# The Functional-Engineered Product-Service System (FEPSS) Model

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# Abstract

Throughout recent years, environmental perils have increased and awareness regarding such dangers has improved proportionally. In light of the growing concerns, and coupled with fiercer competition and legislation, product based solutions to meet present and future needs have been deemed insufficient to ensure the planet's survival. Thus, the birth of integrated product-service offerings, where the product is associated to add-on services, enhancing its performance and achieving higher levels of value for the customer, as well as the manufacturer, with embedded ecological advantages. The service-oriented perspective of delivering solutions is known as Product-Service Systems (PSSs). However, despite advances in acknowledging the benefits that lie in adopting a PSS to answer consumer needs, a formal approach to developing PSS solutions is absent.

This dissertation investigates the integration of product design and service design strategies into product-service offerings: overall processes for this integration are present, but the intricate steps of each phase are missing. A literature review examines the most dominant design approaches, as well as design frameworks to structure the PSS design process. The outcome of the review led to the absence of a generic design framework as existing design approaches and processes seemed adapted to a specific context and field.

From the examination of the respective literature, we present a four-stage design process, entitled the Functional-Engineered Product-Service System (FEPSS) model, built on a design science approach. Ideation and task analysis, conceptual design, embodiment design, and validation and release are thoroughly detailed with the appropriate tools to define the elements of a PSS. The research then concentrates on the first two stages as they represent the core of PSS design and development process.

Ideation and task analysis highlight the use of qualitative tools to define customer requirements, as well as quantitative ones, such as the Kano model, Quality Function Deployment (QFD), the fuzzy logic, and the Analytic Hierarchy Process (AHP) to prioritize these requirements and define the value-creating ones as the basis of the PSS design.

Conceptual design presents two approaches to define PSS concepts. The first consists of a functional decomposition approach based on adapting morphological matrices (MMs) to a product-service extending traditional MMs to include the service elements and selection of stakeholders in a product-service integrated setting. The choice of the concept is determined according to a life cycle modelling that illustrates the environmental impact of the proposed concept(s) and compares it/them to the existing offering. The second opts for the QFD for PSS tool augmented by fuzzy logic and the AHP to determine the product and service components of the PSS. Then, the use of Axiomatic Design (AD) shows how a functional decomposition and QFD for PSS can be used to develop PSS modules. Four case studies conducted in the agricultural and biomedical field illustrate the use of the FEPSS and, in particular, its first two phases. The results achieved show the potential of such an approach when implementing a PSS approach, especially in the case of a manufacturer that wants to shift from producing products to providing integrated product-service offerings.

At the same time, from a more general perspective, the research work highlighted the benefits of PSSs as they allow the achievement of more sustainable solutions without decreasing the customer values.

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# Key terms and acronyms

The following presents a reference on how the most recurrent key terms are used in this paper and in which context, as well as a recapitulative of the abbreviations and acronyms present in the following sections.

The customer: in this dissertation, no distinction is made between a customer who purchases a product/service, a client who pays a company or person for a service or result, and a user who operates the service or product at hand. The customer can be a single person, a group of people or a firm.

The company: a group of people executing activities for set out objectives. A company creates products and develops services or product-service integrated solutions. It may also be referred to as a customer if it seeks products and services from other companies.

The actor: an entity that is active in the company-customer relationship. An actor can designate stakeholders, suppliers and distributors. It can in some particular cases be non-human such as a technology or procedure that may be catalytic in the overall scheme.

The design: covering all activities that lead to an end product such as product design, service design and industrial design: identifying requirements, idea generation, and evaluation schemes… Designers are the personnel elaborating the design activities.

The strategy: a plan of action to accomplish a set out task whether it is employed in a generic context or in a tighter, more defined realm such as a project team, an individual or a functional team.

The concept: a concept in design is a proposal for a product or service, which is brought to such a level of concretization, that allows someone to communicate to others the most important and distinguishing aspects of the product or service and how it will satisfy the customer needs.

As for the list of acronyms:

| | |
|---|---|
| AD | Axiomatic Design |
| ADVP | Analysis-Development-Verification-Proposal |
| AF | Adaptation Function |
| AHP | Analytic Hierarchy Process |
| ANP | Analytic Network Process |
| AS | Alternative Scenario |
| ASM | Application Space Mapping |
| B2B | Business to Business |
| B2C | Business to Customer |
| B2G | Business to Government |
| BMF | Business Model Framework |
| BMFPSS | Business Model Framework for Product Service Systems |
| BoL | Beginning of Life |
| BS | Base Scenario |
| CA | Customer Attributes |
| CBM | Condition Based Maintenance |
| CBMo | Canvas Business Model |
| CR | Customer Requirement |
| CTQ | Critical To Quality |
| CVCA | Customer Value Chain Analysis |
| DES | Discrete Event Simulation |
| DP | Design Parameter |
| EoL | End of Life |
| ERRC | Eliminate Reduce Raise Create |
| FAHP | Fuzzy Analytic Hierarchy Process |
| FEPSS | Functional-Engineered Product-Service System |
| FMEA | Failure Modes and Effects Analysis |

| | |
|---|---|
| FR | Functional Requirement |
| HoQ | House Of Quality |
| IDEF0 | Integration Definition for Function modeling |
| IF | Interaction Functions |
| IPASS | Innovative Product Advanced Service Systems |
| IPSS | Integrated Product Service Systems |
| LC | Life Cycle |
| LCA | Life Cycle Assessment |
| LCM | Life Cycle Management |
| MCV | Mobile Care Vehicle |
| MF | Main Function |
| MM | Morphological Matrix |
| MMo | Molecular Modeling |
| MoL | Middle of Life |
| MPSD | Modular Product Service Development |
| NPD | New Product Development |
| NPV | Net Present Value |
| PCh | Product Characteristic |
| PCo | Product Component |
| PDCA | Plan Do Check Act |
| PO | Product Oriented |
| P-S | Product-Service |
| PSS | Product Service System |
| PV | Process Variable |
| QFD | Quality Function Deployment |
| QFDforPSS | Quality Function Deployment for Product-Service System |
| RBM | Risk Based Maintenance |
| RDMo | Requirements Data Model |

| | |
|---|---|
| RO | Result Oriented |
| ROI | Return On Investment |
| RSP | Receiver State Parameter |
| SADT | Structured Analysis and Design Technique |
| SB | Service Blueprint |
| SC | Sub Concept |
| SCh | Service Characteristic |
| SCo | Service Component |
| SDB | Structure Design Blueprint |
| SF | Service Frequency |
| SLCM | Screening Life Cycle Modeling |
| SM | Service Mechanism |
| SP | Service Provider |
| SR | Service Receiver |
| SWOT | Strengths Weaknesses Opportunities and Threats |
| TBM | Time-Based Maintenance |
| TPM | Total Preventive Maintenance |
| UO | Use Oriented |
| VP | Value Proposition |
| VV | Velo’V |
| WTP | Willingness To Pay |

# 1. Introduction

## 1.1 Overview

Ever since the mass manufacturing system was been established, companies and business have sought to satisfy their customers' needs with product-offerings designed to answer defined quality requirements. However, the past few years have seen competition become sterner with gaps amongst competitors narrowed to minimal margins. Moreover, customers have developed more personalized needs, necessitating additional attention from developers. Adding environmental hazards to the mix resulted in seeing production shifting towards services, emphasized on providing the consumer with results and outcomes instead of physical artifacts (Tan, 2010).

