easy interpretation of the results: even if the model is not constructed correctly it is possible to see which are the problem of the system (Aldin e de Cesare 2009)	- It may not be feasible to apply the method to large systems (Zhou 1998) - Long run time method: it has difficulty to determine if the system has reached stability and needs to simulate for each different setting (Zhou 1998) - Non-user oriented technique: difficult for inexperienced stakeholders (Aldin e de Cesare 2009) - Modelling complex business processes require a certain level of expertise (Aldin e de Cesare 2009)
MONTE CARLO SIMULATION	- can provide answers where no analytical solution exists (Bonate 2001) - easier to understand by the layman than complex mathematical equations (Bonate 2001) - it allows the developer greater comprehensiveness, clarity, rigour and understanding (Loizou e French 2012) - assists the decision maker to be more consistent and rational in his decisions (de-humanising) (Loizou e French 2012)	- limited to 'static' problems or to solve numerical problems with a stochastic nature (Jahangirian, et al. 2010) - more staff time for data collection and analysis (Bonate 2001) (Loizou e French 2012) - not all simulations will lead to useful results (more information is known greater is the likelihood of success) (Bonate 2001) - The quality of the output is directly correlated to the quality and appropriateness of the input variables that tend to be of debatable quality (Loizou e French 2012) - need to know probability distributions for each outcome of choice (Loizou e French 2012)

For what concern the research related to the *analytical solutions*, it is noticeable that only a few scientific articles or reviews treat these methods from a theoretical perspective. However, within the literature, some methods belonging to analytical solutions were found:

- *Queueing theory*. It is a mathematical modelling method oriented to calculate the measures of effectiveness of a system. (Taha 1981) (Hu, Barnes and Golden 2017).
- *Stochastic dynamic programming.* Stochastic dynamic programming is an optimization tool that is used to support decision-making process when uncertainty affects the system.
- *Stochastic programming.* According to (Kouwenberg and Zenios 2006) it is the most powerful method to support the decision-making process under uncertainty.
- *Fuzzy mathematical programming*. Fuzzy mathematical programming is an optimization model technique that is designed to achieve the optimal solution under uncertainty.

As for the simulation methods, in the following tables (tables 30 and 31) the main applications in industry and the main objectives of the studied approaches are described.

As for the simulation methods, the main limitations and strengths of each method were also analysed. Tables 32 and 33 provide a summary of them.

Table 30 Queuing theory and Stochastic dynamic programming main objectives and application fields

	Application field	Objective
QUEUEING THEORY	- healthcare (Hu, Barnes and Golden 2017) (Au-Yeung, Harrison e Knottenbelt 2006) (Fomundam e Herrmann 2007) (Green 2006)	- redesign facility layout (Taha 1981)
	- Telecommunication (Benvenuto e Zorzi 2011) (Green 2006)	- resource allocation (Green 2006) (Au-Yeung, Harrison e Knottenbelt 2006)
	- Computer science (Benvenuto e Zorzi 2011)	- service design (Green 2006) (Fomundam e Herrmann 2007)
	- Manufacturing (Benvenuto e Zorzi 2011)	- capacity planning (Hu, Barnes and Golden 2017)
	- Air traffic control (Benvenuto e Zorzi 2011)	- flows optimization (Au-Yeung, Harrison e Knottenbelt 2006) (Fomundam e Herrmann 2007)
	- Military logistic (Benvenuto e Zorzi 2011)	
	- transportation (Hu, Barnes and Golden 2017)	
	- Banking (Green 2006)	
	- Airlines (Green 2006)	
STOCHASTIC DYNAMIC PROGRAMMING		- production planning (Sahinidis 2004)
	- economics and finance (Sahinidis 2004) (Marescot, et al. 2013)	- design of experiment (Sahinidis 2004)
	- biological sciences (Sahinidis 2004) (Marescot, et al. 2013)	- scheduling (Sahinidis 2004)
	- aviation (Sahinidis 2004)	- SCM (Sahinidis 2004)
	- agricultural and forestry (Sahinidis 2004) (Marescot, et al. 2013)	- reservoir operations problem (Sahinidis 2004) (Marescot, et al. 2013)
	- mathematics (Marescot, et al. 2013)	- resource management (Marescot, et al. 2013)
	- engineering (Marescot, et al. 2013)	- pest control (Marescot, et al. 2013)
	- ecology (Marescot, et al. 2013)	- fisheries management (Marescot, et al. 2013)
	- fisheries sciences (Marescot, et al. 2013)	

Table 31 Fuzzy programming and fuzzy flexible programming main objectives and application fields

	Application field	Objective
STOCHASTIC PROGRAMMING	- agricultural (Sahinidis 2004) - banking (Sahinidis 2004) - environmental (Sahinidis 2004)	- production planning (Sahinidis 2004) - transportation problems (Sahinidis 2004) - resource management (Sahinidis 2004) - capacity expansion (Sahinidis 2004) - portfolio selection (Sahinidis 2004) - pattern selection (Sahinidis 2004) - environmental management (Sahinidis 2004)
FUZZY MATHEMATICAL PROGRAMMING		- Waste management (Sun, et al. 2012)

Table 32 Queuing theory and stochastic dynamic programming advantages and disadvantages

	Advantages	Disadvantages
QUEUING THEORY	- Explicit structure of the system (Belusso, et al. 2016)	- lack of formal interpretation (Belusso, et al. 2016)
	- provide analytical formulae that facilitate the development of various performance measures from simulation, while offering generalizable insights that are less sensitive to parametric changes (Hu, Barnes and Golden 2017)	- Building an accurate queueing model can be challenging (Hu, Barnes and Golden 2017)
	are able to find the bottle necks (Fomundam e Herrmann 2007)	- variations in system conditions are difficult to capture in an analytical formulation (Hu, Barnes and Golden 2017)
	- cheaper and easier to use (Green 2006) (Hu, Barnes and Golden 2017) (Fomundam e Herrmann 2007)	- DES models imitate system behaviour using the sequential execution of events while exhibiting great flexibility (Hu, Barnes and Golden 2017)
	- can be more readily used to find optimal solutions rather than just estimating the system performance for a given scenario (Green 2006)	- Simulation models have the advantage of incorporating more detailed behaviour and generating more actionable results (Hu, Barnes and Golden 2017)
	- require very little data (Green 2006) (Hu, Barnes and Golden 2017) (Fomundam e Herrmann 2007)	- requires several inputs
	- result in relatively simple formulae for predicting various performance measures such as mean delay or probability of waiting (Green 2006)	- provide more generic results than simulation (Fomundam e Herrmann 2007)
	- fast to use (Green 2006) (Hu, Barnes and Golden 2017)	- difficulty of formulating and solving the mathematical model even though the distribution of arrivals and departures may be fully known (Taha 1981)
	- take an advantage of the possibility that certain assumptions of available queueing model can be violate without resulting considerable error in the system's measures of performance (Taha 1981)	- difficulty of obtaining numerical results from a solved model due to the complexity of the mathematical expression describing the measures of effectiveness of the system (Taha 1981)
		- complex waiting line situation cannot be analysed by queueing theory (better to use simulation) (Taha 1981)
STOCHASTIC DYNAMIC PROGRAMMING	- can be used for solving problems containing discrete variables, non-convex, non-continuous and non-differentiable objective functions (Saadat e Asghari 2017)	- The implementation requires problem-specific algebraic manipulations that make difficult the development of general-purpose software (Sahinidis 2004)
	- determines state-dependent optimal decisions that vary over time (Marescot, et al. 2013)	- when solving any DP or SDP optimization problem, significant obstacles emerge when dimension of state variable is large due to computation of objective function for each combination of values (Saadat e Asghari 2017)
		- "Curse of Dimensionality" (Saadat e Asghari 2017)
		- choosing the time horizon is quite challenging (Marescot, et al. 2013)

Table 33 Fuzzy programming and Fuzzy flexible programming advantages and disadvantages

	Advantages	Disadvantages
STOCHASTIC PROGRAMMING	- solving a fuzzy mathematical programming problem can be easier than a stochastic programming problem (Inuiguchi e Ramık 2000)	- Real world problems are not usually so easily formulated as mathematical models or fuzzy models (Inuiguchi e Ramık 2000) - their implementation requires problem-specific algebraic manipulations that make difficult the development of general-purpose software (Sahinidis 2004)
FUZZY FLEXIBLE PROGRAMMING		- FFP has difficulty in tackling uncertainties expressed as probabilistic distributions or interval numbers in a non-fuzzy decision space (Sun, et al. 2012) - it can hardly deal with ambiguous coefficients in the objective function and constraints (Sun, et al. 2012) - its subsequent solution algorithm would be complicated if complexities in objective functions are transferred to constraints when the satisfaction degree for the fuzzy decision is introduced (Sun, et al. 2012)

According to what emerges from literature, summarized in the previous tables, in the last decades, simulation approaches became a quite common practice, and many authors propose their own perspective.

In general, the review prizes the capability of simulation techniques to model a system also capturing its dynamic behaviour, considering the time perspective, so as identifying the effects of the variables changing in order to define the performance of the system (Phumbua and Tjahjono 2010).

The ability to predict how a system state change over time is a core concept pointed out by many authors (Aguilar-Saven 2004) (Pollacia 1989). Furthermore, (Borshchev and Filippov 2004) highlight that: "*Simulation is the process of model "execution" that takes the model through (discrete or continuous) state changes over time. In general, for complex problems where time dynamics is important, simulation modelling is a better answer*".

Another group of authors (Altiok and Melamed 2010) (Imam, et al. 2011) (Hsieh 2002)(Mula, et al. 2013), is more alert in stressing the capacity of simulation modelling to predict the entire system performances in terms of efficiency, therefore supporting the decision-making process.

For what concern the analytical solutions, an analytical model could be defined as *"a set of mathematical equations that translate the entire system, providing exact and static information*" (Hsieh 2002). This type of modelling is concerned with the solution of a mathematical problem and algorithmic steps (Altiok and Melamed 2010) and the solution obtained usually provides a precise performance measurement. During the development of analytical models, the definition and the selection of the input variables play a key role in affecting the model results, and in many cases, due to the complexity in finding the input parameters, an analytical solution cannot be determined (Borshchev and Filippov 2004). In other words, an analytical solution provides precise information about the system. However it does not analyse the real system: "*the overall simplicity of a typical optimization model comes at the expense of generality*" (Ge, et al. 2016). This drawback is due to the inability of the analytical model approach to translate complex systems, characterized by high level of uncertainty, into a mathematical model. (Taha 1981) also stresses the complexity of analytical models in formulating and solving the mathematical model of the system complexity. An additional limitation related to the use of the analytical solutions is the generalization of the system features due to the use of excessive simplifying assumptions. Indeed, through an optimization method, uncertainties and realism are not considered during the modelling phase.

According to the aforementioned features, both analytical solutions and simulation analysis present specific strengths regarding their ability to evaluate the performance level and the accuracy of a system.

A simulative approach provides some advantages in the system modelling due to its ability to replicate different scenarios (Akanle and Zhang 2008). This feature supports an exhaustive comprehension of the system general behaviour without providing an accurate solution because it does not ground on a perfect relationship between the variables used to describe the system (Lewis 2013).
On the other hand, analytical solutions (also referred as optimization models) precisely construct the relationship among the factors that affect the entire system but they usually present difficulties upstream, that is, in the mathematical representation of the entire system (Ge, et al. 2016) . According to the analysed literature, the representation of systems is not always possible due to the overall system complexity.

Considering the PSS main features (detailed in section 2.1.2) the weakness of analytical solutions in representing the system complexity, makes the method not suitable for the assessment of service delivery process. Hence, simulation reveals as the most suitable method for the assessment of service delivery process due to the following capabilities (Hlupic and Robinson 1998):

- Simulation allows the investigation of many different process configurations in one single model, regardless how complex they are.
- Simulation supports “what-if” analyses. It can provide insights into an existing or a hypothetical situation, allowing for a safe, replicable, and usually less expensive performance test and analysis compared to a real-scale implementation, where in the majority of the cases a trial and error approach is not a viable option (Hlupic and Robinson 1998) (Laughery, Laughery, et al. 1998).
- Simulation can allow the analysis and measurement of the dynamic performance of a given process, and the assessment of both the presence and relevance of any queue and/or bottlenecks. Simulation can also allow for a better understanding of the causes of the dynamics that emerge during the execution of the service process. Having control over time and monitor the situation during several years is very useful when observing performance in the long term.
- Simulation offers interactive and visual assistance for PSS modelling, facilitating the comprehension of the model and its results, enhancing the validation process (Phumbua and Tjahjono 2010).

As a result, it could be possible to highlight that business process simulation can be adopted to support engineering and engineering assessment of a service. In particular, according to the given the definition of services comparing it to a process, discrete event simulation (DES) paradigm, traditionally used for the analysis of manufacturing processes, can represent a valid choice for service process analysis. In particular, it can be used as a decision making tool for the assessment and the improvement of the actual service delivery processes (Visintin, et al., 2014) (Chalal, et al., 2015) (Babulak and Wang 2007) since it provides a support for qualitative and quantitative assessment of company decisions.

Given the definitions of service, along with the fact that most services are fairly well defined discrete processes, DES offers great potential as a means of describing, analysing, and optimizing service and service systems of many types (Laughery, Laughery, et al. 1998) and supports their systematic and optimized engineer.

Aiming at exploring the adoption of DES in the PSS field, in the next section, a general analysis of the available literature in the area of simulation applied in the PSS field is presented.

7.2.1 Simulation in the PSS field: literature overview

The analysis of the available literature in the area of PSS and simulation, highlight that, although to a certain degree, this working mechanism is similar to manufacturing systems, service delivery processes have some unique characteristics making the system to be depicted more complex with respect to a traditional manufacturing process. The following differences can be identified (Banks 1998):

- *Arrivals in service are typically random and cyclical*: the arrival of requests for a service can be correlated with the day or the time within a day, for example (Gladwin and Tumay 1994).
- *Resources are prevalently people that have less predictable behaviour when confronted with unforeseen events*. According to (Duckwitz, Tackenberg and Schlick 2011), three main characteristics are quite complex to simulate: i) decision making behaviour (the decision-making process can be influenced by deadlines and rewards, and therefore not being completely rational); ii) cooperative work (different people have different attitudes toward collaboration); iii) human reliability (related to personal, organizational and environmental factors). In addition, human resources may have different skills and qualification, and in many cases they are moving resources (i.e. they are required to move to customer premises in order to deliver the service, as in on-site technical assistance services) (Lagemann, Boblau and Meier 2015). Therefore, due to the prevalent presence of people, system variability in service is often much higher than in systems with automated resources and, therefore, of greater importance.
- *Entities are also people*: similar to resources, entities being served often represent people that may have a rather non-rational behaviour and preferences. These behaviours change dynamically during the execution time of an activity and waiting times, as well as the saturation of resources (Lee, Han and Park 2015). For example, a customer can enter the system but leave before joining a queue, for example because it is too long (balking).

Otherwise, a customer can join a queue and leave before being serviced because he/she has waited for too long (reneging). Finally, a customer can join a queue and then move to another, seemingly faster one (jockeying) (Chung 2004).

- *Process times are highly variable*: especially when resource and entities are people, the processing time may depend upon the status of the system. In a service delivery process, the value is created from the interaction between the resources (representing the service provider) and the entities (customers). The uncertainty related to those people increases exponentially while allowing their interaction.
- *Lack of steady-state behaviour over the overall running period*: due to the random and cyclic arrivals, service usually does not reach steady states. Moreover, arrivals may change according to the day or the time of the day.
- *There is often no clearly defined set of components as in manufacturing*: the simulation package must often define system behaviour without the use of hard data in the process. The simulation modeller is often called upon to define and understand the process in a complete way than anyone did before.
- *Waiting time tends to have much greater importance than throughpu*t: a service cannot be stocked. Therefore, the process and waiting times have great relevance in a service environment: people hate to wait to be served.
- *Services are often short-term demand driven, and these demands can vary by day and time*: fluctuations in demand (in terms of both mix and quantity) for services will greatly affect the service's ability to provide good service. Again, because of the variability not only of service providers but also of those demanding services, it is important to understand and predict the factors affecting customer demand.

These complexities related to simulation in the field of PSS are directly linked to the PSS features described in section 2.1.2. Hence, it could be possible to highlight how the PSS features also influence the method and tools to be adopted during their engineering phase.

In order to reach a holistic understanding of the topic of simulation and PSS, a specific analysis on simulation adoption in the area of PSS was also carried out. It is worth mentioning that even if the analysis of simulation methods benefits and threats describe the DES as the most appropriate for the analysis of service processes, in the PSS literature others simulation approaches could be also found. This is summarized in table 34. For each paper, the specific simulation method adopted is reported together with the main aim of the paper.

Table 34 Summary of papers in the area of PSS and simulation

Existing work related to simulation and PSS	Paper aim	Simulation modelling approach adopted: ABM	DES	SD
(Bianchi, et al. 2009)	Analysis of the dynamics associated to a transition from a traditional product-oriented to a PSS strategy			X
(Legnani, et al. 2010)	Assess the introduction on preventive maintenance in farm machinery industry			X
(Lee, Geum and Lee, et al. 2012)	Measuring sustainability in a PSS			X
(Lovrić, Li e Vervest 2013)	Decision support system for sustainable revenue management based on economic, social and environmental sustainability	X		
(Maisenbacher, et al. 2014)	Evaluation of the optimal amount of bikes to use in an e-bike system	X		
(Visintin, Porcelli e Ghini 2014)	PSS delivery process optimization		X	
(Lagemann and Meier 2014) (Lagemann, Boblau and Meier 2015)	Design and restructuring of industrial PSS, strategic resource capacity planning decisions	X		
(Lee, Han and Park 2015)	Measurement of PSS functional performance			X
(Weidmann, et al. 2015)	Uses DES to support decision making considering three kinds of PSS: result oriented, use oriented and product oriented.		X	
(Wrasse, Hayka e Stark 2015) (Wrasse, Hayka e Stark 2016)	Assess the company service level	X		
(Pezzotta, Pinto, et al. 2014)	Support the design of the service delivery process of a PSS.		X	
(Kuo 2011)	Comparison of renting and traditional business model for PSS provision		X	
(Alix e Zacharewicz 2012)	PSS business scenario simulation based on G-DEVS/HLA		(X)	
(Elia, Gnoni e Tornese 2016)	Assess the efficiency of a PSS solution			
(Van der Veen, Kisjes e Nikolic 2017)	Assess the impact on sustainability of a PSS solution	X		

According to the table, the state of the art confirms that some attempts to evaluate and assess the service delivery performance through simulation already exist. This also demonstrates that simulation techniques can potentially help to gather the dynamics of a service delivery process. As previously hinted, in addition to process analysis through DES, seminal works based on ABM and SD can be found.

However, among the studies explored, very few of them are focusing on the service process analysis and assessment and they are exploiting the DES method.

In the light of the results of the literature analysis on simulation and analytical methods, and considering the existing research available in PSS domain, DES reveals as a proper method to support the assessment of the service delivery process. In order to verify this result, in the next section, DES is adopted into multiple cases in order to verify in practice its capabilities for the assessment of the service delivery process.

7.3 Adopting DES to assess the service delivery process: industrial cases

According to what emerged from the literature analysis (section 7.2), simulation, and specifically DES, revealed as a proper method to support the assessment of the service delivery process hence the proper method to answer the second research question of this thesis.

In the direction of verifying the literature results, DES was adopted in real cases in collaboration with ABB. Table 35 summarizes the validation cases carried out and classify them in terms of the industry to which they belong, the analysed services and the objective of the study. The cases were selected because of the variety of goals concerning the service delivery process assessment. Two of the studies are mainly aimed at the "pure" assessment of the existing service delivery process (case #1 and case #2). The first refers to Make to Stock products whereas the second focuses on Engineering to Order products for which the customization are the customer vicinity are more relevant. Case #3, in addition to the assessment of the process, focuses on the identification of a proper configuration of the service delivery process to manage very different customers. Case #4 refers to the assessment and the optimization of the process in order to make it replicable in the units around the world. The variety of objectives makes the sample of selected cases a good ground where to test the DES capabilities and to explore different PSS applications. Even if they were all explored in collaboration with ABB, it could be highlighted that they all belong to different contexts and products. Therefore they could represent a heterogeneous sample.

The services analysed through the units are similar to each other, hereafter is a brief description:

- *Preventive and corrective maintenance*. It refers to all the activities performed on the customer's product in order to make it functions as efficiently as possible or, in case of corrective, to recondition it to proper functioning. In the analysed case, maintenance can be performed at the customer site or at the ABB plant.
- *Replacement.* It consists in the provision of products currently out of production. A limited amount of these products is still produced for customer with plant's specific needs.

- *Retrofit*. ABB provides specific kits for adapting a new product to the fixed part of an old one. This helps in adding functionalities to an aged product.
- *Remote support*. It consists of an online support granted to customers. This is allowed by the products that are connected to the internet or to a cloud.
- *Commissioning and installation*. This service refers to the product placement and setting that is performed at the customer site.

Table 35 Summary of business units and analysed service delivery processes

Case #	Business units in which the service has been analysed	Business Unit business	Service	Goal of the analysis
1	**Low voltage products**	Power management	Preventive maintenance Corrective maintenance Retrofit installation Replacement	Assessment of service delivery process or multiple services of a Make To Stock product
2	**Low voltage system**	Power management	Preventive maintenance Corrective maintenance Commissioning and installation	Assessment of service delivery process or multiple services of Engineering To Order product
3	**Robotics**	Automation	Preventive maintenance Corrective maintenance Remote support	Assessment of the service delivery process to manage multiple and extremely different customers
4	**Motors and generators**	Power generation	Preventive maintenance Corrective maintenance Remote support	Assessment and optimization of the service delivery process in order to replicate it in multiple units.

According to table 35, all the services processes provided in each unit were studied with DES. Each case was developed through multiple semi-structured interviews involving employees from different functions: service operations managers, sales managers, field service operations managers and back office employees. Additional data and information were also gathered offline. In order to apply DES, for all the processes three main steps were followed:

1. *Process mapping* through blueprinting method in Microsoft Visio. In multiple meetings with involved people were held to represent the process as it is.
2. *Model development and data collection* about the process and definition of a simulation model. In this phase, the people involved were asked to share information regarding activities duration, service demand (the input of the simulation model) and specific information about the resources involved and their timetable. The data were all included in ProModel Process Simulation[1] software. The DES model was developed considering customer requests

[1] ProModel Process Simulation is the software selected inside ABB for the analysis of processes. The selection of the software in this work is defined based on this.

associated with the different offerings as entities. The steps of the service delivery were represented as the service delivery process activities. Each activity was then assigned a duration and was coupled with a resource or a group of resources that perform the activity. For what concern human resources (actually the majority) the weekly working schedule was defined to schedule the amount of their time dedicated to the service process under investigation. The final simulation model appears in the exemplification in Figure 36. Many simulations run were done to validate the model against the actual process. Appendix B includes the process mapping of the simulation models built during the applications.

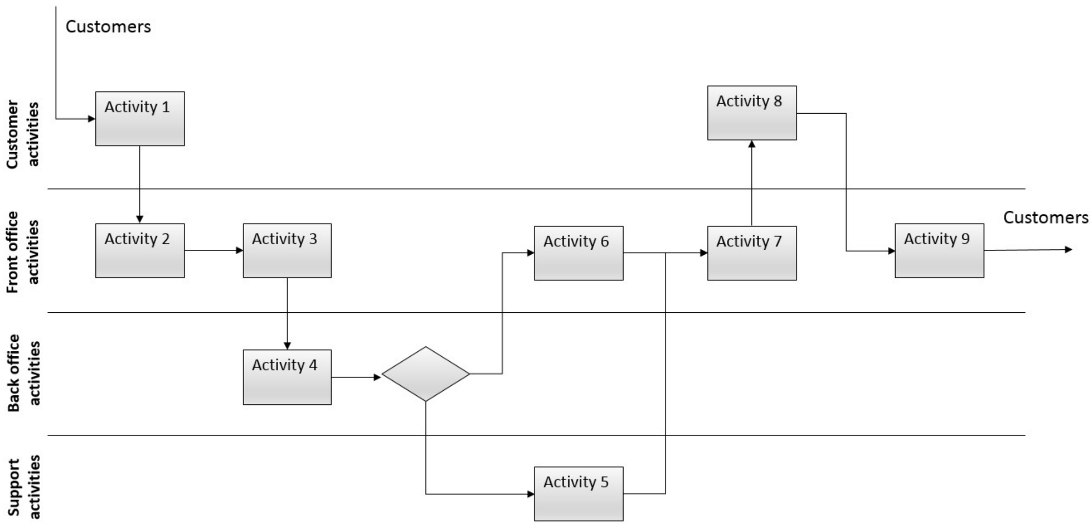


Figure 36 Simulation model structure

3. *Process assessment and what-if analysis*. Multiple KPIs were analysed as a mean to engineer appropriate process configurations balancing customers and company perspectives. In particular, the following indicators were considered

   - *Company internal measures:*
     - *Number of completed service jobs per year*. For each kind of service, the number of requests yearly received, together with those completed has been identified. The number of entities still in the system or exit from the system is automatically shown by the simulation software;
     - *Time to complete a service job.* The time for processing each kind of service request has been measured with an "ad hoc" function monitoring the time laps between the request arrival and its conclusion;

- *Resource utilization.* It represents the utilization of the human resources based on the time they dedicate to the process activities. Resource utilization is a standard output of the simulator;
- *Queues*: they were measured as the waiting time to perform an activity and it is a standard output of the simulation software. The queue lengths along with the resource utilization were used to identify the bottlenecks in the system.

- *External KPI (Customer satisfaction)*. The process assessment from the customer perspective was measured considering customer waiting time in relation to each service activity. The most critical activities were paid higher attention. These data are standard output of the simulation software.

In accordance with the application in the abovementioned cases, the practical application of the DES into the service context revealed more challenging than expected. Practically, what was almost consolidated from an academic point of view, was not as trivial as expected.

Even if the service delivery process is very similar to a manufacturing process, the service features (section 2.1.2) and the related simulation complexities (section 7.2.1) make the representation of the service process challenging and time consuming. This stresses the fact that simulating the service provision process is far more complex than dealing with a traditional manufacturing environment. Besides the complexities of the management of the service delivery process, the specific objectives of the cases were also complex to achieve due to the limitations of the DES approach. In the following paragraph, the main limitation of the DES regarding the overall assessment and the main objective of the studied cases are discussed and summarized.

7.4 Discussion

The applications of the DES method in multiple cases stress the difficulties of depicting service delivery process into a simulation model. Apart from the complexity of the practical application, not trivial as expected, the application in industrial cases (in all the analysed units) highlights few benefits that can be achieved from the utilization. In particular, the cases highlight the potentiality of the approach in:

- Evaluate the internal (company) performance of the prototyped service delivery process
- Assess and compare a variety of service delivery configuration before the actual implementation of the solution in practice (lower costs and effort required).