Koudal (2006)'s study shows that service shares in business sales occupy a significant proportion of 26%, which increased to 36% in 2014 (Deloitte, 2016), arguing that the consumer is paying for the use and benefits of the physical artifact and not the product itself (Salter and Tether, 2006). The incentives driving the rise of the service industry fall under three pillars: economic value, dematerialization, and customer relationships.

Product sales are becoming more and more limited with several companies failing to reach their intended targets. Accordingly, a new means of creating value is through extending the artifact's value via the integration of services and products. The latter makes space for customization and personalization, catalyzing improved customer experience and market extension by strengthening manufacturer-customer relationships given the intangible value of shaping the experience to suit its user's own desires. To achieve such a target, the product-service integration utilizes the customer experience and interaction with the service and the product to better understand his requirements. Service differentiation creates profit margins by exploiting the quality drivers of price, serviceability, delivery time, use, and maintenance to tailor the economy towards one relying on profits achieved through results and not solely one-time product sales and ownership changes. Hence, product and service design barriers fade as technical engineers and product designers collaborate with marketing and service personnel to create integrated product-service offerings known as Product-Service Systems (PSSs) (Aurich et al. 2006).

Furthermore, environmental advantages have been linked with PSSs given their potential of decoupling the economy from material and energy consumption by substituting a material product with an immaterial way of fulfilling the same need or function, i.e. a service (Mulder, 2006; Tan, 2010). Table 1 presents examples on how manufacturers and industries have utilized their resources and products to shift towards service-based solutions.

Table 1 – Examples on the shift from products towards service-integrated solutions

| Manufacturer | Product | Transition to services and holistic solutions |
|---|---|---|
| Rolls Royce | Aircraft engines | Fixed fee maintenance, back-up service, condition monitoring, parts life management (Total care package and Power by the hour). |
| IBM | Computer hardware | Business and software consulting. |
| Azimut | Environmental data measurement, sensors and data processors | Environmental data required by clients. |
| Toshiba | Diagnostic imaging equipment | Asset management of medical diagnostic systems – equipment procurement, replacement, management, maintenance, repair and financing. |
| Zipcar | Transportation vehicle | Delivered and charged for according to an hourly rate of use. |

Davis et al. (2010) and Akeylken et al. (2013) argue that growth and sustainability ought to be separated from the planet's resources in order to be achieved: in other terms dematerialization. Dematerializing the economy implies reducing the material flows in production and consumption: creating products and services that provide consumers with the same level of performance, but with an inherently lower environmental burden (Table 2) (Mont, 2001). A crucial factor however to ensure the eco-advantages would be a holistic consideration of the life cycle stages of the proposal parallel to commitment, long-term approaches, flexibility and efficient collaboration between all the stakeholders involved (Bartolomeo et al. 2003).

Table 2 – Comparison between materialized and dematerialized economies

| **Traditional-materialized economy** | **Dematerialized economy** |
|---|---|
| Manufacturer is selling a product. | Manufacturer is selling a performance via a product-service combination. |
| Manufacturer responsibility for product quality. | Responsibility for performance quality and customer experience. |
| Ownership transfer to the client | Ownership may/may not change hands. |
| Manufacturer involvement in the product's use phase varies from limited to none. | Manufacturer plays a significant role in the product's lifespan. |
| Payment takes place when shift of ownership occurs. | Payment when performance satisfies client. |
| Benefits for the paying customer:<br>• Intangible value of ownership<br>• Allowed a possible higher value | Benefits for the using customer:<br>• More flexibility<br>• Cost is performance based<br>• No needed knowledge for maintenance / repairs. |
| Inconveniences for the buyer:<br>• Needed knowledge<br>• Operation under his own risk<br>• Responsible for product disposal | Inconveniences for the user:<br>• No right for a possible value increase. |
| Marketing based on forecasts, company reputation and publicity. | Marketing relying on customer service and retention, innovation and exposure. |

PSSs unite dematerialization, service extension and development, and functional extension to combine economic and environmental performance: a possible solution to the problem mentioned above.

Additionally, PSSs have the potential to answer the matter by centering the attention on efficiency and satisfaction to enhance the outcomes with the belief that production is not solely responsible for the offering's impacts, but its use as well (World Business Council for Sustainable Development, 2001; Tan, 2010). Moreover, ecological performance depends highly on the PSS provided as rebound effects are always present, and the customer's use of the product may lead to detrimental consequences that the PSS was trying to avoid. This concern puts more stress on the manufacturer to conceive a robust, sustainable design respecting environmental regulations without jeopardizing quality.

From a business perspective, economic reasons are the main driver for a service-oriented model, as no firm would risk a structural transformation without potential profits in the horizon. Manufacturing firms already provide services such as maintenance, after-sales support, customer service… but do so in an intuitive matter as a response to customer feedback. From here on, industries have realized that expanding services is the next niche for obtaining new income sources and creating new revenue-generating value.

## 1.2 Research Questions

Despite the benefits and advantages of PSSs exposed earlier, existing approaches to design PSSs are only described in a broad manner without providing details on the intricate steps needed to carry out the design (Tran and Park, 2014; Haber and Fargnoli, 2017a; Haber and Fargnoli, 2017b). Some processes/models focus on designing the solution from a customer's perspective, thus prioritizing customer requirements at the expense of the product-service integration activity (Alonso-Rasgado et al. 2004; Berkovich et al. 2014; Touzi et al. 2013). Others prioritize the environmental performance of the PSS (Aurich et al. 2006, Shekar 2007; Pezzotta et al. 2012). And in other studies, the integration and the design of the products and services are highlighted as the core of the solution (Marques et al. 2013; Maussang et al. 2009; Tran and Park, 2014).

Additionally, while product attributes and requirements can be quantified by their tangible characteristics, service attributes and requirements are more challenging to identify and define (Song and Sakao, 2016). In fact, customers' perceptions of services are harder to explicate due to the intangible nature of services, as well as their ambiguities and subjectivities (Aurich et al. 2010; Hakanen et al. 2016; Lo et al. 2016).

Thus, the need for a proper understanding of PSS design through an effective approach based on a systematic procedure that properly incorporates customer requirements is needed (Rapaccini et al. 2013; Sabbagh et al. 2016).

Hence, the purpose of this dissertation is to offer a pragmatic, robust, and flexible methodology to construct an integrated product-service solution based on a proper understanding of customer requirements. The latter can be summarized through the following research questions that consider three main aspects:

RQ1. How to implement a PSS considering the manufacturer/provider perspective?

RQ2. How to take into account the customers’ needs and expectations effectively when developing a PSS?

RQ3. What type of benefits can be achieved in practice when adopting a PSS approach?

## 1.3 Dissertation structure

A literature review (Section 2) examines the state of the art of PSSs, specifically regarding the dominant design tactics leading to the required solution. The most widespread approaches proved to lack uniformity and consistency, whereas it appears that each methodology is developed in a particular context given specific requirements and circumstances. Consequently, a unified design process was compulsory to ease the PSS design task in order to meet its intended objectives.