Moreover, according to managers' feedbacks, the process mapping lead to an improved understanding of existing processes and inefficiencies. In addition, it supported the analysis of a variety processes characterized by a better resources planning.

On the other hand, the adoption in industry emphasizes the main weaknesses of the DES approach.

Distinctly the following issues emerged:

- *The assessment approach is an extremely time consuming activity*. Every time a new process has to be evaluated, the simulation model has to be built from scratch and this requires a relevant effort for the people managing such activity. In the light of industrial feedback, this effort is not always feasible in practice. The technical skills necessary to manage the model contribute to the complexity of the approach adoption.
- The detail at which the approach monitor and assess the service delivery process imply a *huge data collection* in order to make the model running. This also contributes to the complexity of the approach.

Both the two issues were pointed out in all the cases (case #1, case#2, case#3 and case#4) and as soon as additional cases were included in the study, the problem became clearer and clearer. Although the processes were partially similar (the overall process structure to deliver a service to the customer is similar throughout services) the time required to set up a new model was significant and not feasible in practice. In the case of motors and generators, where the main goal was the replicability of the process into other units around the world, the problem was further exacerbated considering the multiple model setting and data collection activities required.

- As stated in section 7.2.1, one of the main features of the service delivery process is the *uncertainty that rise from the customers and the human resources* engaged in the process. To deal with this uncertainty, many assumptions about the customers have to be set. The customer behaviour indeed was represented through a distribution that approximately describes the human behaviour, but that could prevent a precise description of it. In the case of Robotics (case #3), in which the main goal was the assessment of the process considering very different customers, the modelling of a variety of customer preferences revealed technically complex both to design and to understand. The weaknesses of the assessment method emerged from the industrial applications spur the improvement of the overall approach in order to make the method easier to use and more fitting with reality.

In line with the gaps, two main improvements were explored more in detail. First, the definition of a **modular approach for service delivery engineering** that could facilitate simulation model implementation and service delivery assessment. Second, the study of the **hybrid simulation paradigm** was developed trying got improve the customer representation into the simulation based assessment approach. The gaps together with the possible improvements are summarized in Figure 37. The two enhancements are respectively presented in chapters 8 and 9.

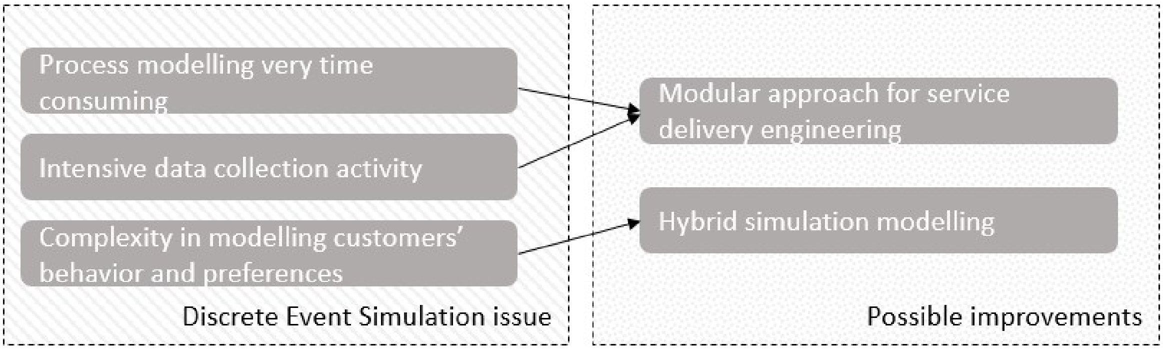


Figure 37 Summary of gaps and possible improvements regarding service delivery process assessment

8 Modular engineering and standardization applied to service delivery process

The validation cases described in the previous chapter, highlight how the development of a simulation model requires a consistent amount of time that in industry could prevent the adoption of the method itself. The problem is further exacerbated in case many processes have to be modelled and simulated.

On the other hand, considering a variety of services, the overall process has a similar structure. Usually there is a first contact with the customer, then there is a verification phase during which the provider verify its availability and finally, the provider works to solve the customer problem. In the light of these similarities, a relevant number of services could be modelled putting together similar activities. Hence, development of a simulation model would require less time since existing processes could be used as a starting point for the development.

In this direction, the chapter aims at exploring standardisation and modularization in the area of service processes to the extent of reducing the complexity and the variety of service delivery processes variants. In turn, this would lead to a reduced assessment time while allowing an increase in customer satisfaction and reduction of process management costs.

After a literature review in the area of standardization and modularization (section 8.1), the following paragraphs propose a structured technique for service process modularization (section 8.2) that includes: i) a structured approach that guides the identification of a standard process for each single service a company actually delivers (or will deliver), and ii) a service based taxonomy to set concepts inside the company and to contextualize the standard service delivery process into the company structure and offering.

8.1 Explorative literature review

The literature on "service engineering", "service design" and "service operations" has been screened to highlight existing researches around standardisation techniques for the service delivery process. The review has been conducted using Scopus and ISI Web of Knowledge databases as a structured search using "service" as the main keyword coupled with "process standardization" or "business process standardization" or "standardisation procedure". Since after the first search no results were obtained, the collection of papers has been extended pruning the "service" term. Accordingly, the results obtained were mainly in the area of "business process standardization". A first search has led to 256 peer-reviewed papers that, after language and topic screening (2nd step) and abstract reading (3rd step), reduced the research works to the ones mentioned hereafter. It is worth considering that the majority of the papers have been excluded during the 3rd step since their findings are not applicable in the service delivery process context. Indeed, most of the identified research pertains to technical issues in IT and computer science area (e.g. software infrastructure (Verdouw, et al. 2010), cyber physical systems or client architecture) and no procedure for process standardization is explicitly mentioned. To better investigate the topic, ISO standards related to service delivery have been also screened. The only standard refers to business process modelling notation (e.g. BPMN).

Among the analysed papers, there is a common understanding of business process standardization. (Münstermann and Weitzel 2008) define business process standardization as "bringing the selected business process in line with the archetype process", where the archetype process is a business process that serves as master. Similarly, (Romero, et al. 2015) define business process standardization as the activity of unifying different variants of a family of business processes and (Dijkman, La Rosa and Reijers 2012) highlight the different possibilities to manage a large collection of business processes among which the unification of them is in the direction of standardization and unification of procedures.

Through the literature analysis four main areas of investigation emerged (Zellner and Laumann 2013): i) analysis of the advantages related to standardization (Zellner and Laumann 2013); ii) strategic identification of suitable processes to be standardized (Tregear 2010); iii) identification of success factors for process standardization (Rosenkranz, et al. 2009) (Dijkman, La Rosa and Reijers 2012); and iv) creation of business process modelling standards (Ko, Lee and Lee 2009).

In general, very few papers propose practical and usable step-by-step procedures or approaches to standardize processes and no papers specifically address this issue in the service environment. (Münstermann and Weitzel 2008) define a four-step-approach for the standardization of a process, suggesting to i) document all the process variants, ii) define an archetype process and then iii) enhance it to a standard process, exploited at the end to iv) homogenize the variants. Besides, a similar seven-step-approach has been developed by (Grichnik, Bohnen and Turner 2009), called the "standard work wheel". The seven steps are similar to those proposed by (Münstermann and Weitzel 2008), but they stress the importance to define a standard clear to understand and highly accessible.

In parallel, literature highlights the importance of adopting a common and clear nomenclature, which reduces misunderstanding, allowing an easy application in different units and ensuring consistent results from process standardization. This could be also beneficial for the adoption of DES. (Becker, Beverungen and Knackstedt 2009) identify "conceptual modelling" as an established approach to support and guide standardization efforts and consider "reference models" and "modelling languages" as two ways to support the integrated design. (Verdouw, et al. 2010) Highlight the importance of "reference models" to making the system complexity manageable, by providing systematic representations (visualisation, description) of architectures from different viewpoints and at various levels of abstraction. . In the same direction, (Dijkman, La Rosa and Reijers 2012), even if focusing on the data system management, highlight the following aspects to monitor while merging more processes among which the label similarity and the language support (Lonjon 2004) points out the following three main criteria for the definition of a standard representation of a business process: (i) an intuitive notation; (ii) a meta-model and vocabulary—a group of concepts and relationships—that are strictly and consistently defined to provide a solid foundation for the various business process approaches; (iii) a breakdown of the meta-model and notation for each level of analysis of business processes. Finally, (Shitkova, et al. 2015) highlight the need of modelling guidelines, such as the use of a domain-specific glossary and verb-object phrase structures for element labels as a mean to avoid confusion and pitfalls.

Summarizing, even if a comprehensive and shared technique for process standardization is missing, literature highlights two major arguments that disclose fundamental actions to be undertaken during process standardization:

- representation of the process itself through the definition of a *process archetype* (i.e. the content of the standardization);
- identification of a *standard taxonomy*, vocabulary and process nomenclature to be associated with the standard process to make the standard easily replicable in different contexts; this drives to the definition of a *reference model*.

These findings provide a useful trajectory to identify properly an approach for a service delivery process standardization and thus supporting the DES assessment method.

8.1.1 State of the art on process archetypes

According to (Münstermann and Weitzel 2008) the identification of a process archetype is based on four main dimensions: (i) document process, (ii) modularize process, (iii) isolate specificities and (iv) ensure process excellence. For what concerns process documentation, service processes representation adopts common and widespread methods, such as blueprinting (Shostack 1982). Conversely, research in the area of service process modularization is quite limited even if it is considered as a proper method to enhance process standardization (Grichnik, Bohnen and Turner 2009). Regarding the third and the fourth steps, there is no specific way to approach them since they strongly depend on the selected modularization approach.

Modularization refers to the practice of creating modular components (and processes) that can be configured into a wide range of processes to meet specific customer's needs. A modular structure is a structure consisting of self-containing, structural elements with standardised interfaces in accordance with a system definition (Bruun, et al. 2015). A keyword search in Scopus, and ISI Web of Knowledge databases using "service process" and "modularization" as search input has been carried out. As in the case of standardization procedures, the search results were not applicable in the service manufacturing context. Indeed most of the existing researches on modularity focus on product rather than service (A. Bask, et al. 2010).

The first work on service modularity belongs to (Sundbo 1994), the following researches refer to service modularity through multiple approaches where the unit of analysis (i.e. the module) is different: it can include the entire process, specific software connections, activities or value proposition (Iman 2016) (A. Bask, et al. 2010) (De Blok, et al. 2011) (Pekkarinen and Ulkuniemi 2008) (Piran, et al. 2015). (Böttcher and Klingner 2011) try to adapt software engineering modularization concepts into the field of service and provide a method to structure service modules for service configuration. (A. Bask, et al. 2011) introduce a framework to combine service modularity and customization of the service offer. (Geum, Kwak and Park 2012) propose an approach based on House of Quality structure to modularize services. (Wang, Ming and Wu, et al. 2014) design a modular system of product-service and a meta-ontology associated with it. (Eissens-van der Laan, et al. 2016)try to enrich service modularity theory by identifying and comparing 16 different ways to decompose service offering into modules. (Hao, et al. 2012) define service module as the abstraction from tangible service or intangible service with independent function, and it realizes service functions through the interaction of physical modules and services process.

For what concerns explicitly service process modularity, research is still in its infancy and there is not a clear understanding about the subject, the modules, their features, and the way in which they must be used. (Tuunanen and Cassab 2011) study the impact of IT service process modularization on customers and their preferences. (Liu, et al. 2016) highlight the possibility to separate service processes into different modules in line with different processes. However, no definition of service process modules is proposed neither mentioned. It is not possible to identify a specific service process modularization approach to enhance standardization.

8.1.2 State of the art on reference models

According to (Becker, Beverungen and Knackstedt 2009), a useful approach to devise univocal documentation about process flow, structures and resources is the adoption of a reference model. Indeed, it can contribute to simplify and fasten the implementation of the standardization approach, while providing a better understanding of the processes. A reference model can be defined as "an abstract framework for understanding significant relationships among the entities of some environments" (OASIS, 2006). Its main objective is to provide a consistent breakdown of the process under analysis while using a taxonomy suitable for different implementation across and between different industries. Although different reference models have been developed in different industries and fields, such as (Kalpic and Bernus 2002) (Hanneghan, Merabti and Colquhoun 2000) some reference models (summarized in Table 36) can be analysed in relation to the service domain.

Table 36 Reference model literature review (Curiazzi, et al. 2016)

Reference Model	Purpose
APICS-SCC Framework	
SCOR	SC performance measurement and comparison (Supply Chain Council, 2010b)
DCOR	Link R&D business processes, metrics and practices (APICS Supply Chain Council, 2014 a)
CCOR	Link sales operations and customer support business process, metrics and practice (APICS Supply Chain Council, 2014b)
PLCOR	Link product lifecycle processes, metrics and practices (APICS Supply Chain Council, 2014 c)
Federal Enterprise Architecture (Chief Information Officers Council, 2013)	
PRM	Link strategy, internal business component and investments
BRM	Link business function and IT investment
DRM	Facilitate the discovery of existing data
ARM	Categorize standards and technologies that support the delivery of IT service
IRM	Provide a categorization scheme for physical IT assets
SRM	Controlling security and privacy
Other Models	
VCOR	Release a unified reference model for the entire enterprise (Group 2006)
E-TOM	Provide a common language for service providers' internal process, collaborations, alliance, agreements with other providers (Forum 2004)
ITIL	Provide a wide accepted guide to Best Practice for the IT Service Management (Cartlidge, et al. 2007)
GSCF	Built on eight key business processes that are both cross firm and cross functional. Focuses on relationship management. (Lambert, Cooper and Pagh 1998)
MIT handbook	A tool for (re)designing business processes and organising business process knowledge (Malone, et al. 1999)

The most relevant reference models belong to three main clusters. The first group includes the models developed by the Supply Chain Council, an independent, no-profit global corporation. Such models guide the process design and performance measurement throughout the different areas of the supply chain. Among them, no one specifically refers to service activities but customer support business processes are encompassed in the CCOR-model. It provides a unique framework that links business process, metrics, best practices and technology features into a unified structure. It is based on four hierarchical levels that collect customer support processes (plan, relate, sell, contract) and the related specific activities.

The second group of reference models collects those from the Federal Enterprise Architecture (FEA). The FEA is a business and performance-based framework for cross-agency, which provides a new way of describing, analysing, and improving the federal government. The main objective that pushes the FEA effort is the improvement of the government's service delivery both to and for the public. However, the scope of such models is mainly on data, technologies and IT assets.

Additional reference models that support the integration of customer support inside the supply chain constitute the third group. The Value Chain Group (VCG) (Group 2006) aims at releasing a unified reference model for the entire enterprise able to expand beyond the domain of supply-chain management. The ITIL (Cartlidge, et al. 2007) stands for "IT Infrastructure Library" and refers to a framework whose aim is to provide a wide accepted guide of Best Practice for the IT Service Management. ITIL architecture is centred on the continuous measurement and improvement of the quality of the services delivered, considering both the business and the customer perspectives. Finally, the Enhanced Telecom Operations Map (eTOM) (Forum 2004) is a framework adopted in the telecommunication sector that categorizes the business of the services providers. eTOM Business Process Framework considers both business and customers' point of view. GSCF model (Lambert, Cooper and Pagh 1998) focuses on relationship management whereas the MIT handbook (Malone, et al. 1999) managing dependencies into the supply chain with little focus on service management.

Although several reference models do exist, none of them refers specifically to the service delivery process. Existing works partially refer to services (e.g. linking services to strategy or to technologies) but they do not take into account the specific activities to exploit the service delivery. In fact, neither they are focused on the service delivery process nor they are able to manage the process systems complexity, i.e. the various activities required, the associated software and tools, and the resources required to perform such activities. Thus, in their current form they are not suitable to describe the service delivery process.

8.2 A structured technique for service process standardization

The literature analysis shows that process standardization in relation to service processes environment is underexplored: there is no general and widely recognized procedure to identify a standard service delivery process. However, it sheds light on the advantages of modular engineering to define the process archetype and on the plethora of reference models that are used in different fields to set relationship and interconnection of entities in diverse environments. In the direction of enabling a quicker and efficient service delivery process assessment, a structured technique for service delivery process standardization based on modularization is described in this section. To main outcomes are described:

- a structured approach to identify a final service process archetype through the adoption of modular engineering;
- a reference model framework that defines the taxonomy, the nomenclature and the relationships of the service delivery process within the organization; this would support the replicability of the standard archetype in various units.

8.2.1 Definition of a structured approach for process standardization

According to the literature findings, process modularization is a critical step in the definition of a standard process and it could support the replicability of service delivery processes as a mean to facilitate the assessment phase. Hereafter is the overall structure of the technique. The approach proposed in this thesis conceives a modular system as "a system built of components, where the structure ["architecture"] of the system, functions of components ["elements", "modules"], and relations ["interfaces"] of the components can be described so that the system is replicable, the components are replaceable, and the system is manageable" (A. Bask, et al. 2010).

The service domain elements are scaled accordingly. The modular system is represented by the decomposition of the service process into modular sub-processes. The delivery process of a single service is the *structure architecture*. The "*modules*", or the elements, are defined as a set of activities that are homogeneous and have high cohesion. Indeed, "a module is a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units" (Baldwin & Clark, 1997). Accordingly, each module of the proposed service process modularization approach contains activities that are strongly connected to each other (e.g. require the same resources skills) and are weakly connected to activities belonging to other modules. In other words, each module can be defined as an elementary building block that, combined with others, creates the overall structure architecture: the delivery process of a single service. Similarly to the approach adopted by (Aurich, Fuchs and Wagenknecht, Modular design of technical product-service systems 2006) for the design process, the modules identified in this work are like "black-boxes" characterized by specific inputs and outputs. The inputs and outputs of the activities inside the modules are the *interfaces***;** each module should have one single input and one single output. Being a set of activities, the modules can be then connected to each other's based on specific sequences.

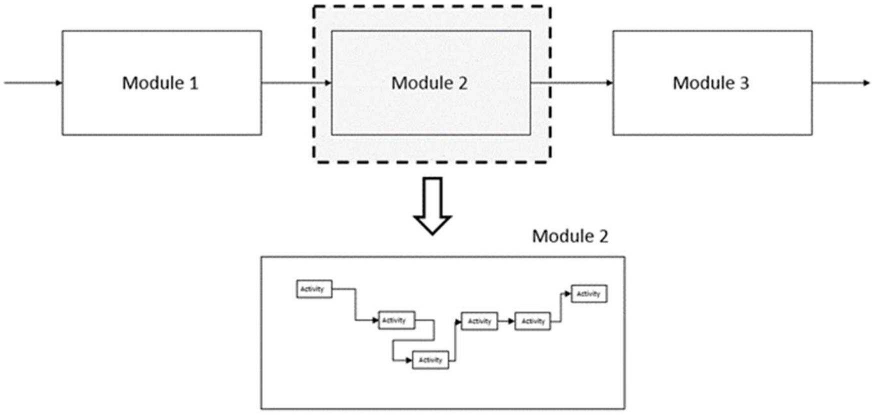


Figure 38 Modular process structure of the proposed approach

Figure 38 shows the proposed concept of a standard module based on a group of activities.

The *process archetype,* similar to a process template (Kumar and Yao 2012), is defined as the standard configuration and connection of the modules. Based on these modular engineering concepts, a service delivery process could be analysed and a process archetype, composed by a determined sequence of certain modules, can be set up.

8.2.2 Definition of a reference model structure

In order to represent properly the service delivery standard process, the definition of a reference model that identifies a unique taxonomy and nomenclature associated to the process archetype has been defined by the literature of utmost importance (Shitkova, et al. 2015). Hereafter, a service process reference model framework to be coupled to the process archetype is proposed. It would support in establishing the relationship of the service processes in the organization and in setting up service concepts and definitions. The proposed model exploits the CCOR hierarchical structure (APICS Supply Chain Council, 2014b) and is structured as in Figure 39: the first two levels mirror the company business and offer whereas level 3 and 4 provide details about the service operations.

- *Level 1* identifies the business area for which the reference model is set. For example, this level can refer to after sales services.
- *Level 2* defines the offer proposed by the company at Level 1. For example, inside the after sales business a company can offer spare parts provision and/ or warranty extension.
- *Level 3* represents the process archetype linked to each company offer. The process archetype structure and its modules constitute this level. For example, the level 3 associated to spare part provision (Level2) could be composed of 4 modules describing the service process high level structure: offer generation process, order management process, spares delivery process, payment process. This is the level that is foreseen be adopted in the DES assessment method.

- *Level 4* is the implementation level and includes all the detailed activities defined in each module (Level 3). In the majority of cases, it describes the specific activities of a company. These activities are included in the single module represented in the simulation model.

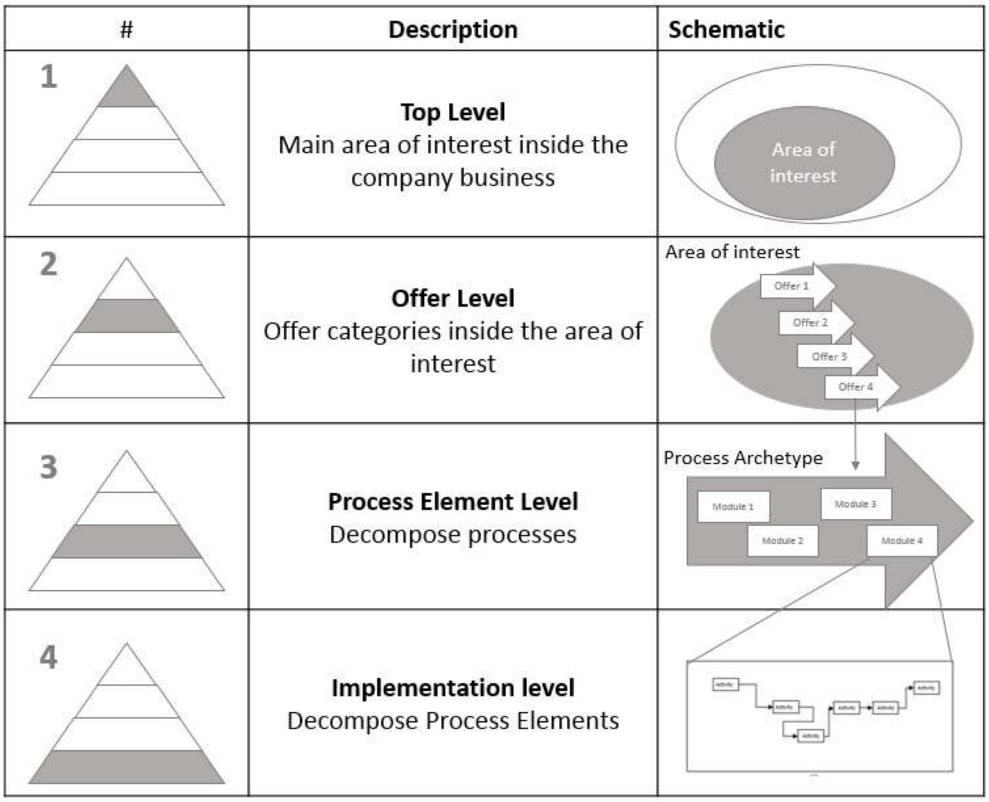


Figure 39 Reference model framework

The structured technique for service process standardization and modularization highlights how to manage the modelling of the service delivery process in order to make it standardized and based on modules. Furthermore, it shows how to couple it with unique nomenclature and taxonomy. This technique would support the engineering team during the assessment phase of the service delivery process. Indeed, assessing a process that is standardized and based on modules would significantly reduce the time to set the first model of the process to be evaluated through simulation. In turn, this would help in solving the major issued emerged from the application of DES in practical cases (Section 7.3). In the following chapter, another improvement to deal with such issues is described.

9 Multimethod simulation for service delivery process assessment

The application of the DES for the assessment of the service delivery process in chapter 7 gives prominence to the difficulties to be faced in order to simulate customer behaviour. This is particularly challenging when many customers are involved in the process and they differ in behaviour.

However, as documented in the literature analysis (section 7.2), in order to face the challenge some advancement emerged in the area of simulation. In particular, agent based modelling (ABM) is a recent approach developed to model individuals' behaviour, through a bottom-up perspective in which agents have their own rules and become active elements of the model.

One the one hand, ABM could easily represent customers' behaviour. On the other hand, this could not substitute the DES in representing the service delivery process that could be compared to a "special" manufacturing process.

The quest for the adoption of two simulation approaches at the same time pushed toward the analysis of hybrid simulation. Indeed, hybrid modelling grew out of the need to combine the advantages of two or more of the "pure" approaches (DES, SD, ABM), integrating into one single model functionalities and features from the different techniques (Lättilä, Hilletofth and Lin 2010) (Brailsford, et al. 2013). Hence, this allows higher flexibility and the exploitation of different levels of abstraction in a single model, benefitting at the same time from the strengths of each method (Wang, Brême and Moon 2014).

This chapter explores the possibility to adopt ABM in the area of the product-service system. First, it includes a brief literature analysis on the topic (Section 9.1) then it reports an explorative study on hybrid modelling together with a preliminary application of the approach in a simple case to verify its applicability in the studied context (section 9.2).

9.1 Literature analysis of hybrid modelling

As a starting point, a literature analysis, similar to the one carried out for the other simulation methods, has also been done for hybrid simulation modelling. Since this technique came into the world from the combination of different simulation approaches (Wang, Brême and Moon 2014)usually DES, SD and ABM a variety of hybrid applications with their advantages are available. The results are summarized in table 37.

Table 37 Summary of literature regarding hybrid modelling

	Advantages	Drawbacks
SD+DES	- provides a general depiction of the aggregate flow and also it provides a micro level description of the individual characteristics (interaction) (Viana, et al. 2014) - creates a dialogue between strategic level and operational level management (Chahal 2010) - analyses the ripple effects of local operations from a global perspective (Chahal 2010) - flexibility: model continuous and discrete events (Brailsford, et al. 2013)	- the challenge is to develop both a conceptual philosophy and a practical methodology for combining SD and DES in a real context (Viana, et al. 2014) - Difficult to do because of technical problem in moving between an individual-based and a mass-based approach (Brailsford, et al. 2013) - The user needs some familiarity with Java code (Brailsford, et al. 2013)
ABS+SD+ DES	- allows different views of the system: holistic level, process level, individual level, internal Level (Djanatliev e Meier 2016)	- Building hybrid models in this context is not a trivial task (Djanatliev e Meier 2016) - Understand the most appropriate level of detail (Djanatliev e Meier 2016) - Building executable models in this context requires a powerful tool support (Djanatliev e Meier 2016)
DES+ABM	- the problem in the area human movement and decision patterns not suitable to be modelled with DES can be well solved (Huanhuan, Yuelin and Meilin 2013) - will reduce the limitations of individual methods and increase their capabilities (Mesabbah, et al. 2016) - same point of view based on events (Varol and Gunal 2015) -to obtain deep going insight into complex interactions between processes having very different nature (Huanhuan, Yuelin and Meilin 2013) - Easy integration (Huanhuan, Yuelin and Meilin 2013) (Brailsford, et al. 2013)	
SD+ABM	- using both the methods will improve the quality of the model and give more insights (Lättilä, Hilletofth and Lin 2010)	- increase in computational time (Lättilä, Hilletofth and Lin 2010) - Requires good expertise in programming (Lättilä, Hilletofth and Lin 2010)

According to what emerged from the analysis, good advantages emerged from the joint utilization of DES and ABM. This combination, indeed, allows to keep the process perspective having a general point of view based on events (Varol and Gunal 2015) but at the same time the problem in the area of human behaviour and decision patterns can be solved (Huanhuan, Yuelin and Meilin 2013).

In order to understand what could be the most suitable combination of simulation methods for the assessment of the service delivery process, a cross comparison between simulation approaches and service delivery features is reported in the next section. It could confirm the results obtained from the analysis of literature or lead to the selection of another combination.

9.1.1 Theoretical cross-comparison of simulation methods and PSS critical features

To identify the best simulation methods combination to support the assessment of the service delivery process, a cross-comparison of simulation methods together with PSS features (section 2.1.2) is reported:

1. *Resources and customers involved in PSS are prevalently people.* This feature implies that a variety of customers should be modelled in the service delivery process. The uncertainty entailed by a PSS is also related to the wide range of possible behaviours on the customer side. ABM responds directly to the necessity of defining individual rules and behaviour, and describes a decentralized system as agents that can behave independently from one another. Agents would perfectly work in representing various human beings with different preferences, skills and attitudes.
2. *Customers have different preferences, behaviours and attitudes.* According to this, a method capable of describing inner behaviour uncertainties for resources and customers is necessary**.** The use of stochastic variables in DES allows simulating process-related uncertainties (e.g. customer arrival rate, duration of activities, the reliability of resources, etc.) (Weidmann, et al. 2015), while ABM allows extending the uncertainty to the human factor through a direct modelling of behaviours. Being based on differential equations, SD may not be the best choice to comply with this PSS feature (Borshchev and Filippov 2004).
3. *Customer and company interaction.* As much of the complexity entailed in a PSS arises from the value generation process, in which the customer is actively involved, a simulation model should be able to describe this interaction. This can easily happen in an ABM. In a DES, where entities can only have a passive behaviour, the interaction can be defined a priori and can be represented by the company activities interacting with the customer who can be considered as the entities to be processed. Based on stocks and continuous flows rather than on discrete entities, SD can describe interactions only at a high level of abstraction.

4. *Provider resources operate on customer's premises.* In order to cope with this characteristic, the simulation approach to do the assessment should be able to model resources' availability in time and space and model different resources' skills. Both DES and ABM can respond to these two requirements. In DES, resources' modelling is mainly related to their availability over time, but it can also capture spatial factors (Karnon, et al. 2012), while ABM can be used to model resources as active agents if the modeller wants to give higher relevance to their active interaction within the system (Maisenbacher, et al. 2014). The high detail level of SD would not fit the scope.
5. *Service component.* One of the main features of the PSS is the lack of a pre-defined bill of material for the service component. This is usually replaced by a set of activities to be performed to deliver the service. According to this, the simulation method should be capable of managing a sequence of predefined activities to be carried out during the delivery of a service. By definition, DES is the proper method do to cope with this feature.
6. *Waiting time.* Given the relevance of waiting time in the service context the simulation methods should be able to collect statistics about the waiting time associated with each activity in the process.
7. DES simulation could easily summarize information about waiting time for each activity and, due to this, it is the best option to capture such feature.
8. *Resources' skills and qualifications are diverse.* Similarly, to what discussed in point 4, resources can be modelled in both DES and ABM depending on the relevance that the modeller wants to give to their active interaction within the system.

In accordance with the above analysis, ABM could be a well performing approach to manage several criticalities in the PSS provision process. However, companies' operations and organization require a certain level of standardization to foster efficiency and responsiveness. This would push the modeller towards the use of DES due to its process-oriented nature that can better fit the modelling of standard processes and activities. On the contrary, a SD model could support strategic decision making giving insights on long-term dynamics, but the analysis shows that it might not be the best choice for PSS provision process. Table 38 summarizes the comparison.

Table 38 Cross comparison of simulation methods and PSS critical features

#	Critical features	DES	ABM	SD
1	Resources and customers involved in PSS are prevalently people		✓	
2	Customers have different preferences, behaviours and attitudes	✓	✓	
3	Customer and company interaction.	✓	✓	✓
4	Provider resources operate at customer's premises.	✓	✓	
5	Service component	✓		
6	Waiting time	✓		
7	Resources' skills and qualifications are diverse	✓	✓	

According to the analysis, ABM and DES appear complementary (Table 38). Therefore, a possible solution for the assessment of service delivery process is the adoption of hybrid simulation composed by DES and ABM. Hence, agents can be used to model the individual behaviour of customers and their interaction with the PSS provider, while the delivery process (i.e. a set or predefined activities) can be described through DES. This allows representing the service delivery process as a system where entities move through queues and activities.

In order to verify these theoretical considerations, in the next section a comparison between DES and hybrid modelling into a test case is reported. This comparison aims at verifying in practice the theoretical advantages of the combination of ABM and DES with respect to pure DES.

9.2 Hybrid modelling validation in a test case

In this section, hybrid simulation composed of ABM and DES is compared to pure DES in a test case in order to verify the theoretical benefits. A real case in the automotive sector was used as a starting point to develop a simplified case appropriate for the specific needs. Two simulation models were developed taking into account the main observations summarized in the previous section: a DES model, using the software Arena[2], and a hybrid model, integrating DES with ABM, using the multi-

[2] Arena Rockwell simulation software is the most common software for Discrete Event Simulation in industry and academia. In this simple case, the software was selected because of the expertise of the researchers on the software.

environment software Anylogic. The case was selected because of its limited complexity and refers to a truck maintenance service for commercial and private customers. The maintenance service is based on original equipment as well as refurbished spare parts. All the data (e.g. customers' arrival rate and preferences, activities' duration) were collected from the company. An overview of the two models is shown in Figure 40 and 41. Both models follow the same logic in the representation of processes and activities and, although characterized by different structures and features, both were validated against reality by the experts. Whereas the pure DES model works as a traditional DES with entities entering into a set of activities (Figure 41), the hybrid model, as suggested by literature, jointly utilises ABM to model customers (Figure 40) and DES to model the process (Figure 40). The specific working mechanism and the interaction between the agents and the process are described hereafter.

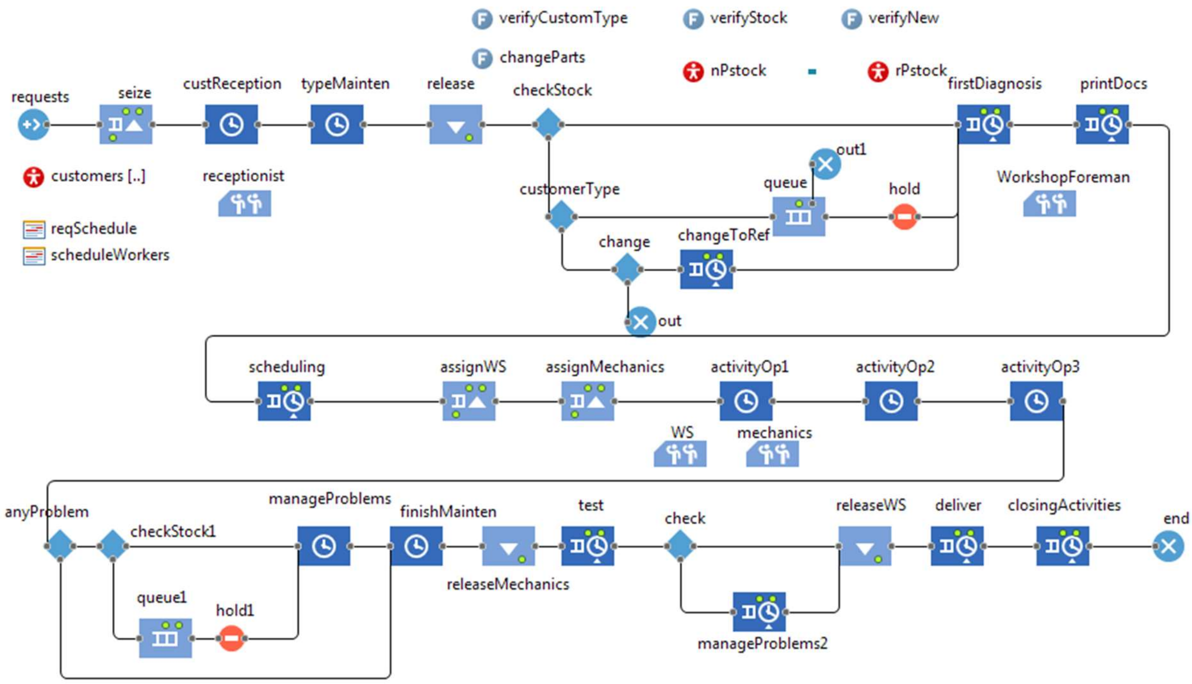


Figure 40 General overview of the discrete part of the hybrid simulation model

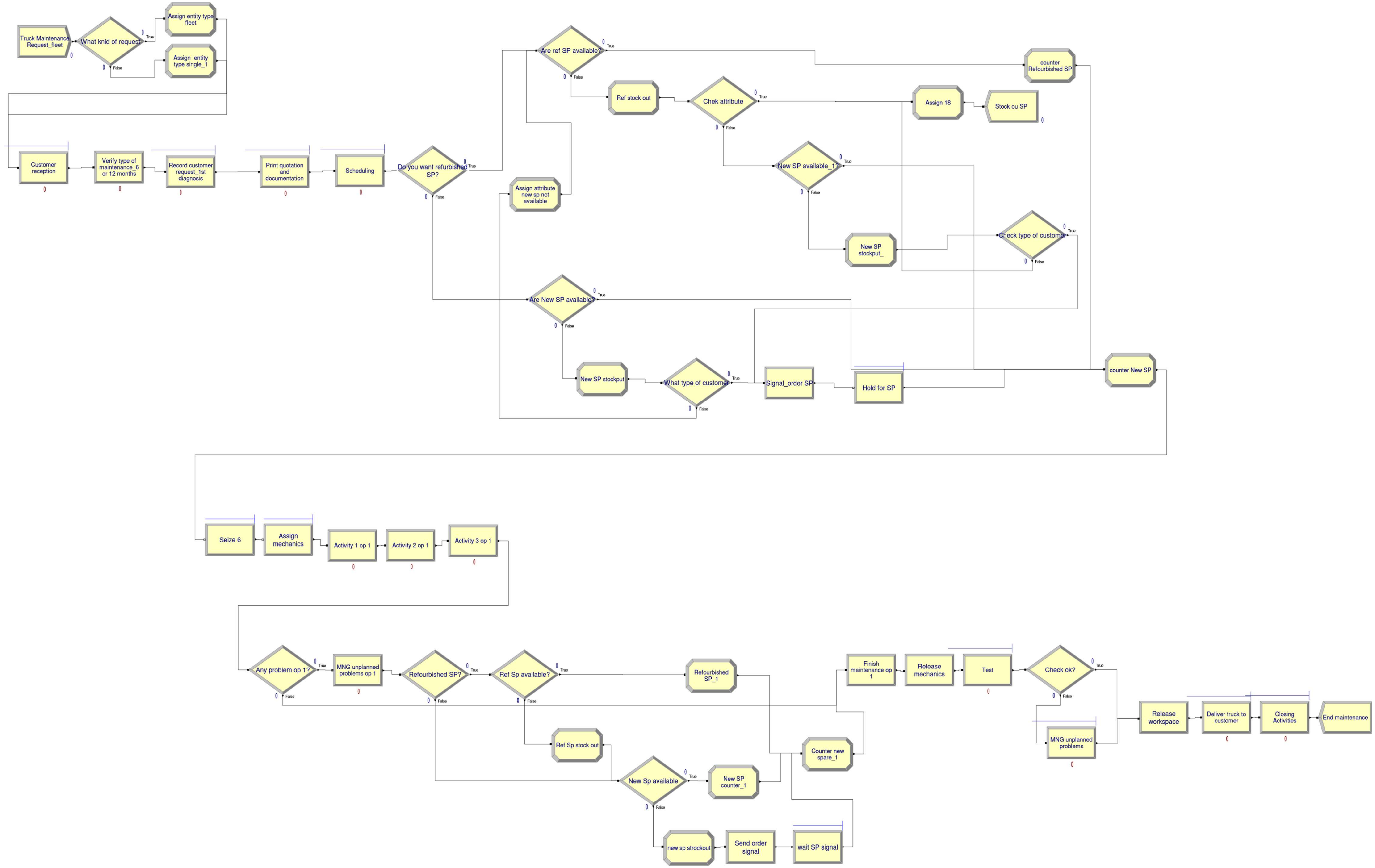


Figure 41 General overview of the pure DES simulation model

All the special features of a PSS are listed and explained in the light of the case, then, one by one, how each model deals with them is described.

1. *Resources and customers involved are prevalently people*. The company manages two main customer categories: customers with a single truck (A) and customers with a truck fleet (B). The customer category A is usually unable to wait for long times: if the expected cycle time for the maintenance activities exceeds a given threshold, he might be willing to leave the company, seeking for a faster alternative. The customer type B, instead, can accept longer cycle times since he may have backup trucks to put at work. When a customer arrives, the workshop foreman shows him the plan of maintenance with estimated cycle time. Each customer decides whether to accept or leave the workshop without any intervention, according to a personal rule based on his needs. To measure customer satisfaction, the average operation and waiting times, together with the number of customers leaving the systems, are monitored during the simulation. In the hybrid model, this feature is modelled through ABM. Each customer corresponds to an agent of type A or type B, and is modelled by the agent state-chart showed in Figure 42 that captures the customer's state. The agent enters the discrete event section of the hybrid model (Figure 40) and, according to the activity it goes through (duration, resources), it changes its status in the agent state chart (Figure 42). Then, the agent's state chart collects statistics facilitating the analysis of results and the representation of the decisions taken throughout the process. E.g., once the customer enters the system and is received by the receptionist (figure 40) it moves into the state "received" (figure 42). According to what is happening in the single activity, if the customer is waiting or is receiving a service, the customer moves into the agent state chart in "served" or "waiting". Then in the agent state chart the maximum time that the customer is willing to wait is set (clock in figure 42) and, based on this, if the customer is waiting in an activity more than what allowed, the customer moves to the area "unsatisfied". The maximum waiting time is different for customers A and B, representing their decision making. The customers in the "unsatisfied" state leave the system in the following part of the DES process, as shown in figure 43.

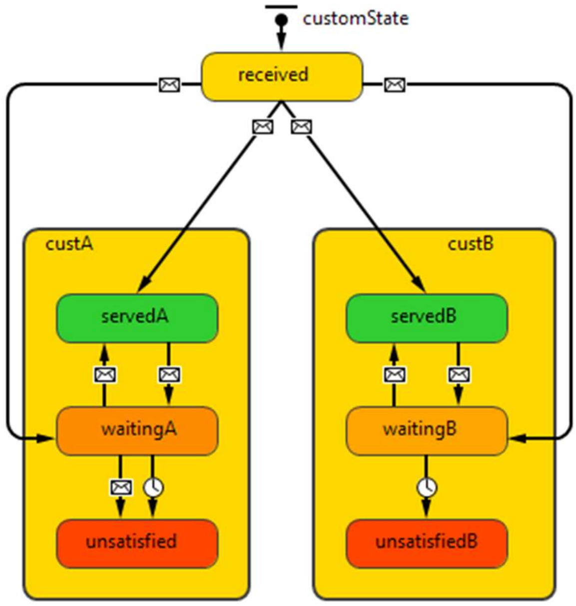


Figure 42 Customer's state chart in the hybrid model

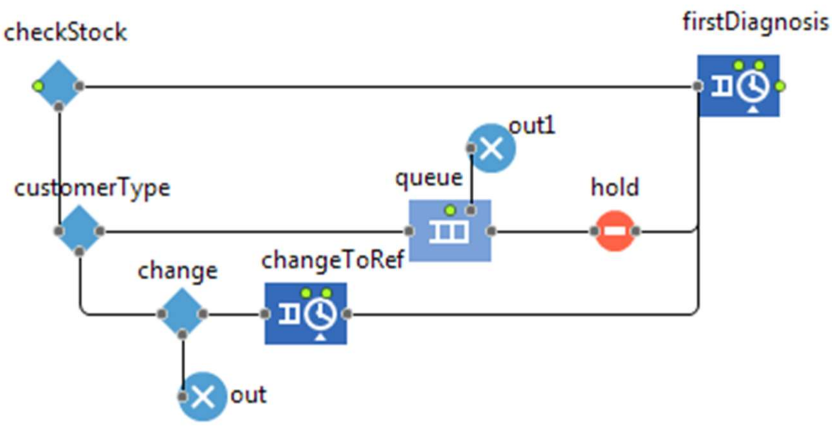


Figure 43 Decision making part in the DES process of the hybrid model

In the pure DES model, different customers are represented by different entity types and the specific features are added to the customer through entity attributes. Every time the process differs based on the different type of customer decisions, this has to be distinguished through decision modules inside the process (figure 41). The maximum time that the customer is willing to wait before exits the queue is set through an attribute and based on the queue system. Since it is not possible to change the state of an agent, multiple decision nodes are set to distinguish the cases. For example, it is necessary to identify the kind of customer that is going through an activity and the attribute assigned to the specific customer at the beginning of the process. In order to change or modify something in the customer decisions, additional attributes have to be defined or new values for existing attributes must be set through the process.

2. *Customers have different preferences behaviour and attitudes*. In the process, both type A and type B customers can opt either for new or for refurbished spare parts. Later, in case of unplanned issues (e.g. a stock out of a new spare part), customers who decided at first not to buy refurbished products can change their initial decision if the estimated cycle time is longer than they could accept. In the hybrid model, these features are modelled through ABM, using parameters and variables belonging to each agent, which influence the path of the entity (customers). Again, in the hybrid, this information is directly sent to the process whenever an agent reaches an activity. In the state chart in Figure 42, the variables are included in the invoices or into the clocks.

   In the pure DES model, these uncertainties and decisions are modelled through a sequence of "if-then" blocks, considering all the possible options as different paths in the process. How the customer behaves and decides is identified through decisional points. This increases the complexity of the overall model shown in figure 44, as well as of the modelling process. In other words, the customer behaviour and decisions that in the hybrid model are represented by the automatic interaction between the process (figure 43) and the state chart (figure 42), in the pure DES this needs to be modelled by multiple decisional paths. Figure 44 shows the corresponding part of the DES that was used to model multiple decisions for the two types of customers.

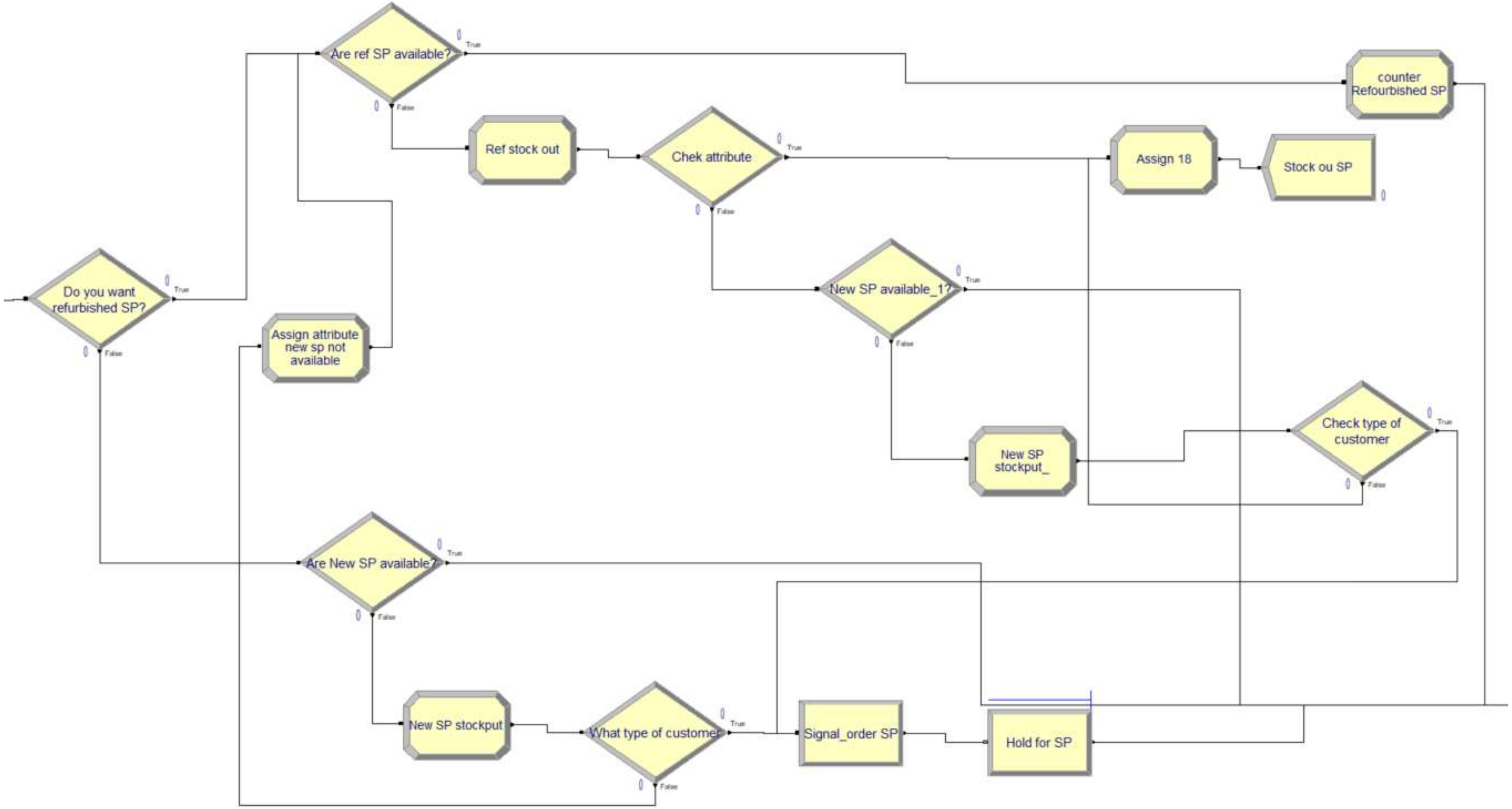


Figure 44 Customer's choice modelled in the DES model

3. *Customer and company interaction.* From the previous points, it is clear that the customer's needs and inclinations lead his decision process, which is also based on the information about the state of the service given by the service provider. Thus, this interaction is crucial for the definition of the PSS offer for each customer: through its modelling, different customer's preferences and needs are considered in the test case. The hybrid model itself describes this interaction; ABM has been used to model customers, with attention to their preferences and needs, while the maintenance process has been modelled through DES, based on the operation times and arrival rates observed in the real case. Customers as entities go through the DES process, following precise rules. At the same time, as agents with their own rules and characteristics, they can interact during the process. Their path is not exclusively determined by the sequence of activities defined, as in the pure DES model, but is defined by the interplay of the service state (e.g. long waiting queues, spare parts availability, forecast of total service time) and the customer's needs (e.g. time availability, willingness to use refurbished parts). In the pure DES model, this interaction between customers and company is not clearly represented. Customers are the entities that enter the activities of the process. From the general model, it is not possible to clearly distinguish customers and company roles into the model. Customers are the entities while activities and resources represent the company. How the different attribute change over time (e.g. how much time customers have to wait before served) is defined by entity statistics.
4. *Model resource's availability in time and space and (7.) resources' skills and qualifications are diverse.* Three different types of human resources were considered in this test case: four technicians; one receptionist; one workshop foreman. All resources follow a fixed work schedule, and the duration of their activities is modelled through triangular distributions, as it depends on both the resource's particular condition (e.g. tiredness, physical and psychological conditions…) and the type of intervention required. Given the necessity of standardization inside the company, resources were associated with company's activities using DES in both the models.
5. *Service component.* The sequence of activities constituting the service process was represented with DES in both the models. By definition, the DES is the proper method to assist process definition and analysis.
6. *Waiting time***.** Both the two models are capable of measuring customer waiting time. In the hybrid model, the statistics are collected by observing the behaviour of the agents. The time

that they spend in the different areas of the state chart summarizes the waiting time and the value added time.

In the DES model, the collection of statistics about the population of the different type of customers (e.g. how many customers type A are waiting on average in the entire system) requires manual definition of variables, statistics that often are quite critical to set.

9.2.1 Discussion

Both the models, although characterized by different structures and features, are representing the service delivery process as it is. Moreover, in both of them, some service provision process KPIs were monitored to measure the system's performance. Among them, workspaces utilization, number of stock-outs for both new and refurbished spare parts inventories, customer waiting time and percentage of customers leaving the system could be mentioned. Since the goal of the validation is the comparison of the two approaches and their capability in modelling the service delivery process specific data concerning the process are not considered key variables to be included in the following discussion. The two approaches are mainly compared considering the technicalities and their strengths and weaknesses in relation to the service delivery process. In particular, test case demonstrates that hybrid modelling can cope with all the critical features of a PSS provision process identified in theory, while DES, as emerged in chapter 7, presents some criticalities in relation to the modelling of customers' preferences and behaviour. In particular, the customer's choice on the opportunity of selecting refurbished parts when new ones are not immediately available, is easily represented in the hybrid model through ABM, using the agent's parameters to enable the choice functions. In the pure DES model, this is much more complicated, involving the use of different decision blocks to model a decisional tree. More in general, in the pure DES model, all the situations where customers can make a variety of choices have to be manually designed while, in the hybrid model, they are the result of the automatic interaction between the agents and the process.

Even if both models allow the analysis of the selected case, some advantages for hybrid simulation can be highlighted based on the case:

- *Models segregation:* the model of the process and the model of the involved entities (i.e. operators and customers) are clearly separated, allowing for a better description of the different aspects via using the appropriate modelling notation (i.e. DES for the process and multi-agent for the entities). From an operational point of view, this separation also allows for a cleaner attribution of the responsibility for the different models: once the interface between the DES and the agent-based models is defined, it is possible to develop the models separately, even attributing the development responsibility to different modellers. It is no longer required to have a single modeller (or a single responsible for the model development) that must have a deep knowledge of both the simulation paradigms simultaneously.