Section 3 investigates the PSS design processes, in other words, frameworks that guide PSS development. This part concludes with an analysis of the existing processes portraying the involved activities in each.

Subsequently, a framework is proposed and described in section 4: the Functional-Engineered Product-Service System (FEPSS) model. The FEPSS is founded on Hubka and Eder (1988) and (1992)’s design science methodology and is composed of four main pillars: ideation and task analysis, conceptual design, embodiment design, and validation and release.

Section 5 portrays four case studies that were carried out to test the practicality and effectiveness of the FEPSS model. The results obtained from each study are discussed in a separate manner, while conclusive remarks are summarized at the end of the section, focusing on the answers to the above-mentioned research questions.

Section 6 summarizes and concludes the dissertation.

The appendices included in the end provide further information concerning the case studies (Section 8).

# 2. Literature Review

PSSs have emerged in the industrial sector as a means of generating value for its providers and receivers in a more sustainable manner than conventional products (Haber and Fargnoli, 2017b). Recent studies in PSS have demonstrated how these integrated solutions have led to increased profits for the manufacturer (provider), increased (receiver) customer satisfaction and an improved environmental performance with reduced impacts (Meier et al. 2010; Lingegard et al. 2012; Beuren et al. 2013; Lindahl et al. 2014).

The increasing interest in PSSs has led to the emergence of several design approaches and processes aiming to generate value for its providers and receivers. The following chapter describes how value in a PSS context differs from value in a conventional product context. Then, a brief overview of the evolution of PSS is presented and its most popular design approaches are reviewed.

## 2.1 Value

Customer requirements do not relate solely on product ownership, as a central physical product can only procure its user with pre-defined results based on previous experiences, customer feedback, expert opinion and little or limited knowledge of any future demand the client might have. From this stance, it is clear that a PSS's key supplement is providing the consumer with a result customized to his own desires and necessities, fulfilling his current requirements and adaptable to future desires and requests. Therefore, the initial step is to understand the value users demand.

In an economical setting, a need designates a survival necessity: a necessary element to realize a defined function. 'Wants' on the other side are more specific and formed by each individual's particularities. Value is therefore the economic worth of a product/service offering from the customer's perspective in terms of the ratio of the function it performs to the cost a client is willing to pay in order to receive that value (Miles, 1972). Consequently, the higher the customer's willingness to pay (WTP) is, the higher the value of the solution is to him (Bowman and Ambrosini, 2000; Hoopes et al. 2003; Ostaeyen, 2014). Two stages can be discerned: value-in-exchange and value-in-use. The first is embodied in the ownership transfer from the manufacturer to the customer. The using consumer defines the second by evaluating the benefits that happen via product-service activities.

For producers, value is inherited in a product or a service seeking to satisfy specified needs and providing them with profits. The product is the physical core and the intangible services are the core's enhancements throughout the PSS's life cycle stages (Baines et al. 2007). The Life Cycle (LC) for a producer goes through product design, manufacturing, servicing and remanufacturing while from a customer's standpoint it consists of product purchase, usage and disposal (Schweitzer and Aurich, 2010). Thus, a holistic understanding of value and PSS life cycle arises from incorporating both LC perceptions. Hence, a life cycle analysis of the embedded cost, quality, flexibility, time, risk, efficiency and environmental effects is required to formally define value for both manufacturers and consumers (Andrew and Lyford, 2000; Chartered Institute of Management Accountants, 2005).

Consequently, an offering can be outlined as a Value Proposition (VP) stating why the customer should purchase the product or use a certain service and how the latter will provide more benefits than what rivals in the same market suggest. Five layers can be identified:

1. The core benefit: the key reason that lures the consumer.
2. The basic product: the realization of the core benefit
3. The expected product: the features or specifications the consumer hopes to find
4. The augmented product: additional services that can enrich and enhance to upkeep the related client activities
5. The potential product: all the possible features and prospects that the provider can supplement the product with in the future.

The VP is guided by the level of product and service considerations: if the essential component is a materialistic commodity accompanied by an ownership transfer, then it is product-centered. However, if the objective is the realization of a result or function, then it is service-centered.

Analogously, stakeholders gaining from the VP are to be defined. After all, a VP is only valid if intended for a specific market segment. A failure in identifying the benefiting actors leads to the system's failure (Crawley and Fend, 2008). Levitt (2014) explicates three categories:

1. Primary stakeholders (uppermost priority): direct actors who must be considered and whose needs must be met. Their overall satisfaction dictates the success or failure of the manufacturer's proposition.
2. Beneficial stakeholders (secondary priority): indirect actors who must be considered and their associated requirements should be met.
3. Charitable stakeholders (tertiary priority): actors who should be considered and whose needs may or may not be satisfied.

For a successful PSS, a merger of products and services relatively to their intended users is required: the company engineers the structure of its VP to implement new methods to satisfy customer needs and distinguish its offering from its adversaries. All value layers and stakeholders would have to be addressed for a strategic edge in a highly competitive environment. Table 3 portrays an example of traditional propositions that were altered into more suitable and profitable ones by understanding customer segmentation and dissecting the provided products and services. The detailed analysis allowed better solutions to prevail, which when integrated in a holistic solution resulted in innovative strategies that differentiated the adopting companies from their rivals and improved their market share.

Table 3 – Traditional VP vs. Solution VP (adapted from Booz-Allen and Hamilton, 1999)

| Industry | Product | Service | Traditional VP | Solution VP |
|---|---|---|---|---|
| Chemicals | Lubricants | Lubricant analysis.<br>Usage design. | Selling a range of lubricants | Increasing machine performance and up-time |
| Utilities | Electricity | Energy asset maintenance | Reliable provision of electricity | Helping reduce energy costs |
| Pharmaceuticals | Drugs | Product support.<br>Outcome-driven information database | Selling pharmaceuticals | Patient base management |

## 2.2 Product-Service Systems

PSS took birth in the mid-1990s as several scientists and researchers questioned the benefits of 'servicizing', dematerializing and the industrial stint to a service-oriented focus. Table 4 displays the definitions that emerged throughout the PSS evolution.

Table 4 – PSS definitions from the literature

| Author | PSS definition |
|---|---|
| Goedkoop et al. 1999 | A Product Service system is a marketable set of products and services capable of jointly fulfilling a user's need. The Product-Service (P-S) system is provided by either a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. And product and service can be equally important for the function fulfillment. |
| Manzini and Vezzoli, 2002 | A Product-Service System can be defined as the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to 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, a product service system tries to reach the goals of sustainable development. |
| Mont, 2004 | A product-service system is a system of products, services, networks of actors and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and has a lower environmental impact than traditional business models. |
| Tukker and Tischner, 2006 | Product-service system (PSS): the product service including the network, technological infrastructure and governance structure needed to 'produces' a product-service. |
| Baines 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. The PSS logic is premised on utilizing the knowledge of the design manufacturer to both increase value as an output and decrease material and other costs as an input to a system. |
| Leimeister and Glauner, 2008 | The intelligent interlocking of physical products and services that are already in the design and development phase closely linked. Their |

|  |  |
|---|---|
|  | individual components can be decoupled from each other only with difficulty. |
| Sakao and Lindahl, 2009 | Product-Service Systems are a concept that integrates products and services in one scope for planning, development and delivery, thus for the whole life cycle. |
| Tischner et al. 2009 | System of products and services (and infrastructure), to jointly cope with the needs and demands of customers in a more efficient way with better value for both businesses and customers, compared to only offering products. PSS can decouple the creation of value from the consumption of materials and energy and thus significantly reduce the environmental impact in the life cycle of traditional product systems. |
| Meier et al. 2010 | Product Service System (PSS): system combining physical products and services that have been integrated and optimized from a life cycle perspective in relation to customer value |
| Yahchin and associates, 2010 | Product-service (PS): a mix of tangible products and intangible service designed and combined so that they are jointly capable of fulfilling final customer needs.<br>Product-service system: the product-service including the network, technological infrastructure and governance structure (or revenue model) needed to “produce” a product service. |
| Schrodl and Turowski, 2011 | Offerings that provide tangible goods as well as services and intangible assets in an integrated manner. |
| Zhang and Haapala, 2011 | A product service system is an integrated system of people, products, and services engaged in the pursuit of life cycle economic, social and environmental benefits while fulfilling customer needs through added value. |
| Ostaeyen, 2014 | A Product–Service System is an integrated offering of products and services with a revenue mechanism that is based on selling availability, usage or performance. |

Many see PSSs as a way to confront competition in a sustainable manner. In several market segments where products have become quasi-equal, performance escalates to become the dividing consideration when preferring an offer instead of another. PSS models target service performance as the new source of company revenue while adding value to the customer and the customer-service interaction. The models to be successful need to:

1. Fulfill client needs in an integrated and customized way.
2. Build unique relationships with clients whilst enhancing loyalty and retention.

3. Innovate faster given the tighter customer relationship (Tukker, 2004).

A successful transition, backing up a PSS adoption while founded on value creation and sustaining the latter, requires precise information on market value, production and capital costs and the value capturing structure (Tukker, 2004).

Market value comprises of tangible (mainly product-related) and intangible value (mainly service and overall experience related). Tangible value is a candid approach as calculations weighing the costs of buying a product and estimating additional costs needed to operate, run or maintain the former; against the cost of a PSS offering. Intangible value is more conjectural and harder to define but revolves mainly around the customer's experience with the PSS as fluctuations of his WTP regarding a certain system.

Production and capital costs encompass the needed finances for the design, infrastructure and organization of the PSS from one hand and operational costs from the other. The second includes time inputs, labor costs, downtime, and risks. Frequently, when a PSS is service-focused, additional resource-consuming activities take birth and are obliged to generate value higher than the incurred costs; otherwise these tasks cannot be justified.

### PSS structure

The extent of interaction in a PSS justifies its structure (Figure 1). Whenever the product is heavily weighed against services, the system is labeled as product-oriented (PO), when the weights are evened out, the proposal is classified as use-oriented (UO) and when the offering is founded on a service, the PSS is result-oriented (RO) (Tukker, 2004).

**Product-oriented PSSs** are characterized with the ownership transfer from the producer to the client in parallel with service agreements to enhance the product experience. Such after-sale services include warranty, maintenance and customer support. Services, in other terms are induced to complement the product's value by maximizing the product's effectiveness and efficiency, while extending its original lifetime. From a manufacturer's point of view, the objective is to introduce a product that would seek long-lasting performance while maintaining proper functionality aspects and considering End of Life (EoL) features, such as re-use, recycling and modularity. Revenue in PO models is generated from the ownership transition from manufacturer to client and additional revenues occur upon intervention-based services (working hours, materials, repairs).

**Use-oriented PSSs** on the other hand are identified by the retained ownership within the provider's hands and the per time use / unit use of the paying customer (distinctions need to be made between usage-oriented where a consumer is paying for the time during which the product is used; and availability-oriented where the product is available for a fixed time period (Hypko, 2010; Ostaeyen, 2014). Such schemes imply higher than usual material use intensity to maximize the physical artifact's usage. Therefore, a smaller number of products is required to satisfy market demand and the higher use-intensity good lead to product obsoleteness arising prior to technological outdating; meaning that new models with better technological performance regarding ecology and economy will be implemented at a more frequent rate and improving overall sustainability performance. When facing an availability-oriented model, profit is made based on the time during which the product is available for the customer, regardless of whether the client is using it or not. *"For a product this means a monthly rental or leasing fee and for a service this means a fixed monthly sum to be paid for which the provider promises to deliver the service to the customer whenever necessary. In the example of a repair service, a time-based revenue mechanism could mean that, in return for a fixed monthly payment, the provider will carry out all necessary repairs to keep the underlying product functioning correctly, regardless of how intensively the product is used* (Ostaeyen, 2014)". On the other hand, when handling a usage-oriented system revenue takes birth only when the product or service is used (Rolls Royce charges its customers for the flying hours using their engine; Car2go implements a car renting service where consumers are charged for minutes of consumption and not availability).

**Result oriented PSSs** resemble use-oriented PSS in the ownership retention criteria but differ from an output's standpoint since in this type of PSS the client's requirements are achieved by means of a provider 'output' or function without the use of a product for a certain amount of time. The tangible product is always owned by the provider, who receives financial remuneration for providing a function result to satisfy consumer needs. This sort of PSS model urges technological and organizational innovation to optimize solutions and create new opportunities for higher profits and environmental performance. The characteristics of each sub-model in Figure 1 are exhibited in Table 5.

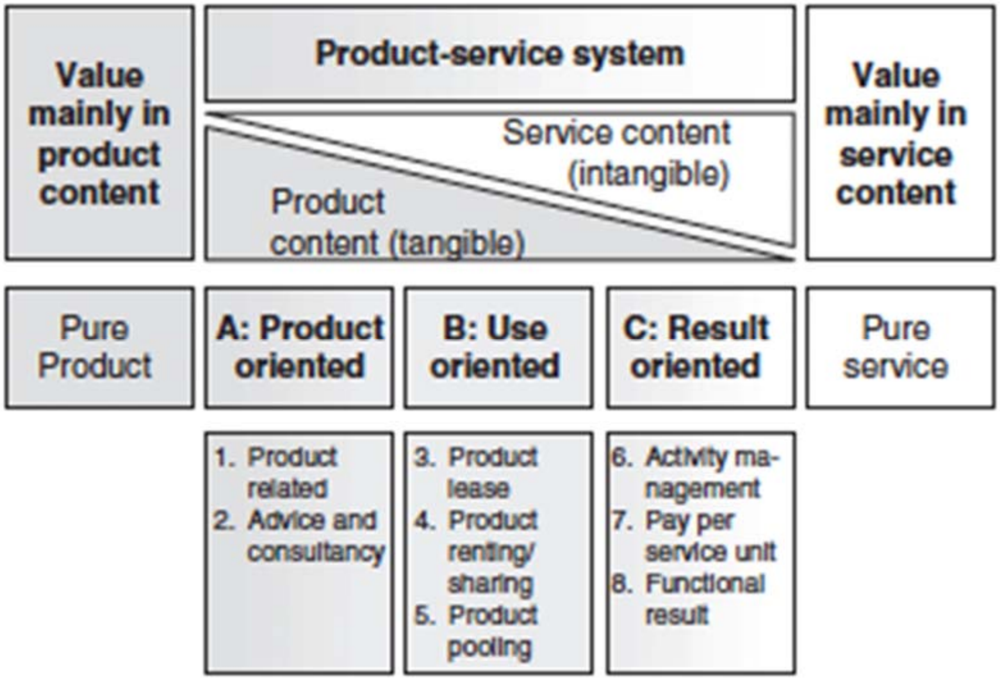


Figure 1 – PSS structures (Tukker, 2004)