- *Flexibility:* although, in general, it is possible to model customers and operators' behaviour using the DES alone through a long and complex sequence of "if-then" blocks (e.g. representing customer behaviour or spare parts type), the segregation of the models allowed by the hybrid approach entices a higher flexibility, especially when new entities (or customers) must be modelled. In fact, the introduction of, say, a new customer in a DES model often requires to change the portion of the model describing the customers' behaviour and the possible entities entering into the system. By moving the customer behaviour model into the agent-based model, it could be possible to introduce new entities without changing the model of the process.
- *Detection of emergent phenomena:* the interactions between entities in the system can result in emergent phenomena (i.e. performance, outcomes…) that cannot be detected by analysing the parts of the model separately. These emergent phenomena can be related to the interaction of several entities with the process or to the interaction between the entities. In summary, the hybrid approach allows for the identification of results and outcome that would be extremely difficult to detect via a DES approach alone. The higher the number of customers or other variables is, the higher is the difficulty of the pure DES to identify additional outcomes.
- *Simplicity/effectiveness:* due to its nature, agent-based modelling allows for a better and simplified modelling of the entities behaviour, eliminating the necessity of modelling decision making processes (i.e. the behaviour of the entities) via complex DES constructs, as shown for the description of customers' behaviours. This particularly meet the need of multiple behaviour descriptions emerged in section 7.4.
- *Visualization of entities behaviour:* separating the models, it is possible to better understand the behaviours of the entities operating in the process model. This is immediately understandable what are the main activities constituting the service delivery process. Figures 35 and 36 are a clear example.

The test case in the truck maintenance demonstrates the theoretical advantages of the hybrid modelling that emerged from the analyses in section 9.1. In particular, the simplified and better modelling of entities behaviour emerged both from the literature and the practical application, is the peculiar feature of hybrid modelling that can support the assessment of the service delivery process. Indeed, it allowed to overcome the main limitation of DES (section 7.4) while collecting statistics and data about the process. In line with this result and with the research presented in chapter 9, the final method developed for the service delivery assessment is described in the next chapter.

10 The FASt method to model and assess the service delivery process of a PSS

In the light of the complexities emerged during the application of DES for the assessment of real service delivery processes (chapter 7), additional research in the topic of process modularization and hybrid simulation modelling are reported respectively in chapter 8 and chapter 9.
Indeed, DES performed poorly in the application in multiple cases due to the relevant amount of time and data required to set the simulation model and to the difficulties in describing the uncertainty of customers interacting in the service delivery process. The studies described in the previous chapters are a step forward the management of the above-mentioned issues. First, a modularization technique for the service delivery process reduces time while replicating the assessment in multiple units. Second, the hybrid simulation modelling demonstrates good capabilities in managing the customer uncertainties.

Hence, this chapter summarizes these researches and provides an answer to the second research question of this thesis proposing the FASt (Final Assessment of Service) method (section 10.1) to model and assess the service delivery process aiming at balancing the excellence in the service provision (customer perspective) with a high efficiency and productivity of the PSS processes (company perspective).
Once the overall approach including modularization and hybrid modelling is described, section 10.2 reports a validation of the method in a real case, in collaboration with ABB.

10.1 The FASt method

The FASt method is summarized in figure 45.

The method is split into two different areas, process modelling and dynamic assessment. The process modelling is aimed at supporting the engineering team in modelling the identified processes considering common modules across the variety of processes. In turn, this structured approach for process modelling supports the dynamic assessment that grasps the overall service delivery complexity and assists in gathering process performance both from the customer and from the provider perspective.

As suggested before, the method shall be used during the engineering phase of a PSS to carry out the detailed assessment of the engineered process in the BOL of the PSS and to monitor and evaluate an existing process during the MOL phase of its lifecycle.

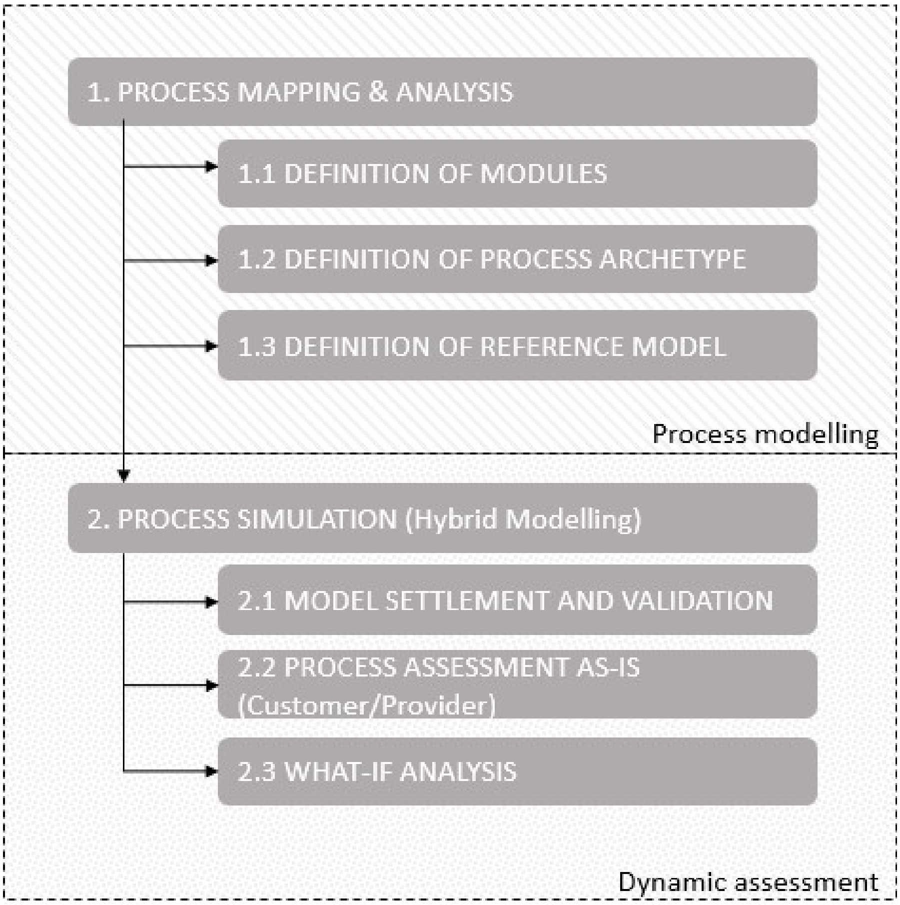


Figure 45 Service delivery process modelling and assessment method – FASt method

10.1.1 Process modelling for service process engineering

The process modelling is the method adopted during the design phase when the service delivery process is engineered. It exploits the blueprinting (Shostack 1982) that is the most common method adopted in the PSS domain. The representation in a structured static model allows a first analysis of the process showing inefficiencies and non-value added activities. Furthermore, it ensures a standard representation of the process that is easy to be understood by multiple stakeholders and to be replicated in other contexts. When used to engineer the BOL phase, the approach helps in setting a specific nomenclature and process structure that could be re-used reducing the time of parallel engineering and increasing the ease of updating. When exploited to monitor the MOL phase, especially in the case of multiple process assessment, the modelling approach ropes the definition of a standard process (a process archetype) with the related nomenclature (reference model) that act as a standard to be imitated in multiple processes.

The input of the process modelling is the service delivery process itself. In case it already exists, a detailed analysis of the process is carried out and translated into the process blueprinting map. In case the process is not existing a list of activities to be carried out is settled and mapped in the blueprinting.

Here are the main steps to be carried out according to the FASt method.

- *Step 1.1 Definition of the modules*
  - *Data collection*: Analyse the existing processes mapped through the service blueprinting (Bitner, Ostrom and Morgani 2008).
  - *Modules identification*: Once the service delivery process of a single service is mapped in a blueprinting structure, identify the modules as groups of activities strongly connected with each other. The first proposal of process modules is set.
  - *Modules update process*: Then, other variants of the same service delivery process are analysed (e.g. the service delivery process performed in other countries or units) and their own modules are identified. The first set of modules can be consequently updated and/or improved. According to such procedure, the modules are iteratively adapted every time a new process of the same service is analysed. Figure 46 shows the iterative process.

The output of this step is a group of modules (M) that compose the analysed process (Equation 8). For each module (m_i) a specific set of activities (z_{ij}) composing it is also specified as summarized in equations 9, 10 and 11.

$$m_1, m_2, m_3, m_i \in \mathrm{M} \quad [8]$$

$$z_{11}, z_{12}, z_{13}, z_{1j} \in m_1 \quad [9]$$

$$z_{21}, z_{22}, z_{23}, z_{2j} \in m_2 \quad [10]$$

....

$$z_{i1}, z_{i2}, z_{i3}, z_{ij} \in m_i \quad [11]$$

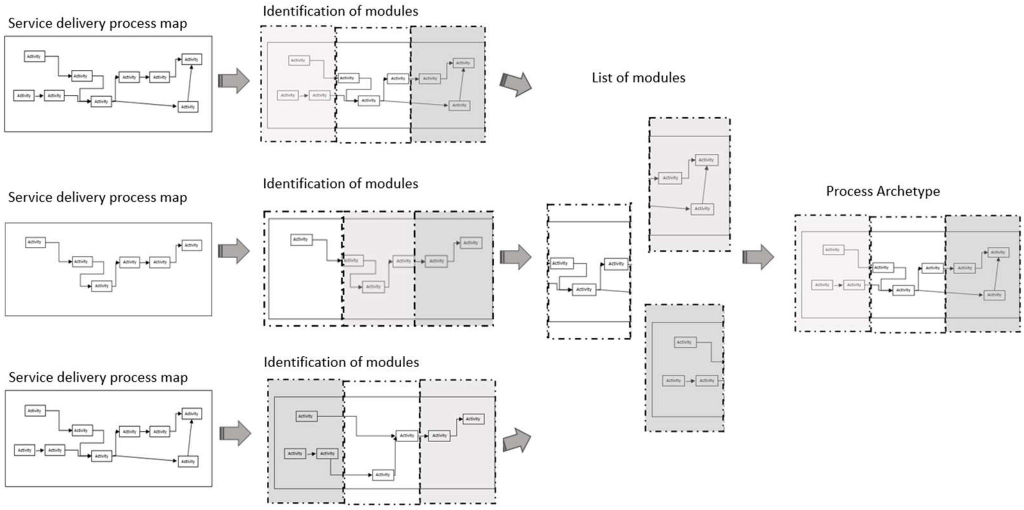


Figure 46 Process module definition procedure

- *Step 1.2 Definition of the process archetype.* The analysis of the service delivery process maps leads to the identification of a standard sequence of process modules that constitute the process archetype of the service under analysis. The different variants of the service delivery process are characterized by difference sequence of modules. It is up to the company rules and best practices to identify the standard order of them.
  The output of this step is an organized list of the process modules that constitute the process archetype. Among the set of possible archetypes (A), each company would hence select the one (a_n) that best suits its needs. Each archetype is then characterized by a predefined sequence of modules as exemplified in equations 13,14 and 15. For example process a_1, is composed of the sequence of modules m_1,m_2,m_4 and m_3.

$$a_1, a_2, a_3\,, a_n \in \mathrm{A} \quad [12]$$

$$m_1 < m_2 < m_4\ < m_3 \in a_1 \quad [13]$$

$$m_1 < m_4 < m_3\ < m_2 \in a_2 \quad [14]$$

$$m_2 < m_3 < m_1\ < m_2 \in a_3 \quad [15]$$

…

- *Step 1.3 Alignment between reference models and process archetype.* The process archetype has to be associated with the taxonomy, and the nomenclature summarized in the reference model. The process archetype and the content of the modules refer respectively to Level 3 and Level 4 of the reference model (section 8.2.2). If the company already has a reference model in place, the archetype information must be aligned with the ones defined by the reference model. If the reference model is not available or not fully defined, the archetype could be used as a main base to define the missing part. This univocal relationship between the reference model and the identified modules is summarized in Figure 47.

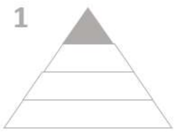
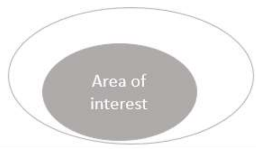
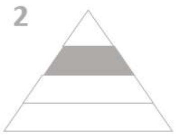
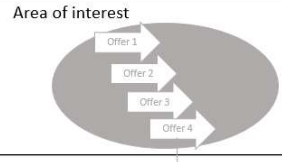
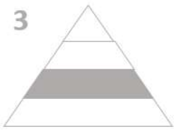
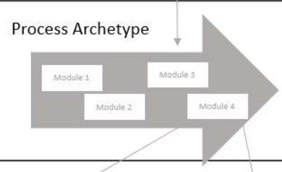
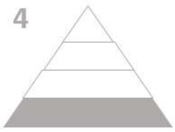
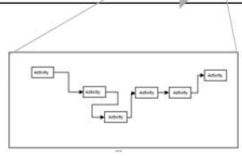
#	Description	Schematic	Process archetype and modules
	**Top Level** Main area of interest inside the company business		
	**Offer Level** Offer categories inside the area of interest		$a_1, a_2, a_3, a_n \in \mathrm{A}$
	**Process Element Level** Decompose processes		$m_1 < m_2 < m_4 < m_3 \in a_1$
	**Implementation level** Decompose Process Elements		$z_{11}, z_{12}, z_{13}, z_{1j} \in m_1$ $z_{21}, z_{22}, z_{23}, z_{2j} \in m_2$ …. $z_{i1}, z_{i2}, z_{i3}, z_{ij} \in m_i$

Figure 47 Connection between the reference model and the process module and archetype

As previously hinted, when the method is adopted to engineer the BOL phase, it could happen that no processes are available for the analysis. In this case, the procedure proposed for the process modelling guides the engineering team in developing a process that could be used in further analysis as a process archetype.

Summarizing, the final output of the process modelling phase is composed of: i) the map of a process archetype that constitutes the standard process to be followed during the provision of a service and ii) a reference model, directly linked to the process archetype and its modules that set the nomenclature to be adopted in the company to refer to the service delivery process.

10.1.2 Dynamic assessment

The second main area of the FASt method proposed in this chapter consists of a dynamic analysis of the service delivery process. The dynamic monitoring guides the investigation of the process performance considering waiting time and activities durations, key indicators in service domain. The input of this phase is the process archetype identified in the process modelling phase and a set of data to be coupled with the process. The dynamic assessment foresees three main steps.

- *Step 2.1 Model settlement and validation.* This phase consists in the definition of the simulation model through ABM and DES. As reported in the previous chapter, the overall process shall be defined through a DES while the customers shall be modelled as agents. For each customer, a state chart has to be identified considering their behaviour throughout the process. In order to let the model run, a set of data has to be collected from an existing process or from estimations in order to have an overview of the process.

- *Step 2.2 Process Assessment (As-Is).* Once the simulation model is ready and validated, the process could be analysed considering both the customer and the company KPIs. For the service delivery assessment, the minimum KPIs defined are those defined in section 7.3. i.e.

  - *Company internal measures:*

    Number of completed service jobs per year.

    Time to complete a service job.

    Resource utilization.

    Queues:

  - *External measures.* Includes customer's waiting time in relation to each service activity.

  According to these KPIs, the process could be analysed in terms of efficiency and effectiveness.

- *Step 2.3 What-if analysis.* After the process is set, multiple scenarios and contexts can be set and analysed considering the change of different controllable factors (f_i). Controllable factors are the elements that could be changed into the process such as activity duration, process changes, resources availability, and resource's skills. According to the different values of the identified factors, what-if scenarios are built. The set of all scenarios (T) is composed of a combination of the factors and can be written as:

$$SC_t = (f1, f2, f3, f4, f5) \quad \forall t \in T \qquad [16]$$

  All the scenarios are consequently evaluated through the KPIs suggested in step 2.2. and are also assessed to evaluated to verify their efficiency and efficacy. Different process scenarios indeed would show different performance from both the customer and the provider viewpoints. The analysis of different scenarios would be used to identify the mix of controllable factors that optimize the process. The final output of the dynamic assessment phase is the identification of a scenario that, according to the simulation, could potentially have good performance both in terms of customer and provider value.

10.2 Validation in industrial case: ABB

In order to validate the FASt method described in the previous section and to describe how it can be adopted in a real case, hereafter is the description of the FASt method in a case in collaboration with ABB. In particular, the case of motors and generators was selected because of the strong commitment of the unit in selecting an optimum process configuration to be spread and replicated in all the local units around the world.

Since a preliminary study of all the ABB processes for the DES method validation (section 7.3) collects all the maps, it is worth mentioning that the process modelling and the definition of the reference model were carried out at ABB level. The following dynamic assessment focuses on the service delivery process of the motors and generators unit, specifically on the standard process identified.

10.2.1 Process modelling

According to the first step of the engineering method, the ABB service delivery processes were analysed.

10.2.1.1 Step 1.1

For each unit, the service delivery processes were analysed according to the specific offer of the unit (table 39). Appendix B reports some of the maps developed during this analysis. Then, the iterative scrutiny of processes and modules was fulfilled, and a list of modules for each process was recognized (Step 1.1).

Table 39 Summary of the cases for the process modelling

Case #	Business units in which the service has been analysed	Service
1	**Low voltage products**	Preventive maintenance Corrective maintenance Retrofit installation Replacement
2	**Low voltage system**	Preventive maintenance Corrective maintenance Commissioning and installation
3	**Robotics**	Preventive maintenance Corrective maintenance Remote support
4	**Motors and generators**	Preventive maintenance Corrective maintenance Remote support

The final list of modules, together with a brief description of them is reported in table 40. Moreover, inside each module, a set of standard activities to be performed is defined. A specific list of the activities inside each module is reported in the overall reference model (Table 42 Level 3 and 4 of the ABB reference model For the sake of completeness, an excerpt of the activities at the bottom level for the module “Perform service job at customer” is reported in Figure 47. The activities inside the module refer to the execution of the service job and the inspection on the ABB product.

Table 40 Standard modules description. "Service job on-site" offer

Process modules identified in the ABB case	Description
Handle customer's requests	This module refers to the activities that are carried out when a request from customers is received. This also includes checking customer reliability and status with respect to ABB.
Assess feasibility and create the offer	As soon as the front office employees register the customer's request, they analyse it and reply to the customer providing quotations or information about the service rates.
Manage order	Once the order is issued by the customer, ABB sales people take care of and register it in the management software, following the ABB procedure.
Mobilize and plan	This module includes all the activities carried out to plan the service activities both at customers' and in ABB facilities. The Bill of Material for the service job is also issued.
Prepare job	Activities related to the check of customers' site and material availability are included in this module.
Perform Service Job at customer	Inspection, corrective or preventive maintenance, commissioning or installation are some possible service jobs that can be executed at the customer's site. This module also includes the safety procedure and the documentation to carry out the service job.
Complete job	All the activities related to the final balance of the service job and the billing are included into this module.
Warranty handling (optional module)	In case the service is required inside the product warranty period, additional activities are carried out to check the warranty terms and conditions. This module is classified as "optional" given that not all the units are allowed to manage warranty.

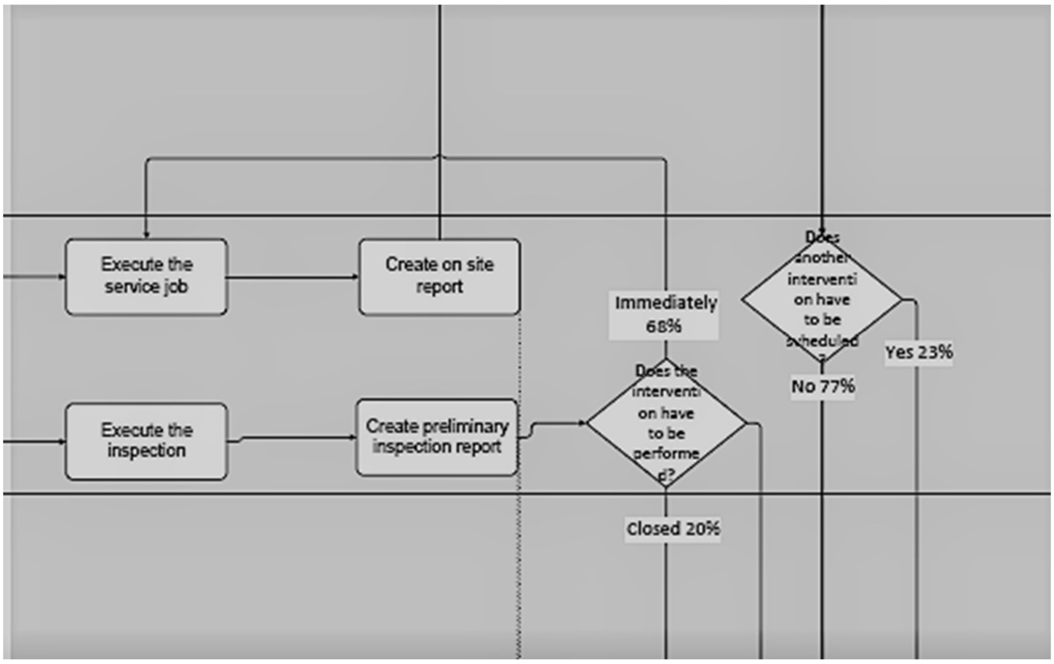


Figure 48: Excerpt of the activities at Level 4 underlying "Perform service job at customer module"

Among the different phases of the FASt method, this one was considered as one of the most complexes. Indeed, in order to reach the final list of modules an iterative analysis of processes and modules was carried out. From a general point of view, the analysis of all the service maps revealed that service delivery practices across the several units are almost similar as well as the sequence of activities. The main difference identified is that the resources (humans) responsible for specific activities and the language adopted to describe activities are quite different. Moreover, activities that in one unit are considered as extremely important, in some others are negligible. For example, the administrative checks that the company does on customer solvency, are almost standard and they are common among the units. On the contrary, the customer approach is highly variable and varies from one unit to another. In the robotics unit, for example, the sales people are very proactive whereas in others unit (low voltage and motors and generators) they are usually more reactive. These discrepancies among activities relevance and approaches to customer make the definition of standard modules quite complex. Many iterations and analysis were required in order to finally set the list of process modules and additional studies were required to identify "standard" or "variants" modules. Whenever discrepancies in the process maps emerged, multiple interviews were held to identify what could be defined as standard and what could not.

More than identifying the modules, the second main criticality of this phase was the identification of activities to be included in a single module. Although the activities performed are similar throughout the units, the identification of a common and univocal sequence of activities was complex. In order to define the "standard" activities, many meetings were required for the identification of standard.

10.2.1.2 Step 1.2

Once completed the process analysis, an in-depth review of the services process maps disclosed the standard configuration of the process modules for each offering, thus setting the related process archetype. From a general point of view, the analysis of the service offering revealed that service delivery practices across the studied units are almost similar and that the sequence of standards modules is comparable.

From a high level analysis, among the services explored, some have exactly the same process archetypes: preventive and corrective maintenance, retrofit, replacement and commissioning and installation. The only difference between them is the specific activity performed at customer's site. In accordance with the guidelines provided by ABB corporate research centre, these services were grouped in one common offering: "service job on site". Figure 42 shows the process archetype (step 1.2) showing the specific order of the modules highlighted in different grey shades.

The development of the process archetype the "service job on site" also required many meetings and interviews in order to be settled. Although the activities and the associated modules were identified, the definition of a specific sequence including them was tricky. According to all the businesses analyzed, the different modules were performed prior or after some others. For example, in the robotics units the "manage order" module follows the "perform service job" module whereas in the low voltage unit and in the other units the order is managed before any kind of service job. This, for example, complicated the identification of the process archetype.

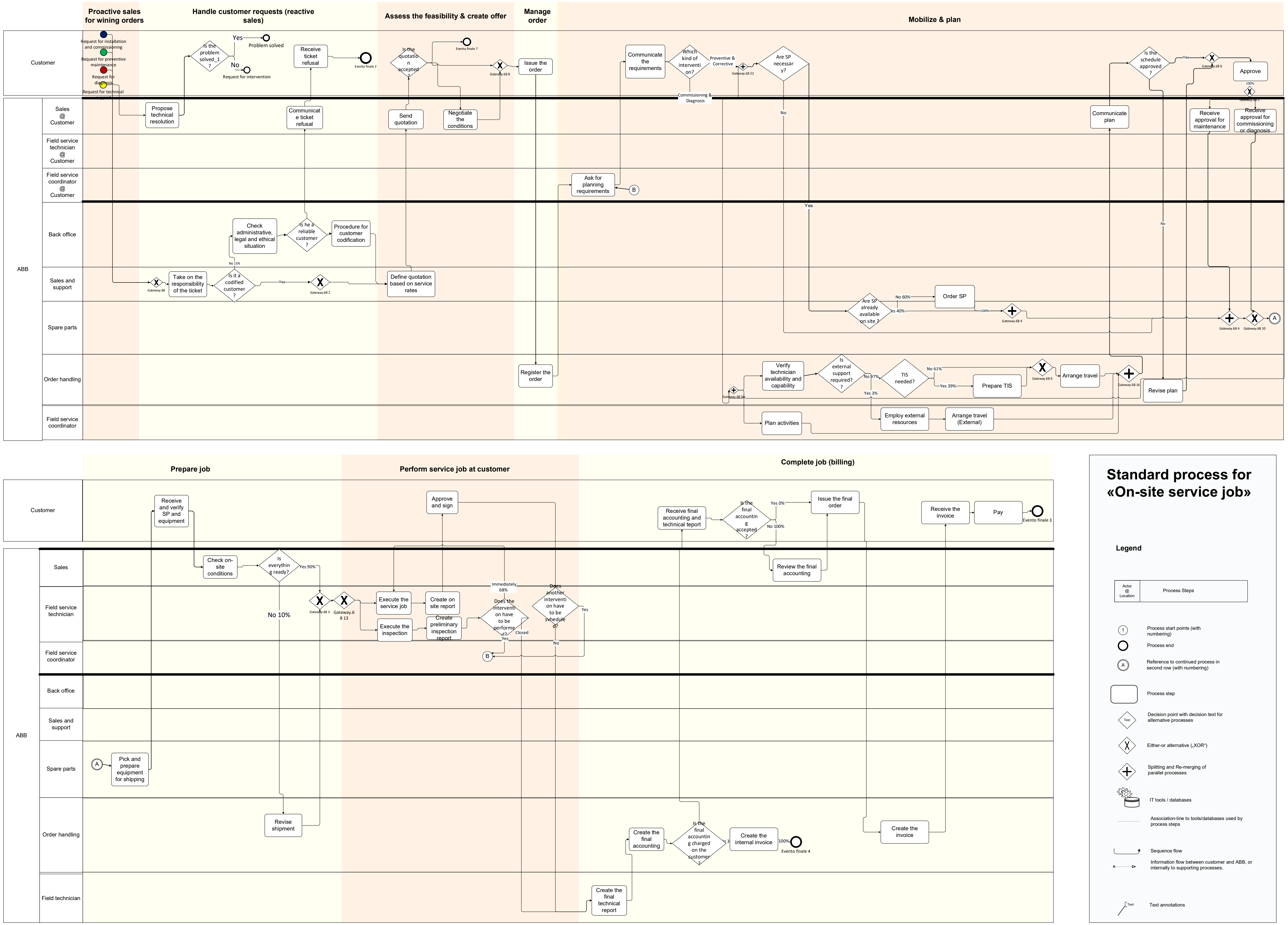


Figure 49 Process archetype for the "service job on site" offering

10.2.1.3 Step 1.3

As suggested by the step 1.3. of the FASt method, in parallel to the analysis of the service delivery process, the terminology and the nomenclature adopted in different business units were investigated. A common thread across the units was the usage of a local terminology that from other units turned out to be complex and meaningless: e.g., the terminology used in low voltage unit was quite different form the terminology used in robotic unit and people involved had some issues in understanding each other even if speaking the same language. The reference model structure (figure 34) was used as a template and a joint effort between the university and ABB researchers led to the identification of a customized reference model. The terms adopted, the description of the offering and of the activities are the results of an in-depth consideration and analysis. Indeed, a trade-off between ABB practices and an easily understandable language was sought. Here is the final outcome of the analysis.