Table 5 – Characteristics of each PSS model (adapted from Tukker, 2004)

| **PSS model** | **Characteristics** |
|---|---|
| Product Oriented (PO) | Mainly product sales but with some extra services supplementing that product. |
| 1. Product-related service | The provider sells a given product along with services required during the product's use (maintenance, material supply) and a take-back mechanism at the product's EoL. |
| 2. Advice and consultancy | The provider adds a sort of advice on what is the most appropriate and efficient way to use the product: logistic, organization, structure… |
| Use Oriented (UO) | The client does not own the product but the provider allows its use to the client: the customer pays for the use of the product but not its ownership (renting/leasing) |
| 3. Product lease | The product does not shift hands; the customer pays a fee for access (unlimited) to that product. The provider deals with maintenance and repairs of the artifact. |
| 4. Product renting or sharing | One customer does not have unlimited use of that product, instead other customers can use that same product at other |

| | |
|---|---|
| | time instances. Maintenance and repair are still on the provider's burden. |
| 5. Product pooling | Similar to (4.) but product use is now simultaneous instead of sequential. |
| Result Oriented (RO) | The provider will deliver a result by any means deemed necessary, the customer will not use any product |
| 6. Activity management / outsourcing | A part of an activity is outsourced to a different party. Performance and quality are regularly checked. |
| 7. Pay per service / unit use | Customer pays for a determined output vis-à-vis level of use. |
| 8. Functional result | The provider has to deliver a result with no obligation or constraints on how to deliver that. The latter has complete freedom as long as the customer is satisfied. |

## 2.3 PSS design

Every product involves services that come in play to provide the user with the maximal use and benefit of that product. Services are most often seen from a customer's standpoint and products from a manufacturer's point of view. The technical staff develops products while services are built and realized by the marketing department (Aurich et al. 2006). What a PSS seek to achieve is combining the two stances and thus departments to seek new opportunities. Inter-departmental collaboration would therefore require designers to acknowledge a broader range of elements to develop a fully integrated solution. Accordingly, a PSS is composed of a physical product core, continuously enhanced throughout its life cycle by non-physical services. A PSS, from this stance, is therefore a product whose associated services deliver value (Baines et al. 2007; Schweitzer and Aurich, 2010).

### 2.3.1 Product design

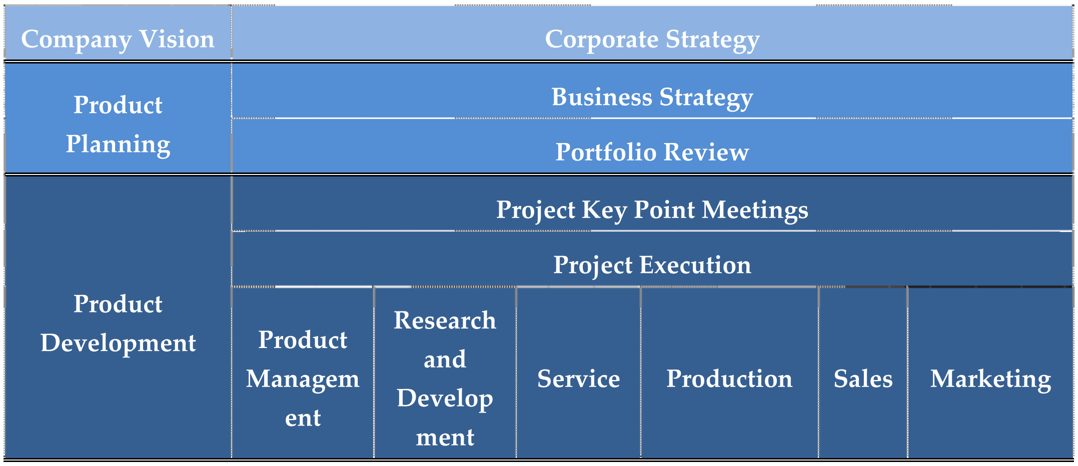
Product design consists of four stages for an effective and successful elaboration: product planning, development, synthesis and problem solving.

Product planning: is mainly concerned with establishing the business strategy to follow and how the chosen one will be developed. Concerns involve project development, resource management and project supervision (Andreasen and Hein, 2000). A holistic project development scheme covers several sub-projects which product planning seeks to harmonize and sustain within the company's objectives and goals (Figure 2). Sub-projects mainly include research and development, design tools, innovation, New Product Development (NPD), sales strategy, cost-reduction opportunities, revenue mechanisms etc.

Product development: essentially comprises of the undertakings that enable a business to run successfully (production, sales, marketing…). Determining the tasks to accomplish will be an answer to defining the problem (need, requirement, demand), conceptualizing the product (how to answer a need or meet a certain requirement) and in-depth designing (comprehensive product depiction). Product development thus consists of different assignments that connect the company to its customers in terms of business policy, products and technological innovation. Other methods are available such as using fishbone diagrams or DMAIC-adjusted approaches. The key point is using the right strategy for the right problem in its adequate context. The problem-solving tools are to be used as flexible guidelines not inelastic tools in order to achieve better results within a long-term time frame.

Product Synthesis: regards the technical design of the product from problem definition and analysis to detailed solution. Synthesis mainly comprises of allocating characteristics. The latter can be realized by a well-thought-out approach based on understanding the problem and analyzing its variants. Denominating the main functions and sub-functions, identifying the structure and levels of details will allow to quantify the current problem, solving relevant issues at a detailed level and finally enclosing the partial solutions into a complete integrated solution.

Problem Solving: in any design, problems arise and require solving. It is a general process that can be applied to any situation, regardless of the end product whether it is a commodity or a service and regardless the design that lead to it. A standardized approach however needs to be followed and can be summed up in a Plan-Do-Check-Act (PDCA) approach (Lodgaard and Aasland, 2011).



Company Vision
Corporate Strategy
Product Planning
Business Strategy
Portfolio Review
Product Development
Project Key Point Meetings
Project Execution
Product Management
Research and Development
Service
Production
Sales
Marketing

Figure 2 – Product planning overview (adapted from Larsson, 2007)

Product design and development necessitates a logical and structured approach by creating associations and connections among the activities in order to enhance and improve the development scheme (Sakao et al. 2009a). The model should allow a clear navigation throughout the process with the utilized tools and procedures specified and documented (Albers and Meboldt, 2007). Aurich et al. (2006) summarize the design procedure as follows:

1. Generating ideas and utilizing brainstorming and idea-finding methods to create solutions implanted in a product, followed by a preliminary analysis to measure its viability.
2. Establishing the concept to fulfill the idea by founding the product's structure and envisaging possible obstacles or problems that could arise.
3. Specifying the product characteristics and specs to outline the artifact's outline and manufacturing process.
4. Establishing technical drawings and procuring the needed resources, materials and parts to assemble the product and satisfy production requirements.
5. Developing a prototype and testing the prior in its intended environment to pinpoint any room for improvement.
6. Optimizing the product with the prototype testing's results and initiating production.

The design procedure must be confronted from the manufacturer as well as the consumer's point of views given that each side visualizes the product according to his own views. For the producer, the life cycle comprises of the design itself, material extraction, manufacturing and re-manufacturing. Whereas the customer views the product stages as acquisition, usage and disposal: The product must be adjusted in the manufacturer's eyes by meeting customer requirements represented by quality at the least possible cost (materials, energy, production time and finances). From the client's perspective, technical services should be established to facilitate purchasing, assist in use and provide support when reaching disposal. It is the designers' role to understand how a product may have several impacts throughout its life cycle and how each of these impacts would affect the actors involved (Aurich et al. 2006). Product serviceability and supportability are highlighted in this manner. The first aspect covers maintenance and repairs. Reliability is a key feature in terms of defining how often a product is likely to breakdown and how long is it expected to continue performing its intended task. Modular design, continuous monitoring, interchangeable parts, parts availability, ease of assembly and disassembly are fundamental factors to address. In order to achieve a proper design in terms of serviceability, certain tools can be used to attack the root of problems and assess the impact of each failure. Some of the most common methods include cause and effect diagrams, Pareto charts, failure modes and effects analysis, 5 why-s, and reliability design, etc. Serviceability also extends from servicing the product when a defect occurs to periodic scrutinizing as a means of avoiding damages and potential failures: notable methods are Time-Based Maintenance (TBM), Condition Based Maintenance (CBM), Risk Based Maintenance (RBM) and Total Preventive Maintenance (TPM) (Takata et al. 2004). Therefore, product components must be capped with an adequate maintenance strategy allowing upgrades, replacements, breakdowns, repairs and assemblies to be addressed and augmented from the get-go. Relatedly, supportability includes product related activities such as maintenance, repair (mean time to repair; mean time before failure), installation, use training, spare parts, complimentary products, advising, insurance and warranty (Goffin, 2000; Tan, 2010). Supportability supplements serviceability and maintainability by its orientation towards revenue generation and not being limited to cost reduction exclusively. The subject is facilitated by deliberating support requirements in the product's early stages to build a harmonious feature-support strategy by a collaborative approach from design engineers and support-engineers.

### 2.3.2 Service design

The basis of service design, as well as product design is customer satisfaction. Yet, the latter two differ since a service is a process in itself whilst a product can be delimited as a material commodity. Nevertheless, the structure to approach service development is founded on product design and extends it to outline a customer-driven value-delivering process based on a deeper understanding of the consumer's activities enabled via the involvement of the marketing staff and the customer-oriented personnel, not solely product engineers (Table 6) (Brezet et al. 2001; Menor et al. 2002; Shekar, 2007; Tan, 2010). Analogously to product manufacturers, service designers need to have a defined strategy in order to induce long-term approaches for maximized returns. These profits would result from the support that services offer to the product (maintenance, warranty…), the financial remunerations from the service's realization and the brand nurturing created by thriving towards long-term customer relationships enhancing the company's brand to bolster customer loyalty and catalyze its market-base expansion. Positive outcomes from a service are correlated with the provider's approach towards developing it: unlike a physical product where its qualities and characteristics can be measured and weighed, the result of a service is most of the time out of the service designer's direct control, but the former can affect the use of that service and therefore its result by providing support and handling knowledge to make the best use out of the service. Service developers must therefore possess not solely the technical skills to design, but also social skills to communicate their knowledge to their intended audience. These dexterities are known as 'Relationship Marketing': Establishing long-term customer relationships and supplier connections to sustain profits and open up new opportunities. The most optimistic outcome would be creating those long-term relationships with high-capital, more profitable consumers. Relationship marketing relies heavily on obtaining information from the customer himself for maximum accuracy to maintain customer satisfaction at a high level. The latter will also pave the path towards customer retention (Tan, 2010). The service design process begins by defining the actors and stakeholders involved in the realization of the service and identifying the relationships that bond them (Morelli, 2006). Hence, the functions between stakeholders are schematized and influences over one another are focalized. More importantly, this sheds light on the customer's experience and how the stakeholder network affects it by clarifying his reactions and interactions.

In other terms, the actor network map seeks to understand what the customer is doing and what decisions is he taking at each stage, what are the motives behind that decision, what reaction is he sensing, what are the hesitations that he is facing and what obstacles does he need to cross to move from one stage to the other (Richardson, 2010). The interactions are bundles of activities, resources and constraints, occurring in parallel with a defined timeline, that make up the customer's activity chain (Shostack, 1982). Once the service elements are mapped out and preliminary assessments are made, prototyping takes place. It serves as an instrument to demonstrate what purposes the service can serve without truly providing it: visualizing the service from a provider's point of view, as well as a client's and evaluating what the service would be in the near future if launched. Two steps are needed in service prototyping: exploring (understandings, brainstorming, perceiving) and evaluating (examining, analyzing and assessing failure modes). A holistic systematic approach is vital for successful use of the prototype method: accounting for several measures instead of single interactions allow a better evaluation of the service and make the prototype more concise (Blomkvist and Holmlid, 2010). The service's performance cannot be quantitatively measured like a product. Instead, customer satisfaction regarding the obtained result judges a service's success or failure. Tomiyama (2001) suggests the Flow/View Model based on the client's change of state: changing the customer's state from its actual form to one that he desires. The term service, in this context, therefore suggests increasing the value a physical artifact carries, vis-à-vis reducing the environmental load (Shimomura and Tomiyama, 2002). Accordingly, the state parameters have to be defined vis-à-vis the supply of contents and relative influences (Shimomura and Tomiyama, 2002; Sakao et al. 2009b).

Table 6 – Product development and service development similarities (adapted from Shekar, 2007 and Scheuing and Johnson, 1989)

| **Development Process** | | |
|---|---|---|
| **Development Stage** | **Product Development** | **Service Development** |
| Identifying problems | User assistance helps classifying the problem. | User and Service staffs assist in recognizing problems. |
| Ideation | Various techniques can be applied to generate new ideas, in which the customer may be helpful. | Service designers and customers are both need to be involved to achieve higher goals. |
| Conceptualization | Basic definition with simple descriptions and drawings to observe clients' reaction. | Evaluation necessitates customer and service staff incorporation. |

| | | |
|---|---|---|
| Analysis | Financial, technical and manufacturing assessment | Economic, technological, training, knowledge, delivery and operational analysis. |
| Development and testing | Prototyping and testing vis-à-vis various scenarios. | Assessing intangible aspects is more difficult than in NPD – Service personnel involvement is a must. |
| Market-testing | Exposure to a defined limited market segment | Simulations and internal examination |
| Marketing | Launch preparation on an internal company level as well as external | Marketing departments need to excel as new service adoption is challenging to achieve |
| After launch assessment | Market feedback will direct the manufacturer where to make alterations | Customer satisfaction and customers' perception of service quality. |

### 2.3.3 Product-Service System design

#### 2.3.3.1 PSS design preface

A PSS aims to combine the product and service stances exposed earlier to seek new opportunities: every product involves services that come in play to provide the user with the maximal use and benefit of that product. Services are most often seen from a customer's standpoint and products from a manufacturer's point of view. The technical staff develops products while services are built and realized by the marketing department (Aurich et al. 2006). Henceforth, an integration of products and services necessitates an interdepartmental collaboration for the required elements of a PSS to be acknowledged and the solution fulfilled.