1. The first level (Level-1: Top Level) is the macro-area where ABB foresees the main advantages coming from the standardization of the service delivery process: "*Field Service*".
2. Level-2: Offer Level includes service offers in the field service area: *Remote Support* and *Service Job on site* (as mentioned before, one offering has been created for all the services that share the same process archetype).
3. Level-3: the Process element Level represents the way in which the offer (Level-2) is provided: the archetype process. The order in which the modules are listed at Level-3 of the reference model reflects the process archetype structure and composition. At this stage, the archetype modules have been associated with specific name and description and resources linked to the activities have been grouped in common roles. The process archetype for the service job on-site in reported in Figure 50.
4. Level-4, the implementation level corresponds to the detailed list of activities inside the modules.

The first three levels of the final ABB reference model are shown in Table 41. It represents the formalization and the detailed definition of what already identified during the analysis.

The standard list of activities to be performed inside each module represents level 4 of the Reference model, also called Implementation level. Level 3 and 4 are reported in Table 42.

Table 41 First three levels of the ABB reference model

Top level	Offer level	Process element level
0.FIELD SERVICE		
	FS1. Remote Support	The process of enabling customers to perform after-sales support for products offering remote assistance. This includes receiving and responding to customer's inquiries or claims, trying to suggest a solution for problems deployable by the customer himself. All these tasks are held directly on phone. • FS1.01 Handle customer's requests
	FS2. Service Job on Site	The process of providing after-sales support for products provided to the customer at the customer site. This includes receiving, logging, assigning support resources and responding to customer inquiries. • FS2.01 Handle customer's request • FS2.02 Assess the Feasibility and Create the Offer • FS2.03 Manage the Order • FS2.04 Mobilize and Plan • FS2.05 Prepare Job • FS2.06 Perform Service Job at Customer • FS2.07 Complete Job

The connection of the process module to a reference model represents the formalization of the nomenclature and the taxonomy in a common frame. A common thread across the units has been the usage of a local terminology that from other units turned out to be complex and meaningless (e.g. the terminology used in low voltage unit was quite different from the terminology used in robotic unit and people involved had some issues in understanding each other even if speaking the same language). This demonstrated the strong need of ABB to align the nomenclature and to define a common language across the units. The reference model structure has been used as a template and a joint effort between the university and ABB researchers has led to the identification of a customized reference model. The terms adopted, the description of the offering and of the activities are the results of an in-depth consideration and analysis. Indeed, a tradeoff between ABB practices and an easily understandable language has been sought. In regard to this, it is worth mentioning the complexity in identifying a common taxonomy that could be understood by all the people throughout ABB. The language adopted in different units indeed is quite different and, sometimes, strongly depend on the product managed in the specific unit.

Table 42 Level 3 and 4 of the ABB reference model

FS2.01 Handle customer request (reactive sale)		
–	Take on the responsibility of the ticket	The process of validating and authorizing customer's request, when the product is out of warranty period.
–	Check administrative, legal and ethical situation	The process of verifying whether a new and unknown customer is reliable in terms of administrative, legal and ethical issues.
–	Codify the customer	The activity of codifying the new customer, inserting him on SAP, if no legal and ethical issues arose.
–	Communicate ticket refusal	The communication to the customer of the request refusal. This activity is performed whenever a check fails and a ticket cannot be processed.
FS2.02 Assess the feasibility and create the offer		
–	Define quotation based on service rate	The process of defining the intervention tariffs (hourly rate, material costs…). This activity is performed immediately after the verifications of customer situation, either a technical evaluation is required or not.
–	Send quotation	The task of sending the quotation to customer, generally through an e-mail. ABB needs to wait for customer's approval before performing the intervention.
–	Negotiate the conditions	The process of negotiating the conditions defined in the service rate. Occurring when the customer has not completely accepted the tariffs. Generally, a negotiation is asked by local ABB since it will charge a further mark up on their final customer.
FS2.03 Manage order		
–	Register the order	The activities associated with the registration of the order on SAP and the opening of the sale WBS, where any kind of cost, related to the intervention, can be charged.
FS2.04 Mobilize and plan		
–	Ask for planning requirement	The interaction with the customers aimed at getting informed about preferences on the intervention date in order to start activities schedule.
–	Plan activities	The process of scheduling the activities that should be performed by the technicians, trying to balance customer requirements and internal resource availability.
–	Verify technicians availability	The process of verifying the availability of technicians capable of performing the required job.
–	Prepare documents	The activities performed at Zurich headquarter related to the release of specific documentation authorizing the travel to high risky country (L1, L2). For this purpose, all the necessarily details are submitted to the headquarter that releases the authorization of technician travel. This phase includes also the preparation of visa.
–	Arrange travel	The process of organizing the technicians' travel, once all the documents required are ready, trying to balance customer's requirements and internal resource availability.
–	Employ external resources	The task of employing external resources, from other local ABB, when there are requests, which cannot be completed with internal resources. In case external resources are employed the resource scheduling is in charge of third party.
–	Communicate plan	The communication of the plan to the customer once all the details of intervention are defined.
–	Revise plan	The activity of revising the plan in case the customer does not agree on the scheduling proposed.
–	Receive approval	The activities of receiving the plan approval from the customer.
–	Order spare parts	The placement of an order to the supplier when the spare parts are not available. The time spent for this activity includes also the shipment of spare parts to customer's site, performed directly by the supplier.

FS2.05 Prepare job		
–	Pick and prepare the equipment for shipping	The series of activities including picking the equipment and preparing it for the shipment in response to a planning. This phase is critical since it includes the preparation of documentation and tag required by destination country legislation.
–	Check on-site conditions	The interaction with the customer aimed at receiving feedbacks about the on-site availability of the materials needed for the intervention and assessing whether everything is ready for the intervention.
–	Revise the shipment	The task of checking shipment progress and material availability on-site, performed in case the condition at customer's plant do not allow the intervention execution.
FS2.06 Perform service job at customer		
–	Execute the service job	The series of activities performed at the customer's plant, necessary to satisfy the customer requests, concerning maintenance, commissioning or diagnosis. Sometimes these activities are reiterated until the conclusion of the service job. For this reason, a re-scheduling could be needed.
–	Execute the inspection	The series of activities, performed at customers' plant, necessary to satisfy the need for further information about the failure, if it is complex. Sometimes no further intervention is needed, but when failures are detected, technicians can immediately perform the repair or they postpone the intervention later.
–	Create on-site report	The process associated with the documentation of the activities performed, the materials replaced and the time spent in order to perform intervention activities. The technician is entitled to write it on-site, upload it to the specific tool (ServIS) and wait for customer approval and sign.
–	Create inspection report	The process associated with the documentation of the motor conditions during the inspection in order to provide useful information for the following intervention. The technician is entitled to write it on-site and upload it to the specific tool (ServIS).
FS2.07 Complete job (billing)		
–	Create the final technical report	The task related to the creation of a detailed technical report of the activities performed by the technician, starting from the draft previously written.
–	Create the final accounting	The activity that represents the first step of the billing process. It comprehends the examination of the reports and the preparation of the final accounting, which includes all the expenses incurred.
–	Create the internal invoice	The task of arranging an internal invoice when costs are not charged on customer because of warranty.
–	Review the final accounting	Activity that allows the customer to ask for an ultimate bill review.
–	Create the invoice	The concluding task of the billing process, including the examination of the reviewed final accounting and the preparation of the invoice

The identification of the reference model and its connection with the process archetype concludes the process modelling phase setting the starting point for the subsequent assessment. Although the definition of standard activities and the set-up of the reference model did not show special criticalities or complexities, the overall company transition toward this standardization is taking a large amount of time and the actual implementation of all the required changes is under development. As hinted before, the current processes are similar in scope and organizations but the actual change of activities and tools requires time and a strong managerial commitment.

Intuitively, the habits of an organization are rooted in the people's experience, and this makes the people resistant to change. To move in the direction of standardization the company is homogenizing and streamlining the software and tools to be used through the process. Such changes are spurring the introduction of new standards. Once all the processes would be aligned with standards, a quantitative estimation of the performance improvements would be available.

10.2.2 Dynamic assessment

The second phase of the FASt method refers to the dynamic assessment, aiming at the analysis of service delivery process in terms of internal efficiency and external performance. As suggested in chapter 9, hybrid simulation modelling composed of DES and ABM shall be used in this phase. The FASt method aims at proposing an easily applicable and effective tool to be used in companies to evaluate a service delivery process. Therefore, the application of the dynamic assessment into the ABB case aims at verifying the applicability of the hybrid simulation into a complex case with the aim of supporting the dynamic assessment and monitoring customer and company KPIs. The following case would help in verifying the validity of the modelling approach and in verifying the adaptability of the hybrid simulation to a complete case very close to reality.

To do so, evaluation of the standard service delivery process identified through the process modelling phase is described hereafter. Importantly, it is worth mentioning that being the standard process it is not yet implemented and validation or comparison with existing processes could not be carried out. It would instead guide the identification of possible changes, improvements or scenarios in order to optimize the standard process. Given the focus of the case on the modelling features and advantages, and given that the current process is not yet implemented, it is very complex to provide specific insights on the actual performance of the process and on different causes or relationship.

10.2.2.1 Step 2.1

The starting point is step 2.1., i.e. the replication of the archetype process into the Anylogic simulation software, the only one allowing hybrid modelling simulation. The model, by definition is composed of two different parts:

The process flow, namely the process archetype. It represents the sequence of activities that constitutes the service delivery process. This is mapped through the DES logic, it includes: the main activities, their duration and the resources that perform each activity. Activities durations and process ramifications were also included. Being a process not actually implemented, an average duration of activities was considered and the number of resources was deducted from all the previously analysed processes. The modelling of this part of the process follows traditional rules for DES, of course considering the software adopted. The overall process structure is shown in figure 50. The red shadowed boxes represent the standard process modules defined in the previous phase. A detail of the “access feasibility and create the offer” module is reported in figure 51. As it could be observed, it exactly consists of the standard activities foreseen by the reference model.

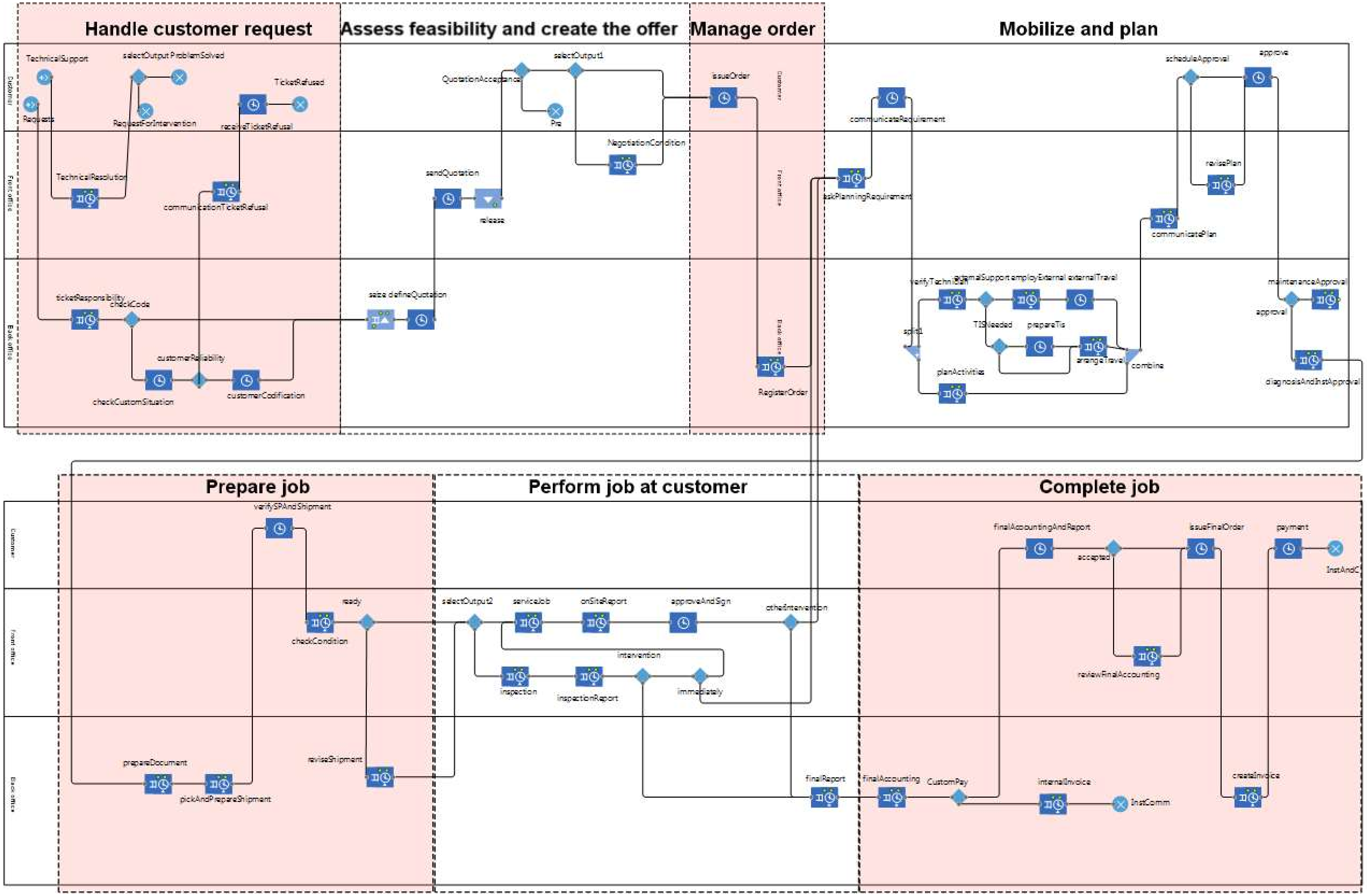


Figure 50 ABB standard process represented in the hybrid simulation model

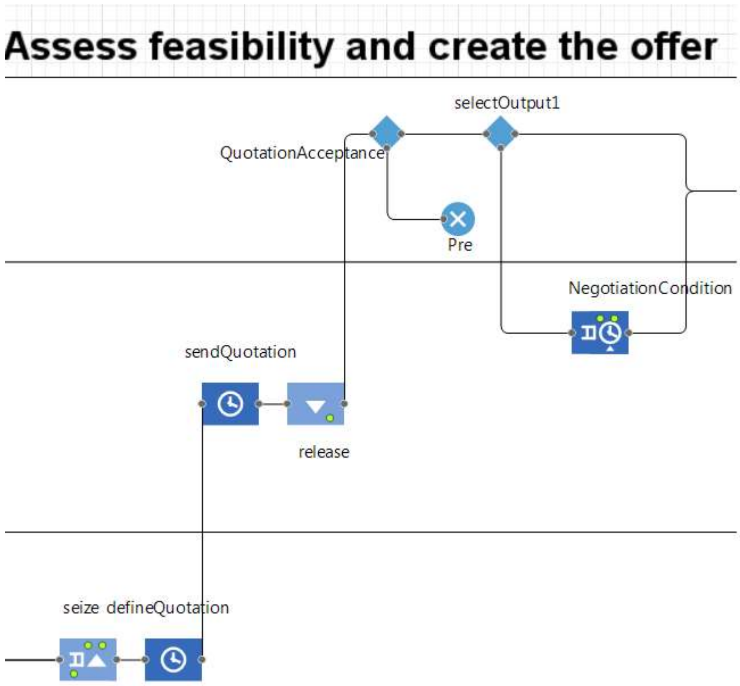


Figure 51 Detailed screenshot of the "access feasibility and create the offer"

The second part of the simulation model is composed of *the customers that are modelled as agents interacting with the process.* Four different kinds of customers were considered. They are classified according to the kind of service required.

- *Preventive Maintenance.* It's planned maintenance, performed with a predetermined schedule established by the company and its customer. Both the customer and the provider can trigger this kind of service.
- *Corrective Maintenance.* The request for corrective maintenance starts with the client only after the registration of a failure in the product.
- *Installation and Commissioning*. The installation and commissioning requests focus specifically on installation and commissioning of the delivered products including related control equipment.
- *Diagnosis*. This request consists of a detailed analysis of the equipment, in order to program and organize the maintenance actions in a targeted way.

The four type of customers were represented by agents that move through the process. According to the interaction between the customers and the provider throughout the process, the agents can assume different states. Indeed, during the process the agents may be involved actively in the process, so that they have to perform action or to make decisions, or may be just passive entities. The following four states were identified in the specific case.

- *Received*. The customer that enter into the process is received by the ABB responsible.
- *Served*. According to the requests of the customers, ABB personnel work to support the request. During the time in which the ABB personnel is taking care of the customer (the operations time) the customer stays in the "served" status.
- *Waiting*. Since the ABB resources are employed in multiple activities and have to manage many customers, it could happen that the customer has to wait before being "served". In this case, the customer is in the "waiting" state.
- *Deciding*. Throughout the process customer is also accountable for some activities. For example he has to decide if he would like to accept ABB offer or he should decide what is the suitable date to receive ABB technicians at his premises. In this situation, customers are in the state "deciding".
- *Exit*. Finally, when all the services are performed the customer exists the process. This last state represents this possibility.

According to the abovementioned situations, the agent state chart in the simulation model was built. Figure 52 shows the state chart adopted by the customers in the specific case. It includes the state chart for the four kinds of customers with their possible states.

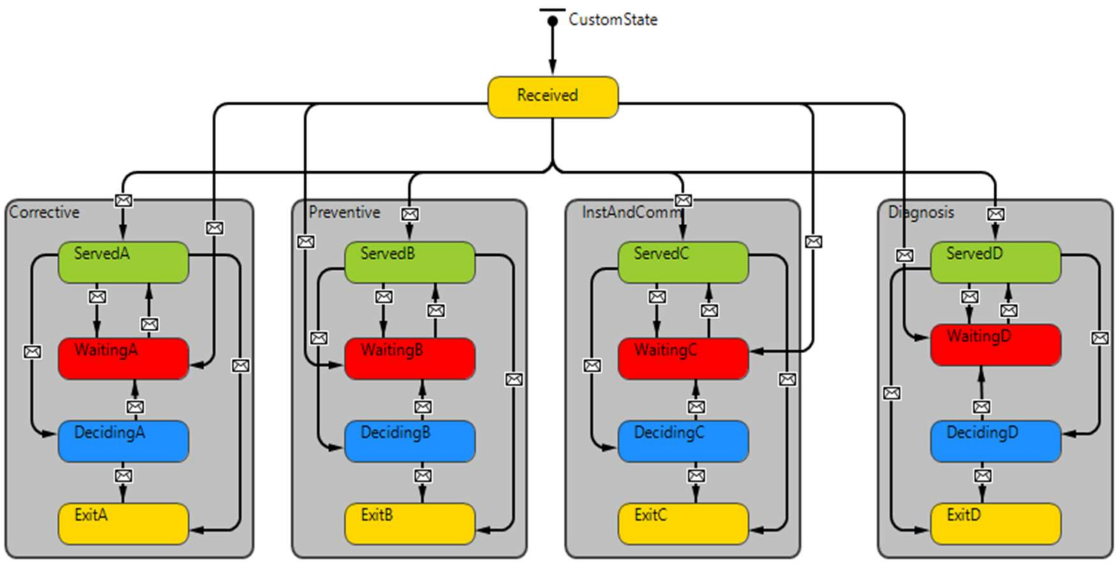


Figure 52 State chart for the four different kind of customers involved in the motors and generators unit

The envelopes in the figure define the possibility of the agents to move from one state to the others. Indeed the messages that indicate when the customer has to be in each state is defined by the position of the agent into the DES process (figure 50). Once the agent reaches an activity in the DES model, a message is sent and the agent changes its status moving to the "waiting" status. As soon as the resources of the activity become available, the agent is ready to be processed and another message is sent to the agent state chart. Thanks to this, the agent switches from “waiting” to “served” state. After being served the agent exists the activity and according to the following step of the DES process could move again to “waiting” or move to “deciding” (in case the following activity represents its decision). At the end of the process, a message would be sent to the agent state chart indicating to move the customer in the “exit” state. The creation of the triggering message that let the agent shifting from one state to another according to what is happening in the DES activity can be performed through the transition arrows with the envelope showed in figure 52. The message reported in the transition that activates a new agent’s state it is recalled in the activities properties: this is the essential link between DES and ABM, according to the agent’s location with respect to each activity. The model characterized by the interaction between the DES and the agents appears as in figure 50. Once completed, it was validated with managers to understand if, with respect to similar existing processes the results obtained make sense or not. The process analysed in the case, indeed, was the service delivery process archetype and, although it boasts similarities with existing processes, it does not yet exist in reality. Therefore, a detailed validation couldn’t be pursued. In order to understand if the process could possibly work the results were discussed with service delivery managers from ABB that were managing a process similar to the one obtained through the first phase of the FASt method.

10.2.2.1 Step 2.2

In a second phase, (Step 2.2) the investigation of process KPI was performed in order to evaluate the process as it is. Being the standard process, the KPI monitored in the case, similarly to those analysed in the DES approach are the following:

- *Company internal measures:*
  - *Number of completed service jobs per year*.
  - *Time to complete a service job.*
  - *Resource utilization.*
  - *Queues*.

  Figures 53 and 54 show examples of the results collected and analysed in the “As Is” scenario. In the first figure the total time to complete a service job (considering the different requests of customers) is compared with the average time in operation. A noticeable difference represents suggests that the company is not actually 100% efficient because the customers have to wait few days for the process activities. X Axe data is not reported for privacy reason. Since it refers to the total amount of time that each entity spends into the service delivery process, this delay and waiting time could be due to a number of reasons. Additional analysis of the process showed that the main waiting time is due to the time that the customers have to wait before the field service technician operates at their premises. Other reasons associated with this waiting time is the administrative control over customer financial situation that is required by ABB.

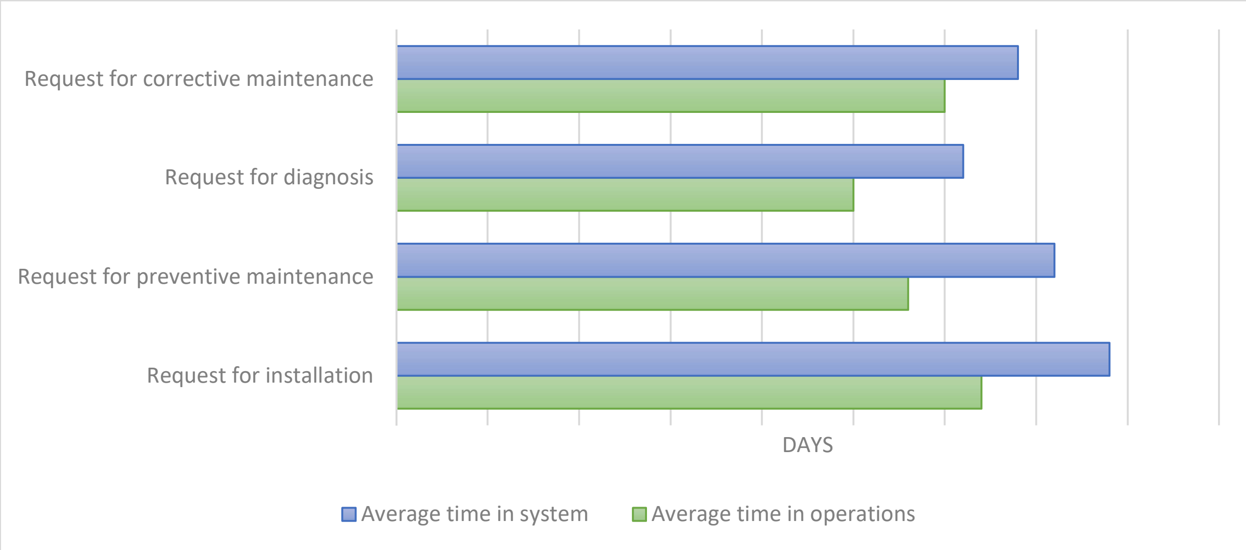


Figure 53 Example or results analysed in the As Is analysis

Figure 54 shows the utilization of resources. Although the precise percentage of utilization is not reported for privacy reason, the analysis showed that the number of resources foreseen by the standard process have an acceptable utilization rate, at least under the 65% the maximum utilization of human resources suggested by (Dutta e Ali January 2011). The utilization rate of field service technician, in alignment with the data about the waiting time, are the resources with a higher utilization rate meaning. This further justifies the delays that they have in performing activities at the customer site.