A comprehensive PSS offering urges designers to adopt a comprehensive tactic that designs the offering from a life cycle point of view. Product life cycle thinking needs to be a topic arising during the design of the product as conceptualizing the life phase systems a product faces is of the same importance: a product's properties will only be visible when encountering the life phase system. Product life systems can be displayed as transformations that affect products. While conventional product engineering seeks to develop the right product, PSS focus on fitting the latter with its corresponding life phase systems. Whilst products are more easily delivered than services, the second requires a more demanding network of actors to be provided to their intended users. Mapping the network (Figure 3) will present the actors, the relationships that tie them and how they are organized. This will provide a clearer view of each actor's requirements and how each participant may influence the product's life cycle. The representation (Figure 4) allows detecting the mechanisms behind value generation in the network through service provision, financial, material, energy and information flows (Tukker and Tischner, 2006). The benefits that arise from such a mapping scheme surface when 'invisible' stakeholders are identified and implicit relations are developed in a more perceptible scheme. The actors and their relations are arranged so that each is given an incentive to continuously reduce costs and increase resource efficiency (Manzini et al. 2004).

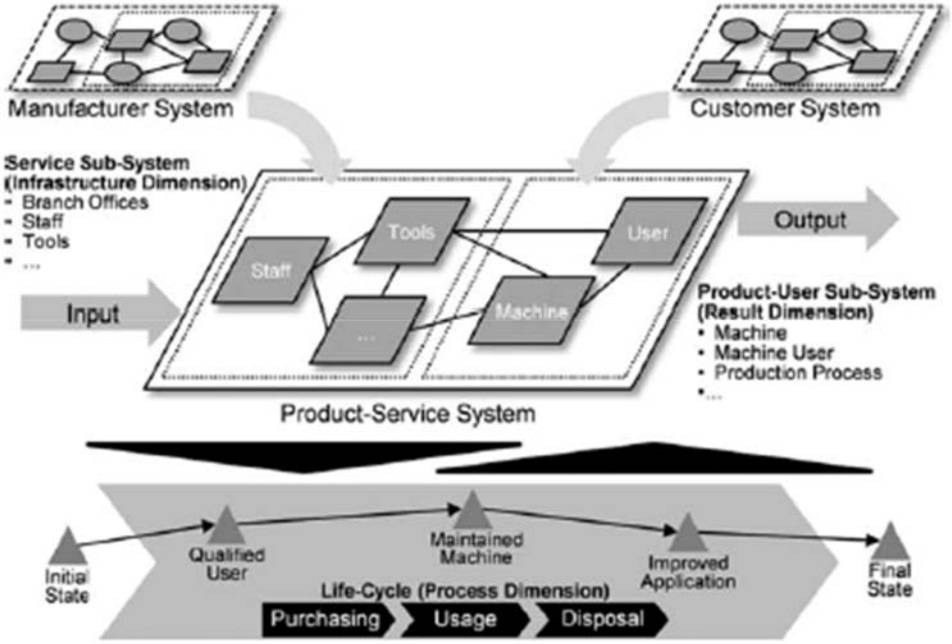


Figure 3 – Generic mapping example (Schweitzer and Aurich, 2010)

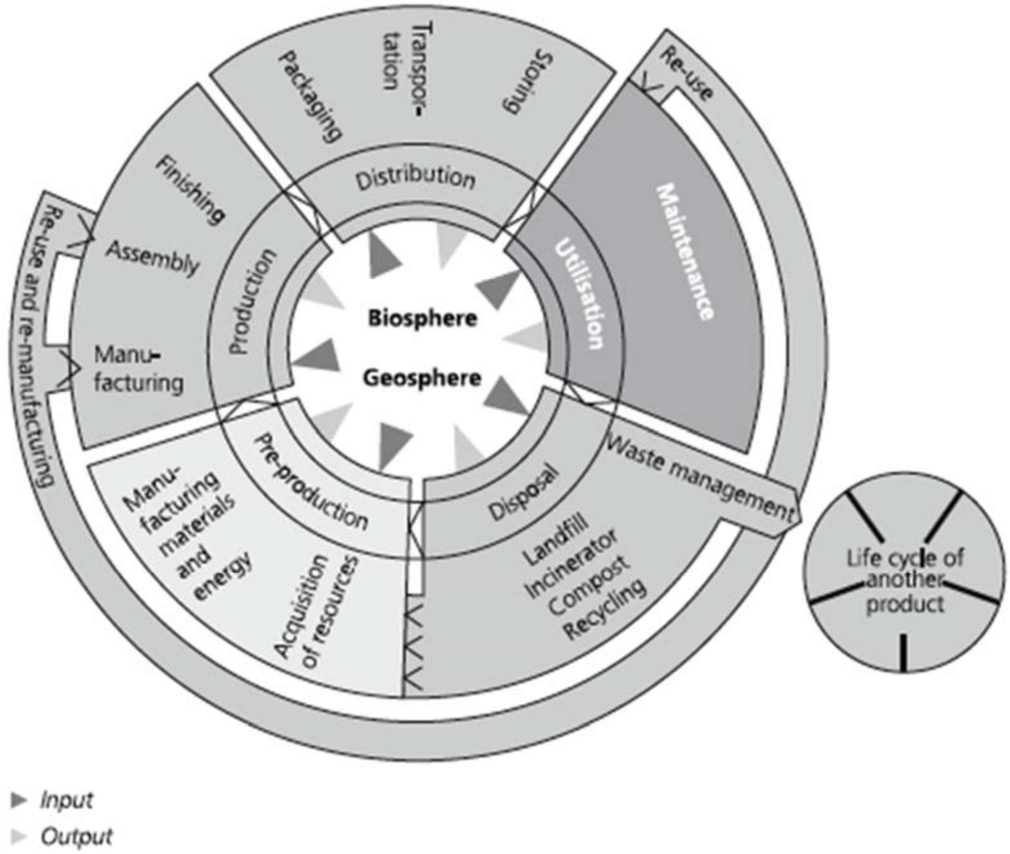


Figure 4 – Product-system life cycle (Vezzoli, 2007)

Formulating a PSS essentially involves considering an existing product or service and targets achieving better results than the ones attained via the product or service on their own, while improving the embedded value and environmental impacts. Focusing on the technical design by itself can only allow limited improvements to take place while considering the life phase systems, actors and customer experiences would allow reaching higher levels of advances. Three angles broaden the conventional design to a more comprehensive strategy: consumer activities, stakeholders' network and product life phase systems. An iterative approach relying on a PDCA action plan stands out when devising such strategies: visualizing the target and setting the purposes to fulfill, formulating a strategy and assessing it, checking opportunities missed, re-iterating and repeating till the desired vision is established.