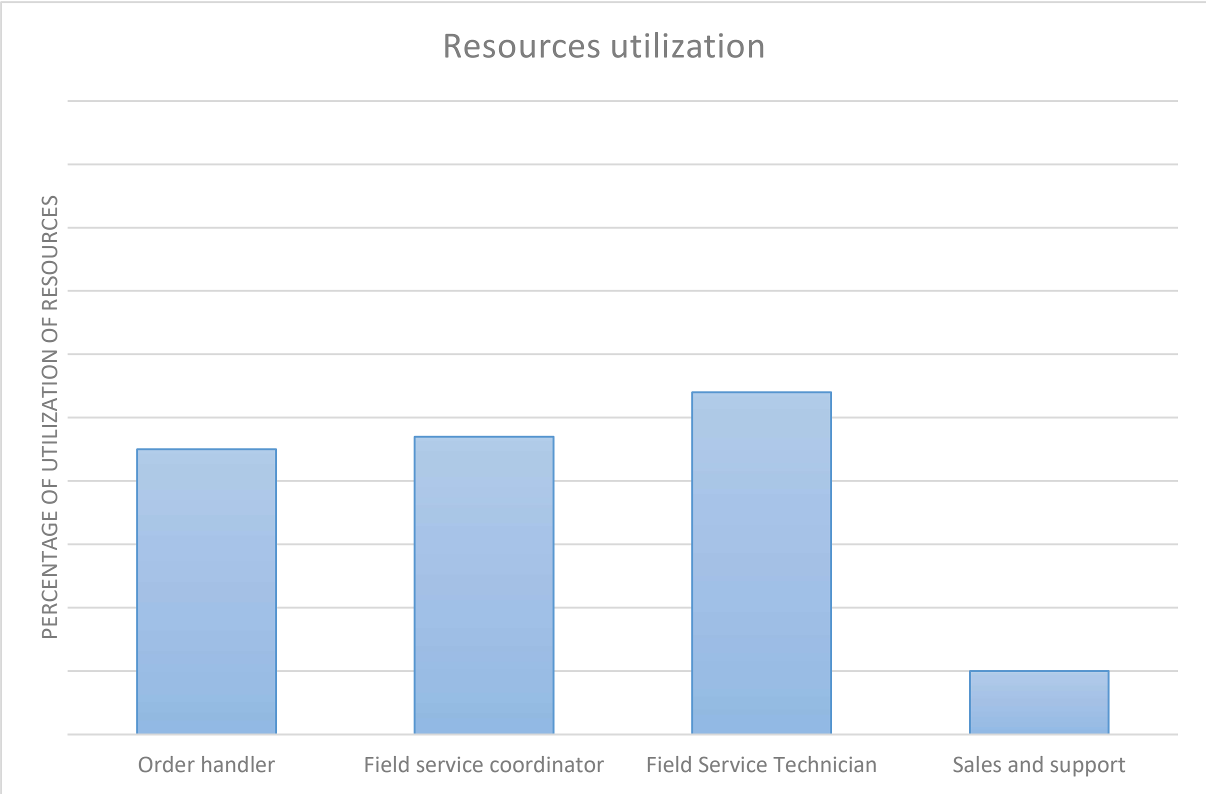


Figure 54 Example of the analysis of results

- *External KPI (Customer satisfaction)*. The analysis of the standard process also included the analysis of external performance, those perceived by the customers. The representation of customers through agents allowed the analysis of statistics for each kind of customer. In particular, a distribution of the waiting time for each specific customer was determined in the simulation model. Figure 55 shows an example of the distribution obtained for the customers requiring diagnosis service.

The distributions of the agents waiting time are showed in figures 56,57,58,59. In the Y axe, there is the number of waiting agents (or customers) that wait for a specific time interval (x axe). The time unit is not specified for privacy reason. The figures show that, on average, every type of customer wait around 6 time units during the service delivery process. Even if the utilization of resources is not at the maximum level, as explained in the previous paragraph, there is a relatively high waiting time for three type of customers out of four. This is mainly accumulated before the service job on site. According to the people responsible for this process, the waiting time could be acceptable for the customer because it also includes the time that the company need to prepare the technician's travel and documentation. It could be worth noticing that the process archetype mapped into the simulation model, potentially refers to technicians that travel all around the world and therefore some days of waiting could be justified, thinking about all the procedures that shall be managed for travelling.

Although these results refer to a service delivery process that is not yet implemented, the results presented are useful to show what could be the possible results and analysis that could be collected from the simulation model. The specific results about the customers also highlight that, thanks to the hybrid modelling, detailed info and statistics could be associated with each customer.

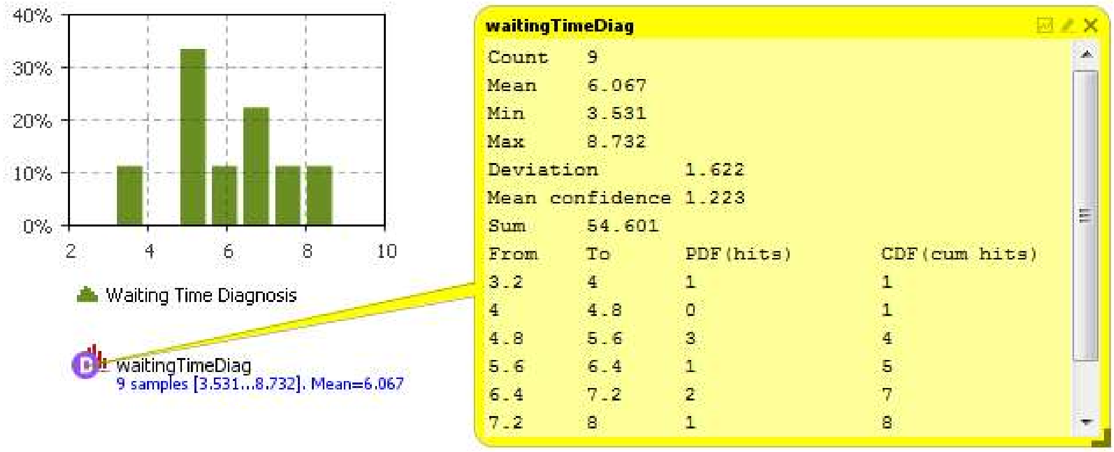


Figure 55 Waiting time distribution for the customers type "diagnosis"

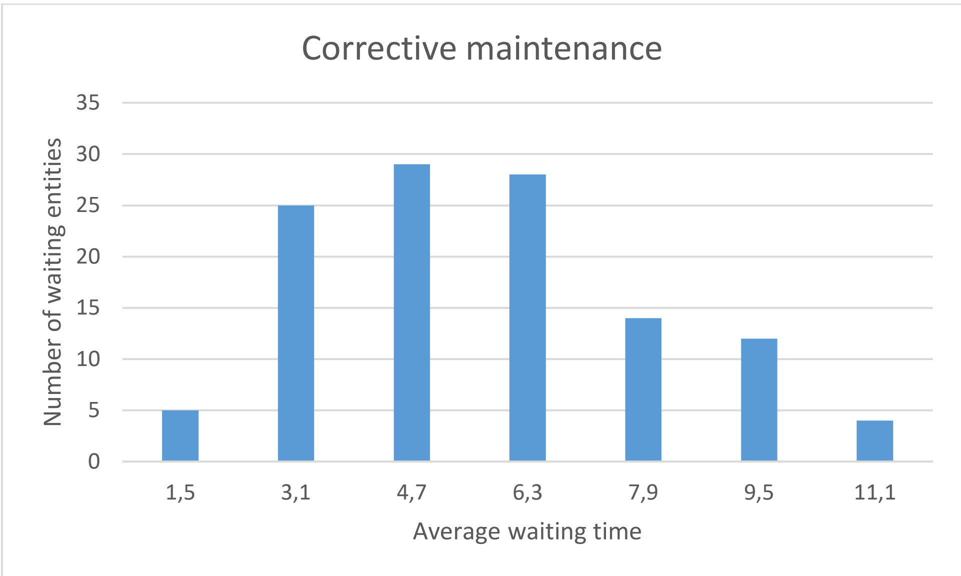


Figure 56 Waiting time distribution for customers asking corrective maintenance

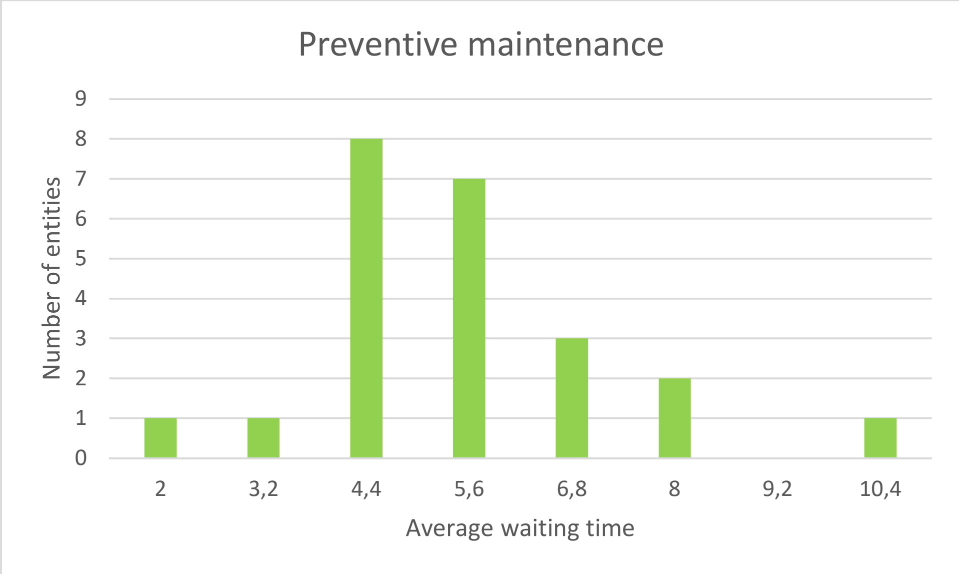


Figure 57 Waiting time distribution for customers asking preventive maintenance

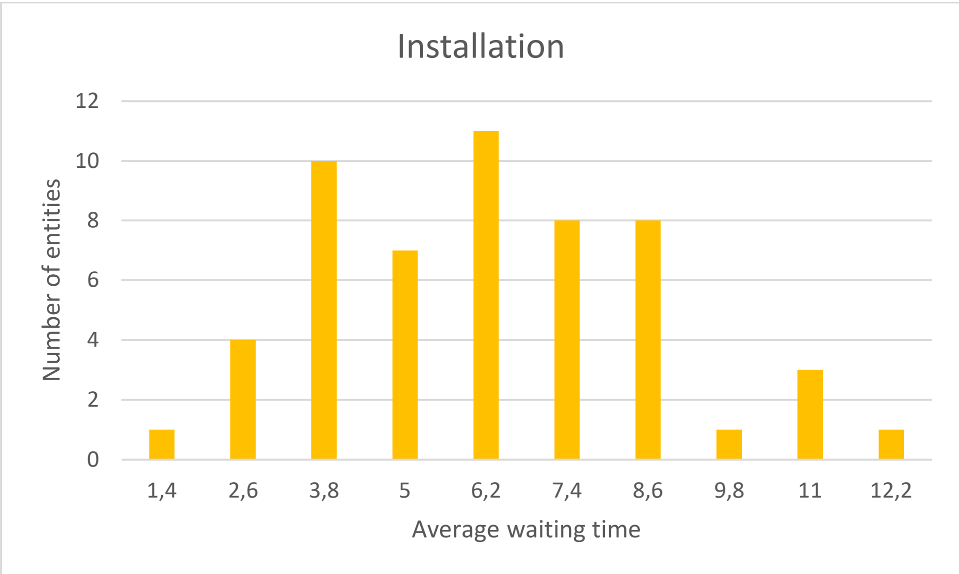


Figure 58 Waiting time distribution for customers asking installation

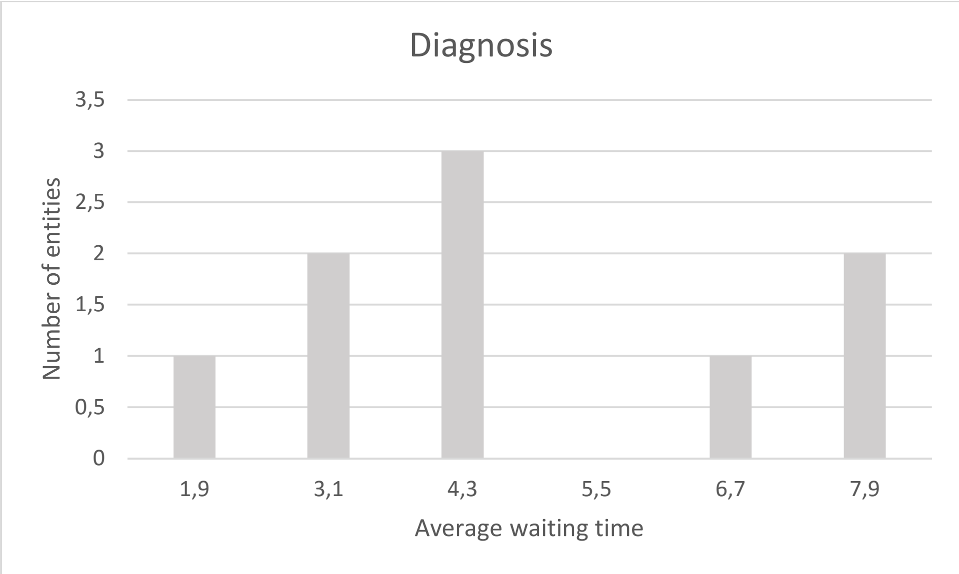


Figure 59 Waiting time distribution for customers asking diagnosis

10.2.2.2 Step 2.3

The last step of the engineering method that is proposed in this chapter (Step 2.3) foresees the utilization of the hybrid simulation model for a "what-if" analysis. This phase aims at supporting the identification of possible process variants and configurations in order to select the optimal one.

As previously suggested, the process analysed in this validation case is a standard process not yet implemented in business units. In order to verify optimize this process in terms of internal and external performance before suggesting it as a best practice, a what-if analysis was performed in order to verify how the process behaves. Many scenarios were developed to stress the model. Hereafter three of them are reported as an example in order to show how the simulation approach is capable of managing a what-if analysis to support companies in the identification of a proper trade-off between the performance of the process measured from the customer and the provider perspective. It would also show the capabilities of the approach in providing an easy to use method to the companies. The application of this third step into a case directly related to the ABB reality would also support the validation of the approach applicability of the entire FASt method in industry also for defining improvement action. In particular, three different improvements have been tested to show different features of the model. They are reflected in the three following scenarios.

1. Scenario 1. Refers to the service demand that the process has to face. In this scenario, an increase by 30% of the demand was foreseen to verify if the standard process, and the related resources, are capable of managing it.
2. Scenario 2 was adopted to verify how the process performance changes considering the variation of the resources availability. In this scenario, the number of technician was reduced

of one unit to verify if the company could be able to face the actual demand with one person less.

3. Scenario 3 was used to test a more customer oriented approach to service. Three more activities aimed at verifying the customer satisfaction were added. First, a proactive activity of sales personnel was included at the beginning of the process, then a double check with the customer before the service job and a contact with the customer at the end of the service job were foreseen by this scenario.

Hereafter is the performance of the three studies. Regarding the company internal measure the average time in operations and the average time in the system of the different type of customers. Figures 60 and 61 report the data for the three scenarios.

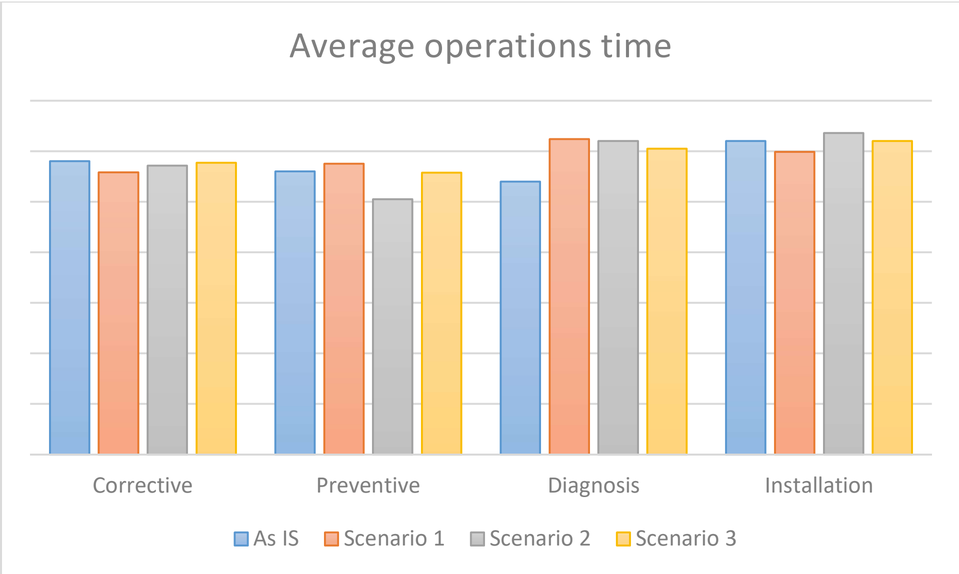


Figure 60 Average time in operations in the three scenarios

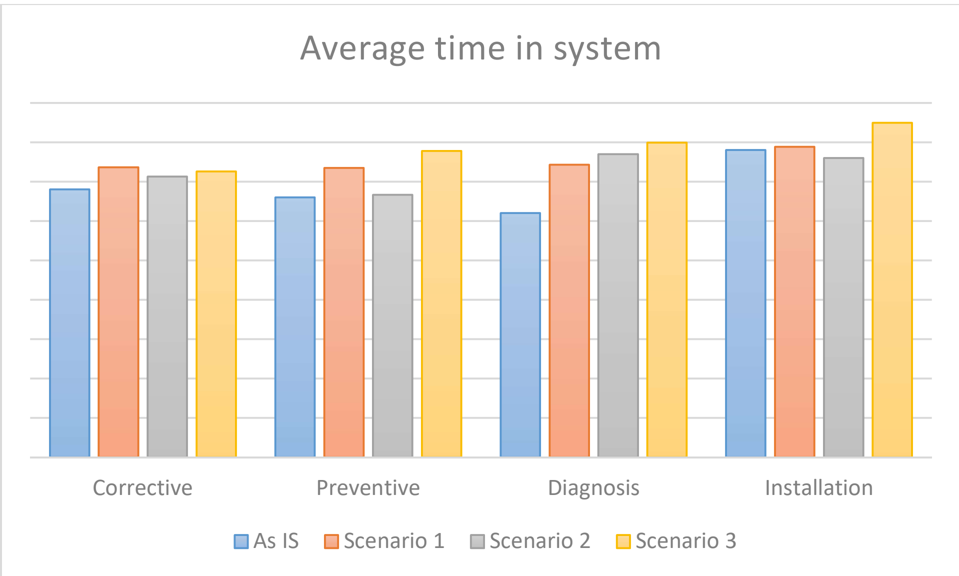


Figure 61 Average time in system in the three scenarios

The average time in operations, obviously, is stable in all the scenarios for all the type of customers while the average time in the system increases specifically in scenario 1 and scenario 3. Indeed, Scenario 1 is characterized by an increase of the demand that can cause some delay in the process and therefore higher time into the system. On the other hand, scenario 3 instead foresees some more activities to support the customers and this explains the increase of time in the system.

For what concern the utilization of resources, Figure 62 summarizes the utilization in the three scenarios.

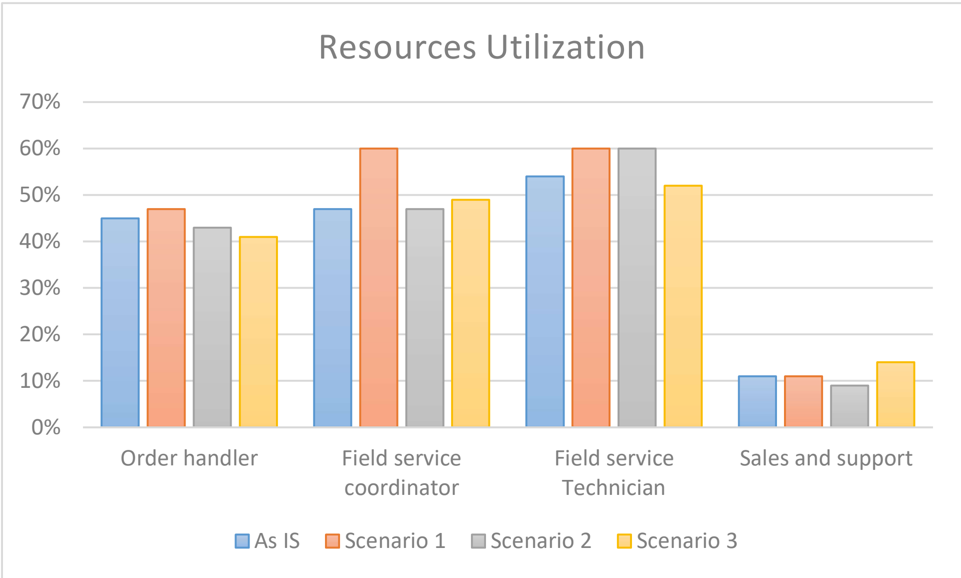


Figure 62 Resources utilization in the three analysed scenarios

Intuitively, the resources utilization increase in Scenario 1 characterized by high level of demand. The "field service technician" utilization is also higher in scenario 2 where one technician was deleted from the resource pool.

Finally, the average waiting time for the four different customers is displayed in figure 63. The most relevant queues can be observed in the scenario 1 with the increase in the services demand. It means that this reduces the availability of resources making them busier.

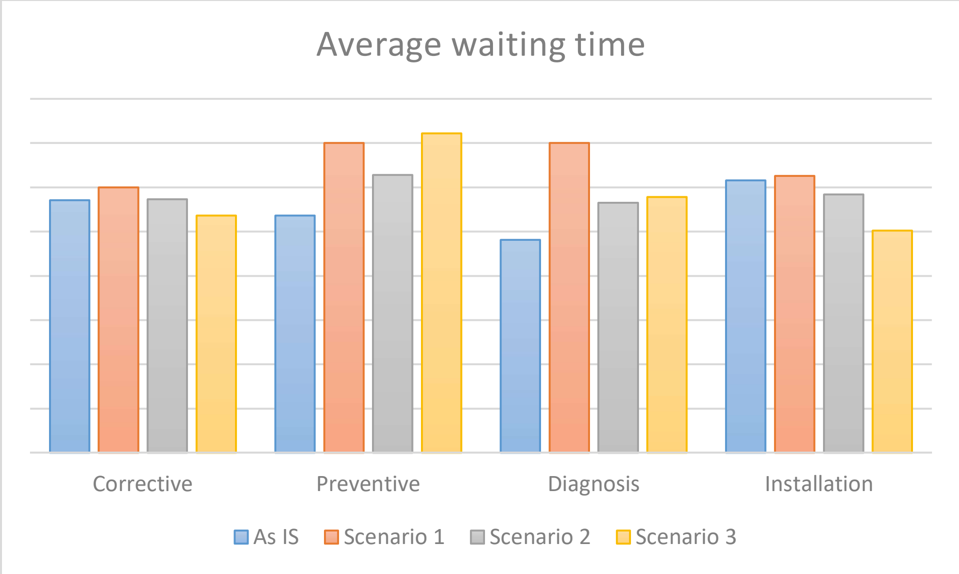


Figure 63 Average waiting time in the three scenarios

The results obtained from the validation case have been described to highlight how the FASt method could enable the analysis of multiple scenarios showing different results and providing useful information to make decisions in both BOM and MOL phases and to identify a proper balance between the customer and the provider perspectives. In other words, it could represent a useful and easy to use tool to be adopted by companies to engineer and monitor the service delivery process and to identify possible improvements. The process analysed, i.e. the standard service delivery process was simulated and analysed considering a set of KPIs. Although the process is not yet implemented in reality, a general analysis of the process performance was carried out to show the potentiality of the model in collecting data and in providing feedbacks for decision. Moreover, multiple scenarios and changes were applied to the standard process to verify the capabilities of the modelling approach in evaluating different alternatives.

Part III - Discussion

Chapter 7 describes a first explorative analysis of methods for the service delivery process assessment according to which DES is the most suitable method to reach the aim of this work

In a first instance, a DES approach was applied in multiple cases in collaboration with ABB. The cases highlight two major weaknesses of the DES method: the complexity and the time required for the process modelling and the criticality in depicting customers' decisions and flowing through a discrete event model.

In order to solve these issues, two major improvements were proposed and included in the FASt (Final Assessment of Service) approach presented in this chapter. The approach respectively proposes:

- The adoption of a modelling approach based on standardization and modularization that could support quicker modelling and engineering of the service while customizing it through the modules. The standard process and the associated modules solve the issue about time assessment time.
- The joint utilization of ABM and DES in a hybrid modelling approach for service delivery process assessment. The hybrid simulation approach favours a better representation of customers' behaviour and decision making.

A validation case in collaboration with ABB was described in the previous section. The case demonstrates that the FASt is actually supporting the service delivery process assessment providing statistics about KPIs from both the customer and the provider perspectives. Moreover, the case highlights how the approach overcomes the limitations of DES during the assessment and make managers capable of taking structured and justified decisions considering resources utilization and customer perceived performance. The service process modularization, make the service delivery process assessment quicker and less costly. Hence, having a set of standard process modules, acting as a reference implies that all the service processes could be engineered by putting together the modules. Based on this, each process assessment can be done "dragging and dropping" the modules into the simulation model. Whenever the modules are simulated the first time, then they can be reused in the same process or in others, significantly reducing the time required for the assessment setting. Modules indeed can i) be reused reducing time of parallel engineering and assessment, ii) ease the process updating phase due to the utilization of modules, iii) increase the variety of engineering solutions. For what concerns the assessment itself, some advantages could be also stressed. The capability of agent-based modelling in depicting customer behaviour is matched with the high flexibility of the hybrid simulation model. Since DES and ABM shall be modelled in different phases the two can be edited, updated and modified independently. Furthermore, the collection of statistics and information about the customers, (the agents) is quicker and easier than in a pure DES model. The Hybrid simulation approach also showed good performance in managing “what-if” analysis and supporting decision making.

Besides, according to managers’ feedbacks, the adoption of such structured approach could be also beneficial during the re-engineering phases since the analysis of processes could improve the understanding about existing processes and inefficiencies and supported the definition of new processes characterized by a better resources planning.

Some weaknesses and complexities also emerged from the validation case. The modularization approach, as previously described, was applied indirectly into the simulation model. Only a graphical analysis was adopted to represent engineering modules. Further developments will be related to the study of simulation technicalities in order to create single modules (a group of activities) also in the simulation model.

Concerning the hybrid modelling, a high modelling complexity was experimented. Adding agents into the traditional DES model means adding a layer of complexity. Therefore, even if the model is more flexible, it requires more time to be developed and maintained. Finally, the FASt approach was tested only in the ABB context and this could restrict the results generalizability. Additional tests outside ABB context would be beneficial and will be part of future studies.

11 Conclusions

In the age of globalization, competition is more and more aggressive and customers' requests are growing and becoming more specific. To cope with these changes, many companies have shifted their focus on integrated product service offerings: the so-called Product-Service Systems (PSS). The introduction of such customer-oriented solutions can support manufacturing companies in generating value from multiple points of view pursuing a new strategy to fight rivalry and boost profitability in the current economic scenario. The benefits from PSS introduction, however, do not come without expenses and many companies experimented difficulties in managing intangible services in association with tangible artefacts. Unlike a product, indeed, service is a combination of processes, people skills, and materials that must be appropriately integrated to result in the 'planned' or 'engineered' service. This thesis focuses on this PSS scenario exploring methods and tools for supporting companies in managing the complex transition. In the direction of contributing to the existing studies, a literature analysis on the main methods adopted in the area, or specifically developed for PSS, is proposed. A cross comparison of the identified methods with the lifecycle phases of a PSS highlights that specific normative methods for each phase of the lifecycle are not yet available. Furthermore, some phases, such as the concept selection are rarely studied and methods are scarce. The narrow focus on the customer satisfaction and on the service component during the engineering phases also emerge as main gaps in the extant literature.

In practice, the need of methods to support the engineering of PSSs also emerges. Two main sources of information were adopted to collect industrial needs: first a three year participatory observation in ABB, the company that founded this research; second the development of a special issue in the International Journal of Production Research collecting cases and lessons learned in industry with respect to PSS. Both the two studies revealed that industry is still at the very beginning of the transformation toward PSS and that companies are not yet acquainted with the few methods and tools available for the PSS, either because they are very complex or because they do not always take care of the company profitability.

As a result, the goal of this thesis is **to develop decision making methods, applicable in industry, for the assessment of industrial Product Service System in strategic phases of the PSS engineering.** The methods aim at assisting decision makers in considering the trade-off between the customer and the provider viewpoints during multiple engineering phases of PSS. To comply with this objective two research questions are set:

RQ1 - ***How to support decision makers in assessing PSS concepts in the early design phase?***

RQ2 - ***How to engineer and assess service processes to deliver the identified PSS?***

To answer to the RQ1, the EVA (Engineering Value Assessment) method to support the PSS assessment in the early design phase was developed. It proposes an assessment approach based on two steps. For each step an existing multi criteria decision making method was selected and a list of value criteria to be coupled with the method for the PSS assessment were identified. The value criteria were further split to pursue the assessment from both the customer and the provider viewpoints. At the end of each step, the IPA map is used to visualize the multiple perspectives and support the value trade-off identification.
The EVA method was exploited in multiple validation cases and it revealed good in supporting the assessment of solutions belonging to a variety of industries and spanning from pure product engineering concepts, to PSS solutions, until pure service concepts. The method flexibility in dealing with both two or three stakeholders, its capability of generating consensus and pushing the discussion among team members and the immediate visualization of the value perceived by decision makers are the main benefits of the EVA method.

The second research question, (RQ2), refers to a more detailed assessment of the service delivery process to be performed during the design phase of a PSS or during the functioning of the PSS (MOL). In this case a multi-step method was proposed: the FASt (Final Assessment of Service) method. First, a standardization approach for service process based on a modular engineering approach is proposed in order to facilitate a quick and replicable process modelling. Then, a simulation approach based on hybrid modelling (ABM and DES) is described in order to properly represent the service delivery process with its distinguishing features. The validation of the method was carried out in a case in collaboration with ABB. The modelling of the service process through customizable modules, the method capabilities in depicting customer behaviour together with the high flexibility of the hybrid simulation model are the main benefits of the approach.

In the light of the strong influence of industry in this thesis, relevant managerial implications of the proposed methods are also described. Indeed, the developed methods are capable of supporting companies in properly engineering valuable PSS solutions since the very beginning phases avoiding re-works and changes in later stages when the PSS is already implemented. On the one hand, the EVA method supports the strategic decisions of the company supporting a first screening of the PSS solutions. It guides the engineering team in the evaluation of the solution (or a set of solutions) that can potentially bring high value to the company. Pitfalls such as the implementation of solutions not appreciated by the customers or providing a loss for the company (because not efficient) would be definitely avoided. Moreover, according to managers' opinions, such an objective analysis of alternatives prevents personal affection to ideas and favours a clear understanding of the team members' opinions on the solutions under analysis. Importantly, the method is extremely easy to use and can be followed also by people with no engineering background and from many functions inside the company. On the other hand, the FASt approach is more oriented to companies' operations and represents support while setting and engineering the service delivery process. It implies a better definition of activities, roles and responsibilities inside the company. It also supports the definition of procedures and tools to be adopted inside the process. Such a structured manner of engineering the process avoids inefficiencies throughout the service delivery activity and makes the company ready for providing an excellent service to its customers. This also indicates a coherent and equal approach to the global customers increasing the image and the brand promise. In terms of monitoring, the detailed engineering of the service also facilitates managerial control over the process and over the people involved. Manager can better justify their decisions and be sure that they are objective as justified by a structured approach.

Weaknesses of the work could be also highlighted. First, since the scholarship for the PhD is founded by ABB, the current work is characterized by a strong influence from industry, especially from ABB. Continuous verification of the research advancement is a common pattern throughout the work. All the findings were verified through industrial cases and from each application feedbacks and suggestions were analyzed and used to improve the results in terms of industrial applicability. Truthfully, ABB company is active in many businesses and a variety of contexts that the analysis of cases inside the company could be comparable to the application in different businesses.

Second, the thesis lays its foundation in the PSS research domain and literature however, a strong emphasis on the service component could be observed, especially for what concern RQ2. This is mainly justified by the existence of well-established methods for the product design and development. This research indeed wouldn't argue with concepts that are frozen and well adopted by companies but instead aims at proposing new and useful methods to cover the gaps.

11.1 Further developments and improvements

Future research developments are related to the abovementioned gaps and to possible future perspectives related to the research in the area of PSS assessment.

As described in the introduction of this work, the methods proposed to answer RQ1 and RQ2 could be part of an integrated methodology that includes both the two methods to pursue a complete engineering approach. A full-scale validation case of the methods in a holistic methodology, that could be for example the SEEM, could support in validating the two approaches from a high level perspective.

Moreover, for both the cases further validation cases could be interesting to verify the applicability and the validity in multiple contexts.

For what concerns the first research question further research will be devoted to the study of methods currently proposed by the EVA. The validation cases provided good feedbacks both about Pugh and TOPSIS but additional research could better highlight if they are "the best" methods to be adopted out there could be an additional method that fit the EVA stucture and purpose. To do so, the comparison of the Pugh method with other approaches would be carried out to highlight strengths and weaknesses of each of them and to further validate the Pugh as the proper method into the EVA. For example the adoption of simple voting mechanism is under analysis. A similar comparison would be carried out for the TOPSIS method with for example VIKOR method.

The pursuit of a sensitivity analysis to evaluate the subjectivity biases could be also worth more exploration to verify the robustness of the results from the EVA method.

Besides, the additional analysis could be focused on the overall structure of the EVA method. It could be interesting to double check the structure of the EVA method to verify if it could be possible to pursue one single step of evaluation avoiding two iterations as in the current form.

In parallel a deeper reasoning on the EVA flowchart that guides the selection of the step would be reviewed.

Regarding RQ2, the major development foreseen is the expansion of the method considering a complete PSS, therefore, considering the product component of a PSS. Although product engineering methods are well developed, the integration of them within the FASt method could be a relevant contribution to an integrated PSS engineering method.Further analysis is also foreseen to deepen the existing research and to explore new developments concerning both the "process modelling" and the "dynamic assessment" phases. Regarding the "process modelling" the current reference model structure will be further validated in more cases. Further development of the reference model proposed in the ABB case could help in settling a general and standard reference model in order to make it useful and valid for many companies, at least in the B2B context. It could be defined as a " service delivery reference model" that could be used as a standard to follow when engineering new processes similarly to the SCOR model.

The hybrid simulation approach currently proposed in the FASt method could be also worth further developments. In the current approach the customer decisions are defined a priori based on specific assumptions. It could interesting to study a dynamic change of customer preferences according to the process functioning and the passing of time. For example, it could be interesting to simulate a situation in which, once the dynamic process starts, they can modify their opinion depending on the interactions with other actors and on the process.

The analysis of process modularity and the possibility use pre-defined model into the simulation model could be also studied. It would imply that a process module as described in the blueprinting map would be associated with the same module into the simulation module already including data. This would further fasten the translation of a process model into simulation.

Finally, specifically for the study of RQ2 a validation case in the B2C context could bring to the fore interesting insights and points to be discussed.

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Appendix

Appendix A – Tables of the EVA method application

Pugh Matrix Step 1 – Customer – ABB case

Customer	WEIGHT	Modular Service contract	Extended warranty	Installation and commissioning	Predictive maintenance	Maintenance	Baseline - Retrofit
Capability creation and retention	6%	1	-1	0	1	0	0
Asset and resources management	16%	1	-1	0	1	0	0
Business opportunity	0%						0
Environment	4%	1	1	0	1	1	0
Intangibles	12%	1	-1	0	1	0	0
Value in use	20%	1	0	0	1	0	0
Acquisition costs	20%	1	1	0	1	0	0
Ownership costs	0%						0
Operational costs	0%						0
Maintenance and repair costs	16%	-1	0	0	-1	0	0
Disposal costs	4%	1	1	1	1	1	0
	100%	**6**	**0**	**1**	**6**	**2**	**0**

Weighted Pugh Matrix Step 1 – Customer – ABB case

Customer	WEIGHT	Modular Service contract	Extended warranty	Installation and commissioning	Predictive maintenance	Maintenance	Baseline - Retrofit
Capability creation and retention	6%	0.06	-0.06	0.00	0.06	0.00	0.00
Asset and resources management	0	0.16	-0.16	0.00	0.16	0.00	0.00
Business opportunity	0%	0.00	0.00	0.00	0.00	0.00	0.00
Environment	4%	0.04	0.04	0.00	0.04	0.04	0.00
Intangibles	12%	0.12	-0.12	0.00	0.12	0.00	0.00
Value in use	20%	0.20	0.00	0.00	0.20	0.00	0.00
Acquisition costs	20%	0.20	0.20	0.00	0.20	0.00	0.00
Ownership costs	0%	0.00	0.00	0.00	0.00	0.00	0.00
Operational costs	0%	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance and repair costs	16%	-0.16	0.00	0.00	-0.16	0.00	0.00
Disposal costs	4%	0.04	0.04	0.04	0.04	0.04	0.00
	100%	**0.67**	**-0.06**	**0.04**	**0.67**	**0.08**	**0.00**

TOPSIS Matrix Step 2 – Customer – ABB case

CUSTOMER	WEIGHTS	Modular Service contract	Maintenance	Installation and commissioning	Predictive maintenance
Capability creation and retention					
Data and knowledge sharing with provider (value co-creation)	7%	5	0	5	1
Upgrade industrial structure	6%	1	3	4	1
Empowerment of resources competences	6%	2	0	4	1
Time to market	0%				
Asset and resources management					
Asset safety and security	7%	3	2	4	3
Improved delivered quality	7%	3	3	4	3
(Optimization) Asset utilization	0%				
Asset efficiency	0%				
Asset Flexibility	0%				
Business opportunity					
Revenue generation opportunity	0%				
Partnership generation opportunity	0%				
New market generation	0%				
Environment					
Lifecycle increase of product	6%	4	1	4	5
Natural resources consumption	0%				
Intangibles					
Healthiness	0%				
Aesthetic appeal	0%				
Experience	0%				
Empathy	4%	2	1	3	1
Value in use					
PSS availability	7%	5	1	5	3
PSS functionality	7%	5	1	5	1
PSS safety and security	3%	1	0	3	3
Ease of use	9%	5	0	5	0
PSs customizability	6%	3	0	3	0
PSS flexibility	0%				
Acquisition costs					
Service Price	9%	-5	-1	-4	-4
Product price	9%	0	0	-2	0
PSS price	0%				
Ownership costs					
PSS commissioning and installation	0%				
Resources training and/or setting	0%				
Operational costs					
Operational costs of PSS	8%	-5	0	-4	0
Maintenance and repair costs					
Maintenance and repair costs of PSS	0%				
Disposal costs					
Disassembly and return costs	0%				
Products and material recycling costs	0%				

TOPSIS Matrix Step 2 – Provider – ABB case

PROVIDER	WEIGHTS	Modular Service contract	Maintenance	Installation and commissioning	Predictive maintenance
Strategy					
Company brand/image	5%	4	3	5	2
Revenue stabilization	4%	5	0	4	2
Alignment with company strategy	4%	4	3	5	3
Capability creation and retention					
Empowerment of resources competences	0%				
VP traceability and learning	3%	3	1	5	1
Data and knowledge sharing with customer (value co-creation)	3%	4	0	5	1
Time to market	5%	3	0	4	1
Design reuse	0%				
Asset and resources management					
Resources (asset/employee) relocation and usage	5%	4	1	0	4
Asset/employee efficiency	0%				
Resources (asset/employee) Flexibility	5%	4	3	0	4
(Optimization) Asset/employee utilization	5%	4	3	0	4
Market					
New customer acquisition	6%	4	3	5	2
New market generation	0%				
Improve retention of existing customers	6%	5	2	4	3
Environment					
Natural resources consumption	0%				
Parts /products reuse and recycle	1%	0	2	0	2
Value chain					
Generation/exploitation of value chain alliances	0%				
Strategic positioning in the value chain	2%	4	2	4	1
Efficiency of stakeholders network	0%				
Design costs					
Service design costs	6%	-4	-1	-5	-1
Product design costs	0%				
Infrastructure design costs	0%				
Implementation costs /investment					
Implementation costs	6%	-4	-1	-5	-1
Resources training and enrichment	6%	-4	-1	-5	-1
Operational and support costs					
Operational costs of service	4%	-4	-1	-5	-1
Operational costs of product	4%	-2	0	-4	0
Operational costs of infrastructure	4%	-2	0	-4	0
Disposal costs					
Products and material recycling costs	0%				
Cost to decommission the solution	0%				
Costs to comply with regulation					
Costs to comply with regulation	0%				
Network costs					
coordination costs	6%	-4	-1	-5	-1
information carrying costs	6%	-4	-1	-5	-1
Innovation					
Innovation	4%	3	0	4	0

Pugh Matrix Step 1 – Customer – Asphalt roller case

Customer	WEIGHT	Wireless control	Foldable frame	Autonomous machine	Modular architecture	Concept freedom	Single drum machine	Hire to rental	Free trial period	Functional results	Maintaining	Leasing	Selective hire	Continuous training	Exist. Offer
Product/service value in use	20%	1	1	1	1	1	1	1	1	1	1	1	1	1	0
System convenience	16%	1	0	1	1	1	1	1	1	1	1	1	1	1	0
Intangibles	10%	-1	0	-1	0	0	-1	1	1	1	1	1	0	1	0
Social benefits	0%	0	0	0	0	0	0	0	-1	0	1	1	0	1	0
Environmental benefits	0%	0	0	0	0	0	0	1	0	1	1	1	1	1	0
Cost	20%	1	-1	-1	-1	-1	-1	1	1	1	1	0	1	-1	0
Time	18%	-1	0	1	0	0	-1	-1	0	0	-1	0	-1	0	0
Effort/ risk	18%	-1	-1	-1	0	0	-1	1	0	1	-1	1	1	1	0
	1	**0**	**-1**	**0**	**1**	**1**	**-2**	**5**	**3**	**6**	**4**	**6**	**4**	**5**	**0**

Weighted Pugh Matrix Step 1 – Customer – Asphalt roller case

Customer	WEIGHT	Wireless control	Foldable frame	Autonomous machine	Modular architecture	Concept freedom	Single drum machine	Hire to rental companies	Free trial period	Functional results	Maintaining	Leasing	Selective hire	Continuous training	Exist. Offer
Product/service value in use	20%	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0
System convenience	16%	0.16	0.00	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0
Intangibles	10%	-0.10	0.00	-0.10	0.00	0.00	-0.10	0.09	0.09	0.09	0.09	0.09	0.00	0.09	0
Social benefits	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.04	0.00	0.04	0.04	0.00	0.04	0
Environmental benefits	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cost	20%	0.20	-0.20	-0.20	-0.20	-0.20	-0.20	0.19	0.19	0.19	0.19	0.00	0.19	-0.19	0
Time	18%	-0.18	0.00	0.18	0.00	0.00	-0.18	-0.17	0.00	0.00	-0.17	0.00	-0.17	0.00	0
Effort/ risk	18%	-0.18	-0.18	-0.18	0.00	0.00	-0.18	0.17	0.00	0.17	-0.17	0.17	0.17	0.17	0
	1	0.10	-0.18	0.06	0.16	0.16	-0.29	0.62	0.58	0.79	0.32	0.64	0.53	0.45	0.00

Pugh Matrix Step 1 – Provider – Asphalt roller case

Provider	WEIGHT	Wireless control	Foldable frame	Autonomous machine	Modular architecture	Concept freedom	Single drum machine	Hire to rental	Free trial period	Functional results	Maintaining	Leasing	Selective hire	Continuous training	Exist. Offer
Brand/strategy	22%	1	1	1	0	0	1	1	1	1	1	1	0	1	0
Customer relationship and knowledge	13%	1	0	1	0	0	1	1	1	1	1	1	1	1	0
Business opportunities	28%	1	0	1	1	0	1	1	1	1	1	1	1	1	0
Social benefits	3%	1	0	1	1	0	0	0	0	1	1	1	0	1	0
Environmental benefits	6%	0	0	1	0	0	1	1	-1	1	-1	1	1	1	0
Product/service cost	28%	-1	-1	-1	0	0	-1	0	-1	-1	-1	0	-1	0	0
Uncertainty/ risk	0%	-1	0	-1	-1	0	-1	0	-1	-1	0	-1	-1	0	0
	1	**2**	**0**	**3**	**1**	**0**	**2**	**4**	**0**	**3**	**2**	**4**	**1**	**5**	**0**

Weighted Pugh Matrix Step 1 – Provider – Asphalt roller case

Provider	WEIGHT	Wireless control	Foldable frame	Autonomous machine	Modular architecture	Concept freedom	Single drum machine	Hire to rental	Free trial period	Functional results	Maintaining	Leasing	Selective hire	Continuous training	Exist. Offer
Brand/strategy	22%	0.22	0.22	0.22	0.00	0.00	0.22	0.22	0.22	0.22	0.22	0.22	0.00	0.22	0.00
Customer relationship and knowledge	13%	0.13	0.00	0.13	0.00	0.00	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.00
Business opportunities	28%	0.28	0.00	0.28	0.28	0.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.00
Social benefits	3%	0.03	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.03	0.00
Environmental benefits	6%	0.00	0.00	0.06	0.00	0.00	0.06	0.06	-0.06	0.06	-0.06	0.06	0.06	0.06	0.00
Product/service cost	28%	-0.28	-0.28	-0.28	0.00	0.00	-0.28	0.00	-0.28	-0.28	-0.28	0.00	-0.28	0.00	0.00
Uncertainty/ risk	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1	0.375	-0.0625	0.4375	0.3125	0	0.40625	0.6875	0.28125	0.4375	0.3125	0.71875	0.1875	0.71875	0

TOPSIS Matrix Step 2 – Customer – Asphalt roller case

Customer	WEIGHTS	Wireless control+ Leasing	Wireless + functional results	Autonomous machine + Leasing	Autonomous machine + Functional results
Product/service value in use					
Product durability	2%	4	4	3	3
Product usability	3%	5	5	4	4
Product quality	2%	5	5	4	4
Product lifecycle	1%	4	4	2	2
Service usability	3%	5	5	5	5
Service quality	1%	4	2	4	2
Assistance customer support	1%	3	5	3	5
Customization	2%	4	3	2	2
Responsiveness	3%	3	5	4	5
System convenience					
Increase of asset flexibility	1%	5	5	1	1
Increase of asset productivity	3%	3	3	5	5
Production time saving	3%	4	4	5	5
Failure decrease	2%	4	4	2	2
Production costs saving	3%	4	4	5	5
Lower responsibility	1%	3	3	5	5
Lower resources consumption	3%	4	4	5	5
Intangibles					
Assurance	3%	4	5	3	4
Kindness	2%	3	5	3	5
Intangible value	0%	0	0	0	0
Experience	2%	4	4	5	5
Excitement	1%	4	4	5	5
Aesthetics	2%	4	4	4	4
Empathy	2%	4	5	4	5
Social benefits					
Increased welfare and care	2%	5	5	1	1
Improvement of social cohesion	1%	5	5	0	0
Empowerment of human resources	1%	4	3	2	1
Support the solution of cultural and institutional problems	0%	0	0	0	0
Environmental benefits					
Reduced pollutants	1%	4	4	5	5
Reduced raw material consumption	0%	0	0	0	0
Reduced energy consumption	2%	3	4	4	5
Support green lifestyle	0%	5	5	5	5
Cost					
Price	3%	4	5	3	4
Price structure	2%	4	5	4	5
Tco	0%	3	4	3	4
Fixed costs	2%	3	3	2	2
Deposit	2%	2	2	1	1
Operational costs	2%	2	2	3	3
Maintenance costs	3%	3	3	2	2
Decommissioning costs	0%	0	0	0	0
Resources costs	3%	4	4	5	5
Plant adaptability costs	1%	5	5	4	4
Ownership sharing costs	0%	0	0	0	0
Time					
Time to implement the solution	3%	3	3	1	1
Time to maintain the solution	3%	4	4	1	1
Time to integrate the product into business	2%	0	0	0	0
Time to integrate the service into business	3%	4	3	4	3
Effort/ risk					
Information sharing	1%	4	3	2	1
Risk associated to PSS	2%	4	5	4	5
Shared product ownership	3%	4	5	4	5
Lose control over knowhow	2%	3	3	1	1
Bad product performing	3%	4	4	2	2
Internal acceptability	2%	2	2	1	1
Privacy risks	1%	3	3	1	1
External factors influence	3%	4	4	1	1

TOPSIS Matrix Step 2 – Provider – Asphalt roller case

Provider	**WEIGHTS**	**Wireless control+ Leasing**	**Wireless + functional results**	**Autonomous machine + Leasing**	**Autonomous machine + Functional results**
Brand/strategy					
Improved company image	3%	3	5	4	5
Improve differentiation from competitors	4%	3	4	4	5
Improve strategic competitiveness	4%	4	4	5	5
Increased risk sharing	2%	4	3	2	1
Quicker time to market	3%	4	3	2	1
Customer relationship and knowledge					
Increase contact with customers	2%	3	4	4	5
More frequent contact with customers	1%	3	4	4	5
Information gathering from customers	3%	3	4	4	5
Information gathering about products	3%	4	4	5	5
Business opportunities					
Stable turnover	4%	5	3	4	2
High market share	4%	3	4	4	5
Increase revenues	3%	4	4	5	5
Enlarge to new mkt	2%	0	0	0	0
Blue ocean market	3%	3	4	4	5
Social benefits					
Increased welfare and care	2%	3	3	2	2
Improvement of social cohesion	2%	3	3	2	2
Empowerment of human resources	3%	0	0	0	0
Support the solution of cultural and institutional problems	3%	3	3	4	4
Environmental benefits					
Reduced pollutants	4%	4	4	3	3
Reduced raw material consumption	4%	4	4	2	2
Reduced energy consumption	4%	3	3	2	2
Support green lifestyle	3%	3	4	4	5
Product/service cost					
Product design costs	4%	3	3	2	2
Technology development costs	4%	3	3	1	1
Service design costs	4%	3	2	3	2
Standardization costs	4%	4	3	3	2
Implementation costs	4%	4	3	3	2
System/infrastructure costs					
Develop expertise inside the company	3%	5	4	3	2
Resources availability adaptability	4%	5	3	2	1
Operationalization of PSS	2%	3	2	3	2
Economies of scales	1%	3	2	2	1
Process required to produce PSS	2%	5	4	5	4

Pugh Matrix Step 1 – Customer – Smart city case

Customer	Weights	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Value in use	20%	1	1	-1	1	0	0	1	0	0	1	1	-1	-1	0
Personal "belonging and lifestyle" management	16%	1	1	0	1	0	1	1	1	0	1	1	-1	0	0
Business opportunity	0%														0
Environment	14%	0	0	1	1	1	1	0	1	1	1	0	1	1	0
Intangibles	18%	1	0	0	1	0	1	1	1	0	1	1	1	0	0
Capability creation and retention	0%														0
Innovation	11%	1	0	1	1	-1	0	1	0	-1	-1	1	1	1	
Acquisition (utilization)costs	20%	-1	-1	0	-1	0	0	1	0	0	1	1	1	0	0
Ownership costs	0%														
Operational costs	0%														0
	100%	**3**	**1**	**1**	**4**	**0**	**3**	**5**	**3**	**0**	**4**	**5**	**2**	**1**	**0**

Weighted Pugh Matrix Step 1 – Customer – Smart city case

Customer	Weights	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Value in use	20%	0.20	0.20	-0.20	0.20	0.00	0.00	0.20	0.00	0.00	0.20	0.20	-0.20	-0.20	0.00
Personal "belonging and lifestyle" management	16%	0.16	0.16	0.00	0.16	0.00	0.16	0.16	0.16	0.00	0.16	0.16	-0.16	0.00	0.00
Business opportunity	0%														
Environment	14%	0.00	0.00	0.14	0.14	0.14	0.14	0.00	0.14	0.14	0.14	0.00	0.14	0.14	0.00
Intangibles	18%	0.18	0.00	0.00	0.18	0.00	0.18	0.18	0.18	0.00	0.18	0.18	0.18	0.00	0.00
Capability creation and retention	0%														
Innovation	11%	0.11	0.00	0.11	0.11	-0.11	0.00	0.11	0.00	-0.11	-0.11	0.11	0.11	0.11	0.00
Acquisition (utilization)costs	20%	-0.20	-0.20	0.00	-0.20	0.00	0.00	0.20	0.00	0.00	0.20	0.20	0.20	0.00	0.00
Ownership costs	0%														
Operational costs	0%														
	100%	**0.45**	**0.16**	**0.05**	**0.59**	**0.02**	**0.48**	**0.86**	**0.48**	**0.02**	**0.77**	**0.86**	**0.27**	**0.05**	**0.00**

Pugh Matrix Step 1 – Provider – Smart city case

Provider	WEIGHT	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Strategy	13%	1	1	-1	1	0	0	1	0	0	1	1	-1	-1	0
Value chain	10%	1	1	-1	1	0	-1	1	0	0	1	1	-1	1	0
Capability creation and retention	6%	1	1	0	1	0	0	1	0	-1	0	0	1	1	0
Environment	10%	0	0	1	1	1	1	1	1	1	1	0	1	1	0
Market	3%	1	1	-1	1	0	1	0	1	1	1	0	1	0	0
Asset and resources management	9%	1	1	1	-1	1	-1	1	1	0	1	-1	-1	-1	0
Design costs	0%														0
Implementation costs /investment	15%	-1	0	-1	-1	-1	-1	-1	0	0	1	0	-1	-1	0
Operational and support costs	12%	-1	1	0	-1	0	0	-1	0	0	1	1	0	-1	0
Disposal costs	3%	0	0	-1	-1	0	-1	0	-1	0	1	0	-1	-1	0
Costs to comply with regulation	10%	0	0	0	-1	-1	-1	0	1	1	1	1	0	-1	0
Network costs	9%	0	-1	1	0	0	1	0	0	0	1	1	1	-1	0
	1	**3**	**5**	**-2**	**0**	**0**	**-2**	**3**	**3**	**2**	**10**	**4**	**-1**	**-4**	**0**

Weighted Pugh Matrix Step 1 – Provider – Smart city case

Provider	WEIGHT	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Strategy	13%	0.13	0.13	-0.13	0.13	0.00	0.00	0.13	0.00	0.00	0.13	0.13	-0.13	-0.13	0
Value chain	10%	0.10	0.10	-0.10	0.10	0.00	-0.10	0.10	0.00	0.00	0.10	0.10	-0.10	0.10	0
Capability creation and retention	6%	0.06	0.06	0.00	0.06	0.00	0.00	0.06	0.00	-0.06	0.00	0.00	0.06	0.06	0
Environment	10%	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0
Market	3%	0.03	0.03	-0.03	0.03	0.00	0.03	0.00	0.03	0.03	0.03	0.00	0.03	0.00	0
Asset and resources management	9%	0.09	0.09	0.09	-0.09	0.09	-0.09	0.09	0.09	0.00	0.09	-0.09	-0.09	-0.09	0
Design costs	0%	0.00	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Implementation costs /investment	15%	-0.15	0.00	-0.15	-0.15	-0.15	-0.15	-0.15	0.00	0.00	0.15	0.00	-0.15	-0.15	0
Operational and support costs	12%	-0.12	0.12	0.00	-0.12	0.00	0.00	-0.12	0.00	0.00	0.12	0.12	0.00	-0.12	0
Disposal costs	3%	0.00	0.00	-0.03	-0.03	0.00	-0.03	0.00	-0.03	0.00	0.03	0.00	-0.03	-0.03	0
Costs to comply with regulation	10%	0.00	0.00	0.00	-0.10	-0.10	-0.10	0.00	0.10	0.10	0.10	0.10	0.00	-0.10	0
Network costs	9%	0.00	-0.09	0.09	0.00	0.00	0.09	0.00	0.00	0.00	0.09	0.09	0.09	-0.09	0
	1	**0.15**	**0.44**	**-0.16**	**-0.06**	**-0.06**	**-0.25**	**0.22**	**0.29**	**0.18**	**0.94**	**0.46**	**-0.22**	**-0.44**	0

Pugh Matrix Step 1 – Stakeholders – Smart city case

Stakeholders	WEIGHT	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Value chain	15%	1	1	-1	0	0	0	1	1	1	0	0	-1	1	0
Innovation	13%	1	0	1	1	0	0	1	0	-1	-1	1	1	1	0
Market	20%	1	1	-1	1	1	1	-1	1	1	0	1	0	1	0
Environment	9%	0	0	1	1	1	1	0	1	0	1	0	1	1	0
Capability creation and retention	11%	1	1	-1	-1	0	-1	1	0	-1	0	0	0	1	0
Strategy	15%	1	1	-1	0	-1	0	0	-1	0	0	1	0	1	0
Asset and resources management	17%	1	1	-1	0	0	-1	0	-1	1	1	0	1	1	0
	100%	6	5	-3	2	1	0	2	1	1	1	3	2	7	0

Weighted Pugh Matrix Step 1 – Stakeholders – Smart city case

Stakeholders	WEIGHT	Inter. tour	BG tourist card	Smart light.	Smart park Mng	Electric buses	Charging station	Online mun. portal	Up Bike sharing	Airport shuttle	Wellness paths	Smart aging	Smart sensors	Smart load and unload	wifi
Value chain	15%	0.15	0.15	-0.15	0.00	0.00	0.00	0.15	0.15	0.15	0.00	0.00	-0.15	0.15	0.00
Innovation	13%	0.13	0.00	0.13	0.13	0.00	0.00	0.13	0.00	-0.13	-0.13	0.13	0.13	0.13	0.00
Market	20%	0.20	0.20	-0.20	0.20	0.20	0.20	-0.20	0.20	0.20	0.00	0.20	0.00	0.20	0.00
Environment	9%	0.00	0.00	0.09	0.09	0.09	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.09	0.00
Capability creation and retention	11%	0.11	0.11	-0.11	-0.11	0.00	-0.11	0.11	0.00	-0.11	0.00	0.00	0.00	0.11	0.00
Strategy	15%	0.15	0.15	-0.15	0.00	-0.15	0.00	0.00	-0.15	0.00	0.00	0.15	0.00	0.15	0.00
Asset and resources management	17%	0.17	0.17	-0.17	0.00	0.00	-0.17	0.00	-0.17	0.17	0.17	0.00	0.17	0.17	0.00
	100%	0.91	0.78	-0.57	0.30	0.13	0.00	0.20	0.11	0.28	0.13	0.48	0.24	1.00	0.00

TOPSIS Matrix Step 2 – Customer – Smart city case

Customer	WEIGHTS	Wellness path	Tourist card	Up Bike sharing	Online mun. portal
Capability creation and retention					
Data and knowledge sharing with provider (value co-creation)	0%				
Upgrade industrial structure	0%				
Empowerment of resources competences	0%				
Asset and resources management					
Asset safety and security	0%				
Improved delivered quality	0%				
(Optimization) Asset utilization	12%	2	3	5	4
Asset efficiency	0%				
Asset Flexibility	0%				
Business opportunity					
Revenue generation opportunity	0%				
Partnership generation opportunity	0%				
New market generation	0%				
Environment					
Lifecycle increase of product	0%				
Natural resources consumption	9%	5	3	5	2
Intangibles					
Healthiness	0%				
Aestethic appeal	11%	5	3	5	3
Experience	11%	5	4	5	2
Empathy	0%				
Value in use					
PSS availability	14%	5	4	2	5
PSS functionality	14%	5	4	3	3
PSS safety and security	0%				
Ease of use	14%	5	5	4	3
PSs customizability	0%				
PSS flexibility	0%				
Acquisition costs					
Service Price	16%	0	-5	-4	0
Product price	0%				
PSS price	0%				
Ownership costs					
PSS commissioning and installation	0%				
Resources training and/or setting	0%				
Operational costs					
Operational costs of PSS	0%				
Maintenance and repair costs					
Maintenance and repair costs of PSS	0%				
Disposal costs					
Disassembly and return costs	0%				
Products and material recycling costs	0%				

TOPSIS Matrix Step 2 – Provider – Smart city case

	WEIGHTS	Wellness path	Tourist card	Up Bike sharing	Online mun. portal
Strategy					
Company brand/image	10%	3	4	4	5
Revenue stabilization	0%				
Capability creation and retention					
Empowerment of resources competences	4%	0	4	1	3
VP traceability and learning	0%				
Data and knowledge sharing with customer (value co-creation)	9%	0	2	3	3
Time to market	5%	5	3	4	0
Design reuse	0%				
Asset and resources management					
Resources (asset/employee) relocation and usage	8%	1	2	4	4
Asset/employee efficiency	0%				
Resources (asset/employee) Flexibility	0%				
(Optimization) Asset/employee utilization	8%	0	3	3	4
Market					
New customer acquisition	2%	3	5	4	0
New market generation	0%				
Improve retention of existing customers	0%				
Environment					
Natural resources consumption	8%	5	2	4	3
Parts /products reuse and recycle	0%				
Value chain					
Generation/exploitation of value chain alliances	7%	2	5	2	4
Strategic positioning in the value chain	0%				
Efficiency of stakeholders network	7%	2	4	3	4
Design costs					
Service design costs	0%				
Product design costs	0%				
Infrastructure design costs	0%				
Implementation costs /investment					
Implementation costs	11%	-1	-3	-3	-5
Resources training and enrichment	0%				
Operational and support costs					
Operational costs of service	9%	0	-1	-4	-4
Operational costs of product	0%				
Operational costs of infrastructure	0%				
Disposal costs					
Products and material recycling costs	0%				
Cost to decommission the solution	2%	0	-2	-4	0
Costs to comply with regulation					
Costs to comply with regulation	7%	0	-1	0	-4
Network costs					
coordination costs	5%	-1	-3	-1	-4
information carrying costs	0%				

TOPSIS Matrix Step 2 – Stakeholders – Smart city case

	WEIGHTS	Wellness path	Tourist card	Up Bike sharing	Online mun. portal
Brand/strategy					
Company brand/image	10%	4	5	3	1
Improve communications	7%	2	5	2	3
Environment					
Lifecycle increase of product	0%				
Natural resources consumption	5%	5	2	4	3
Market					
New customer acquisition	12%	4	5	3	1
New market generation	0%				
Improve retention of existing customers	12%	4	4	4	1
Capabilities creation and retention					
Data and knowledge sharing with municipality, citizens and other stakeholders (value co-creation)	6%	1	5	3	4
Empowerment of resources competences	4%	1	3	1	3
Time to market	6%	5	2	4	1
Value chain					
Generation/exploitation of value chain alliances	8%	2	5	2	4
Strategic positioning in the value chain	0%				
Efficiency of stakeholders network	0%				
Public-private partnership possibilities	8%	1	4	1	5
Asset and resources management					
Asset safety and security	0%				
Improved delivered quality	0%				
(Optimization) Asset utilization	7%	1	5	1	0
Resources (asset/employee) relocation and usage	0%				
Innovation					
Improvement of technological standards	0%				
Innovativeness	5%	1	2	4	5
Connectivity	11%	3	5	4	4

TOPSIS Matrix Step 2 – Passengers – Airport case

Passengers	WEIGHTS	**Concept 1** *Retro fit – one step*	**Concept 2** *Retro fit – two-step*	**Concept 3** *New fit – one step*	**Concept 4** *New fit – two-step*
Problem resolution					
Promptness of handling requests and complaints	6%	4	5	2	3
Helpfulness of handling requests and complaints	5%	4	5	2	3
Performance					
Efficiency	5%	2	3	4	5
Waiting time	7%	2	1	4	3
Service time	4%	2	3	4	5
Responsiveness - promptness	5%	2	3	4	5
Accuracy - reliability	5%	3	2	5	4
Ease of use	6%	2	3	4	5
sense of safety and security	6%	1	1	1	1
Convenience					
Opportunity to book and pay through internet	4%	0	0	0	0
Service frequency	3%	0	0	0	0
Schedule flexibility and convenience	6%	0	5	0	5
Network externalities	1%	0	0	0	0
Employee					
Appearance	2%	0	0	0	0
Knowledge	2%	0	0	0	0
Promptness - responsiveness of providing service	1%	0	0	0	0
Courtesy	4%	0	0	0	0
Accessibility					
Clearness and accuracy of information	5%	2	3	4	5
Promptness and timeliness of information	5%	2	3	4	5
Availability	5%	5	5	5	5
Walking distance	2%	2	1	2	1
Image					
Appearance- modernity- attractiveness	4%	1	2	5	4
Cleanliness	2%	0	0	0	0
Environmental impact	2%	4	3	2	1
Price					
Price	7%	-1	-1	-3	-3

TOPSIS Matrix Step 2 – Airport – Airport case

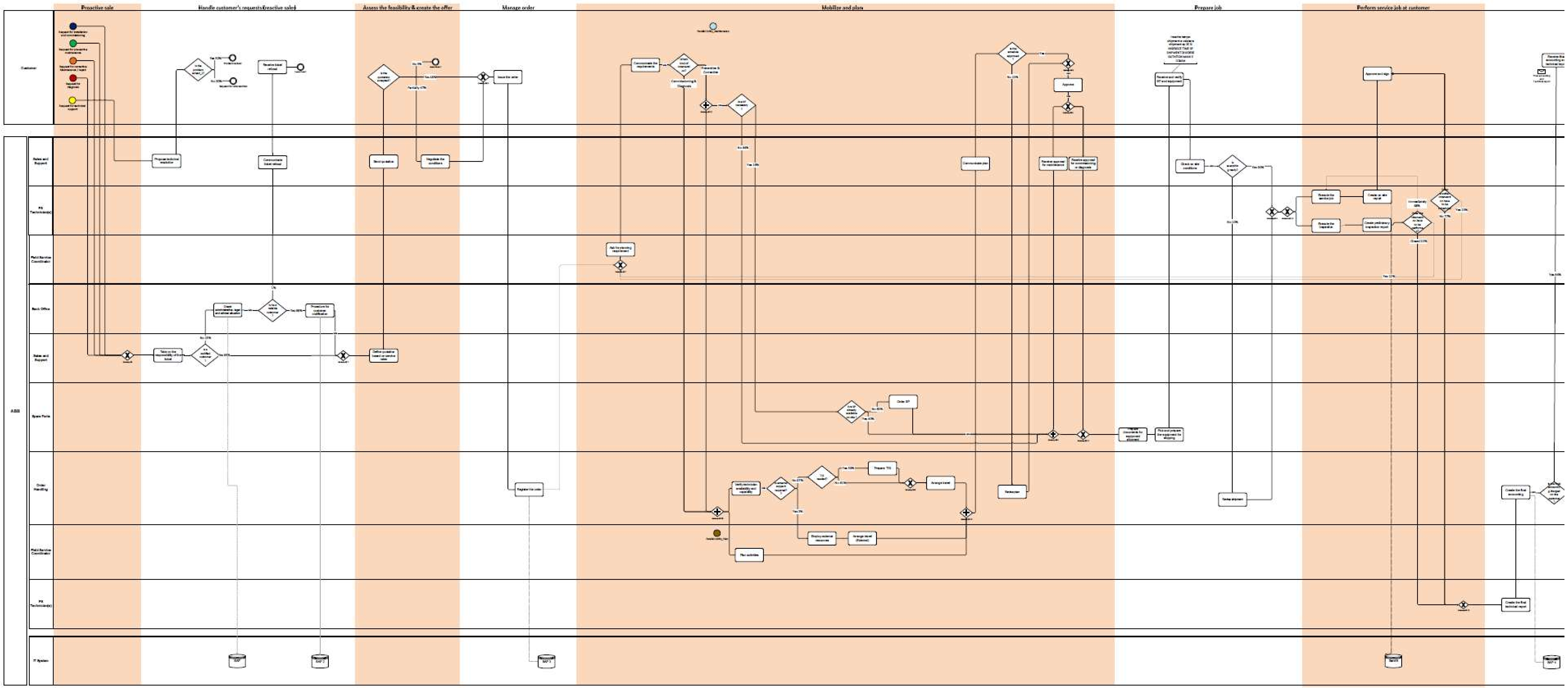
Airport	**WEIGHTS**	**Concept 1** *Retro fit – one step*	**Concept 2** *Retro fit – two-step*	**Concept 3** *New fit – one step*	**Concept 4** *New fit – two-step*
Revenue					
Aeronautical revenue -passenger	12%	3	3	5	5
Aeronautical revenue - airline	12%	3	3	5	5
Non-aeronautical revenue -parking	1%	0	0	0	0
Non-aeronautical revenue – shops	1%	3	3	3	3
Non-aeronautical revenue – advertisement	1%	2	3	4	5
Reliability and safety					
Number of accidents/incidents	5%	2	3	5	4
Time to resume normal service	10%	0	0	0	0
Image					
Number of jobs created	4%	0	0	0	0
Technology appearance	9%	3	3	5	5
Strategy					
Alignment with strategy	13%	1	2	4	5
Cost					
Investment cost	12%	-2	-2	-4	-4
Operational cost	5%	-4	-5	-2	-3
Disposal cost	5%	-2	-3	-4	-5
Social impact					
Number of community complaints about operations	5%	-3	-4	-1	-2
Natural resources consumption	5%	-1	-1	-1	-1

TOPSIS Matrix Step 2 – Airlines – Airport case

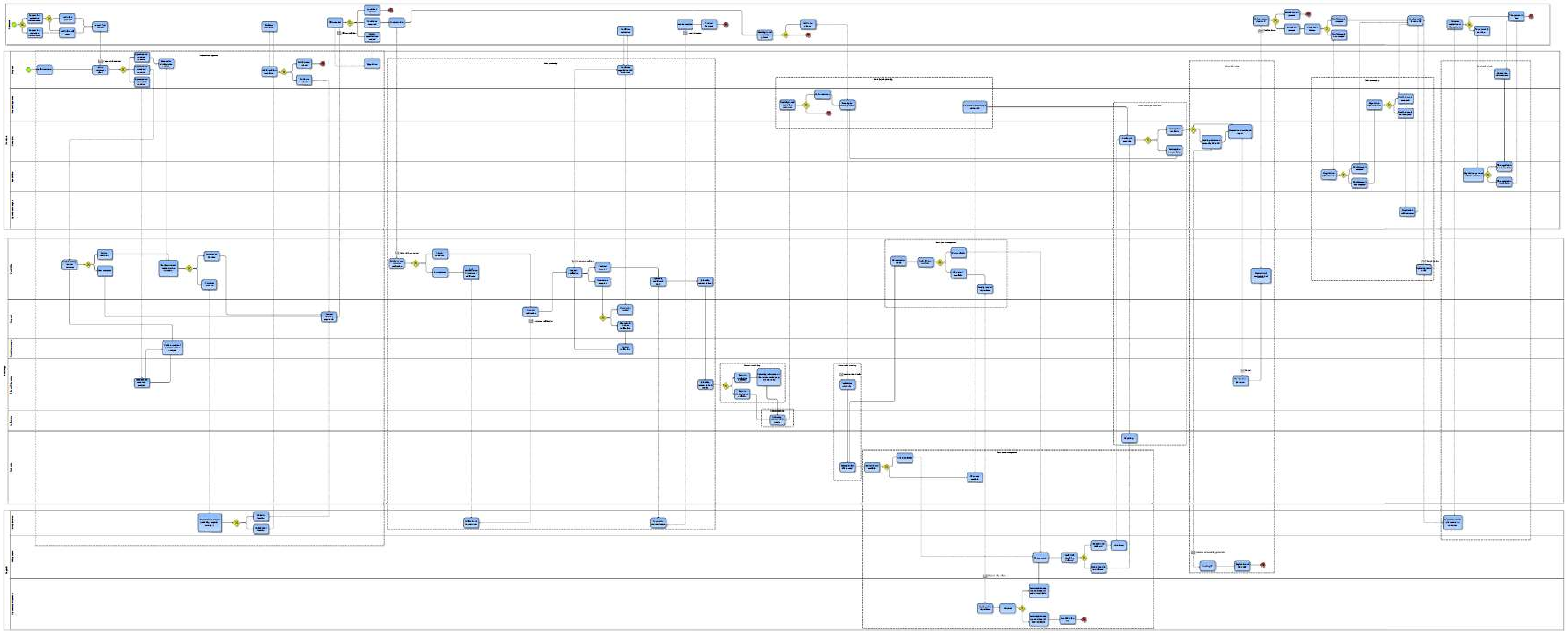
Airlines	**WEIGHTS**	**Concept 1** *Retro fit – one step*	**Concept 2** *Retro fit – two-step*	**Concept 3** *New fit – one step*	**Concept 4** *New fit – two-step*
Revenue					
Load/yield factor	16%	3	3	5	5
Image					
Number and type of complaints	12%	3	2	5	4
Technology appearance	12%	3	3	5	5
Impact on operations					
Punctuality	16%	2	3	4	5
Energy efficiency of installations managed	10%	0	0	0	0
Cost					
Airport fee	16%	-2	-2	-4	-4
Operational cost	12%	0	0	0	0
Advertising expenses	7%	-3	-2	-5	-4

Appendix B – Process mapping of the service processes in ABB

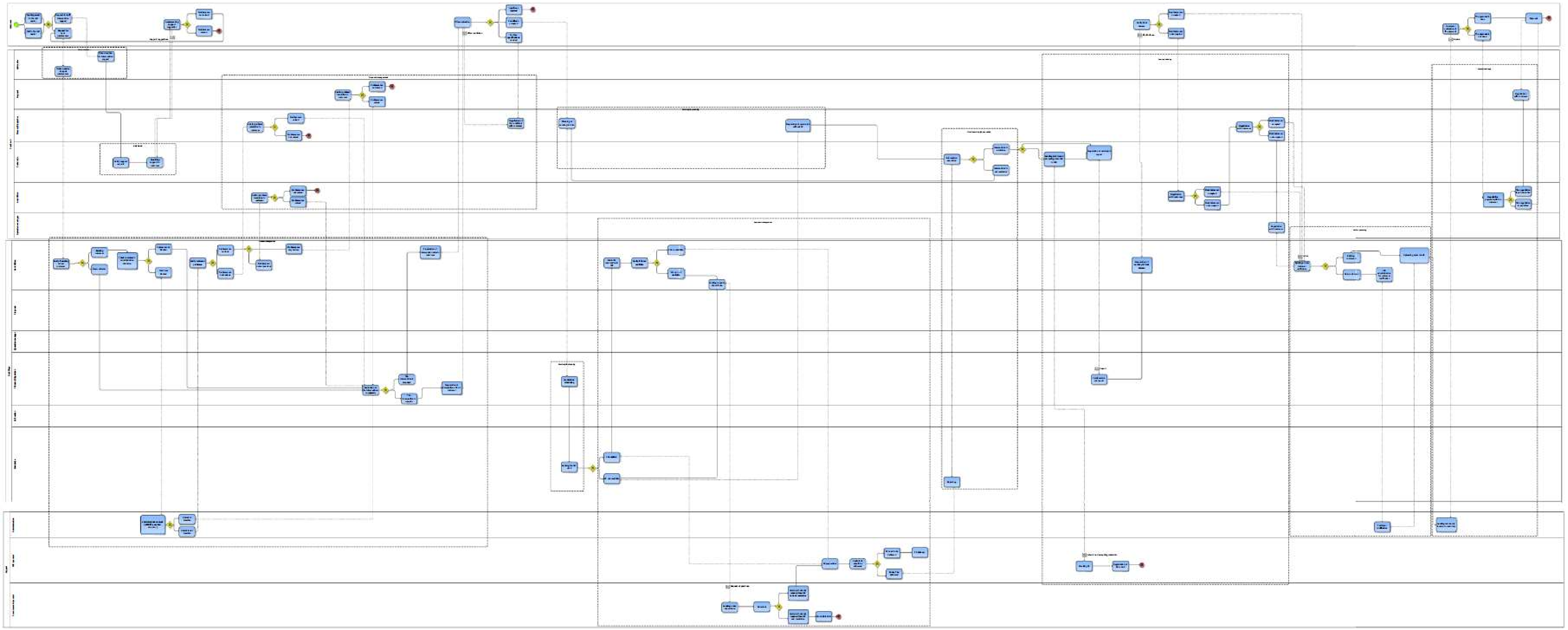
Process mapping Motors and generators business unit



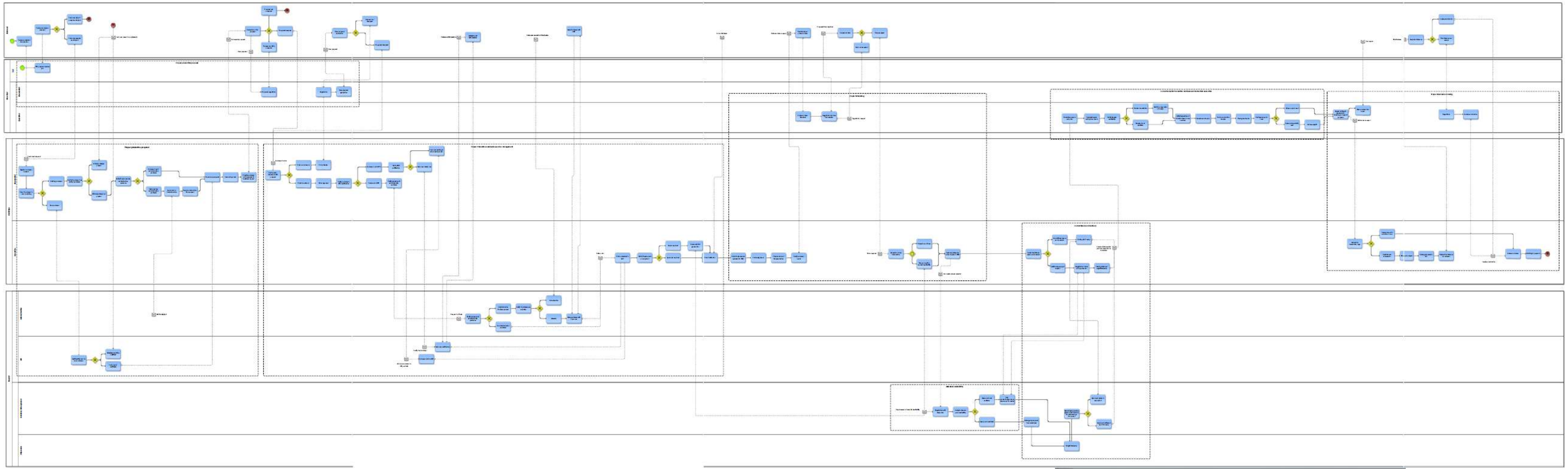
Process mapping Robotics business unit-Customer type “contract”



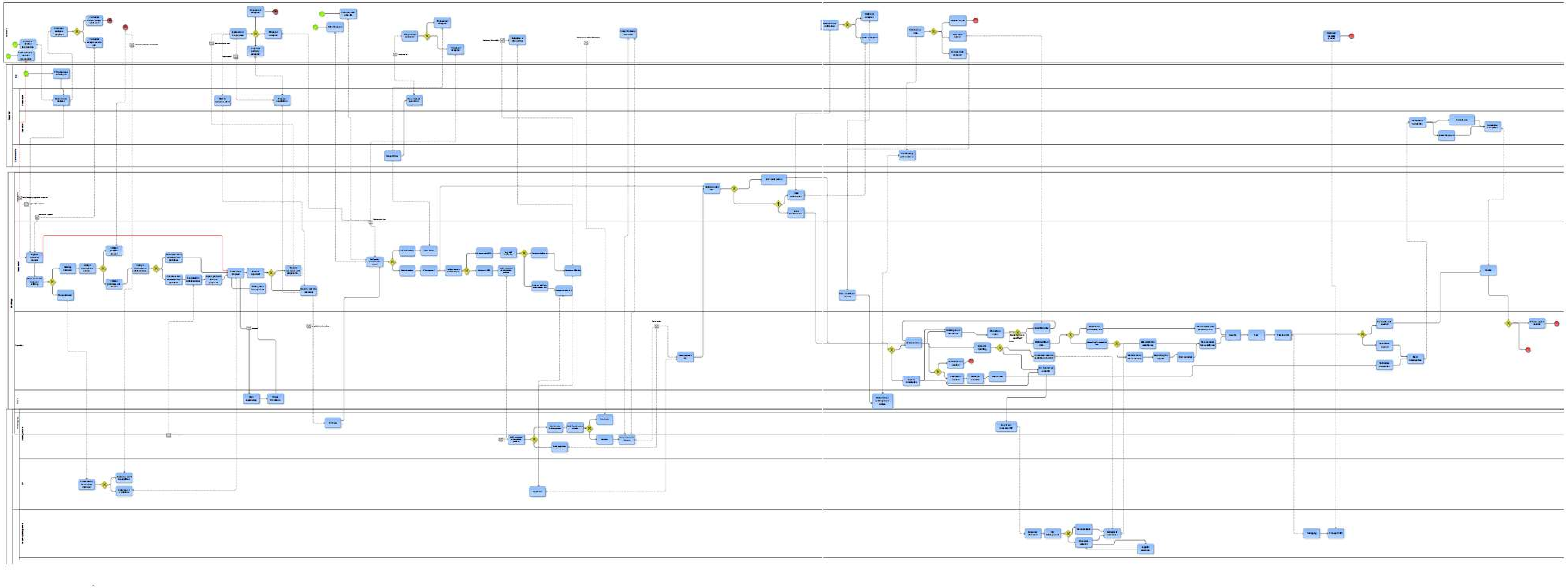
Process mapping Robotics business unit-Customer type “spot”



Process mapping Low voltage unit-Onsite service



Process mapping Low voltage unit-Retrofit service



Process mapping Low voltage unit-Replacement service