Existing products and services need to be evaluated as well as their impacts with respect to the constituents of quality. Such analysis methods involve LCA and profitability studies amongst others. For a complete and thorough report, customers should be well understood, their demands clear for all departments and the customer-product-service interrelations grasped. This preliminary vision will narrow down the topic to select the better rationale to implement: in other terms, the approach that would deliver the highest beneficial changes on a customer and ecological scale. The selected solution should be followed with a sustainability study. The main idea behind PSS is generating long-term solutions with as little resources used and minimal environmental threats. Consequently, sustainability would comprise of the resource consumption/efficiency strategy, product life phase management, activities' support, stakeholder partnerships, offering's availability and the profit generation structure/mechanism. In other terms, the value proposal consists of a business value and an environmental value where the first comprises of products and services intended for defined market segments, and the second involves ecological considerations to reduce environmental hazards.

PSS benefits and advantages on an ecological and economic level are possible when matching the latent utility of the central product with the added value achieved throughout customer activities (Tan, 2010). Successively, PSS development requires a comprehensive integration within the company's organization, structure and culture.

From an organizational scale, PSS relies on the corporation's external partners and actors' networks to acquire market competencies to undertake new endeavors and create new income possibilities. At a business stage, it morphs the manner of doing business from traditional product development to service availability and bolstered client connections. On a system level, departments (product, supply chains, life cycle systems, marketing etc.) are linked through interdependent chains that aren't present in conventional systems (Tan, 2010). The reasons to adopt a PSS model instead of a product-based model arise from product characteristics that require resources a company is seeking to minimize. In clearer terms:

- Products with high maintenance and operational costs.
- Products demanding specific knowledge and training to operate and maintain.
- Products with devastating consequences if misused.
- Products with a narrow consumer market segment.

Transitioning from a product-based model or even a service-based model to a PSS model can follow several routes. Tan (2010) describes the latter: "*Some* *companies build upon a consolidation of their product-related services and then enter the installed base market* (Oliva and Kallenberg, 2003) (Figure 5). *Others make the migration by building up competences in e.g. systems integration, operational services, business consultancy and financial services to deliver integrated solutions* (Davies et al. 2007). *Most often however, companies are not that well-coordinated and simply attempt to adhere to customer's requests provisionally. No matter what the chosen path will be, a coordinated approach guided by the strategic commitment of the company is necessary to yield the largest benefits from the migration."* The service unit is more apt to succeed when following sequential activities since its recognition, as a part of the enterprise, would facilitate the growth of a 'service culture' from the womb of the company itself, with its designated resources and departments. These units will operate in parallel with the product units to develop holistic service-product integrated solutions. Nonetheless, integration is subject to variants:

1. Solution type: specific to the customer and industry or targeting a broader application range.
2. Scale and Scope: the needed number of units is proportional to the number and nature of offered products and services.
3. Integration: the higher the dependency amongst the constituting elements, the higher the need for cross-departmental cooperation.
4. Profits generated: the higher the remunerations, the more justified is the need for consumer oriented units (Galbraith, 2002).

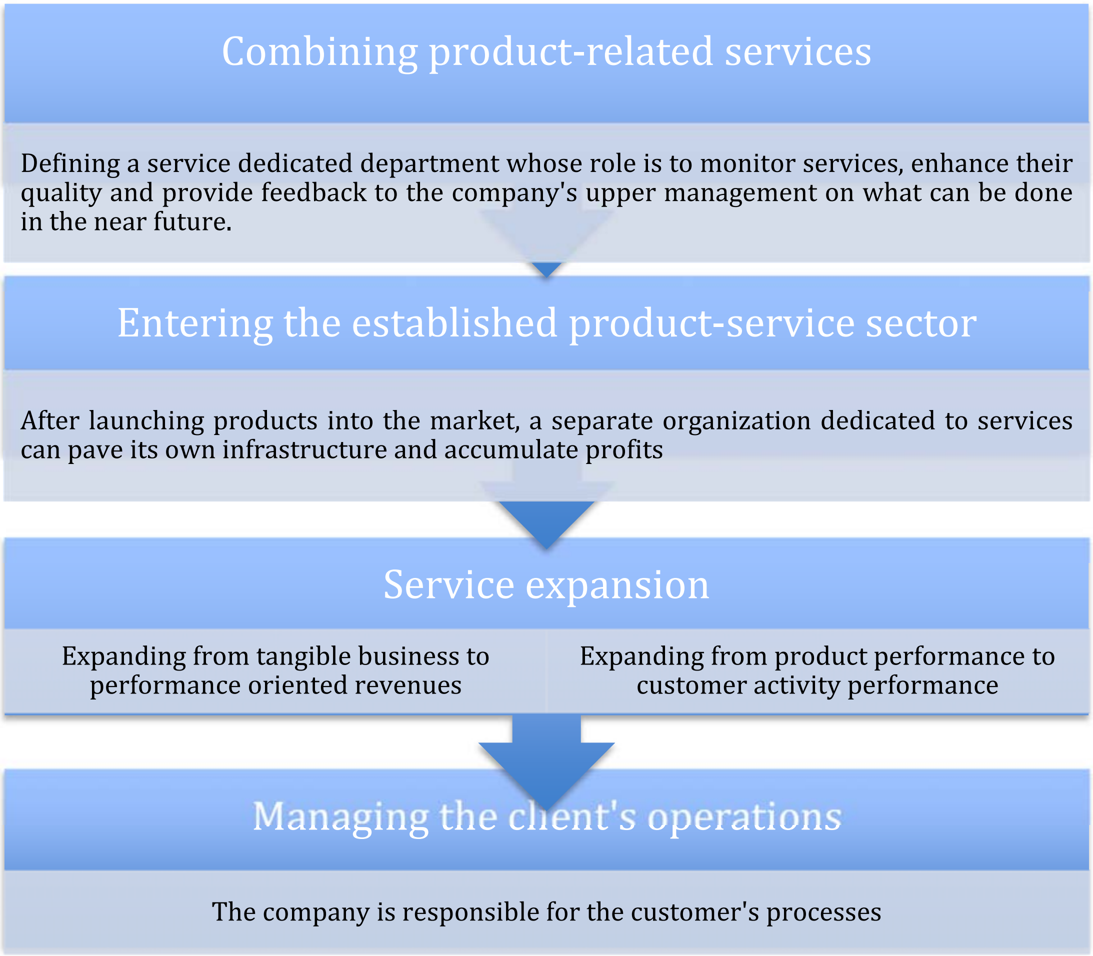


Figure 5 – Phases to shift from product development to integrated product-service provision (adapted from Oliva and Kallenberg, 2003)

#### 2.3.3.2 PSS design approaches

Approaches to generate successful PSSs are diversified in the literature and are in a major part developed in an intuitive manner and in specific contexts. The most widespread design methodologies, depicted by Vasantha et al. (2012) and Tran and Park (2015), are summarized in Table 7. Posteriorly, each of the approaches is described.

Table 7 – Most common PSS design methodologies

| Design Approach | Overview of the approach | References |
|---|---|---|
| a. Integrated Product and Service Design Process | The relations between the tangibility of a product and the intangibility of services provide potential for integrated design processes: the joint development of an increased value solution consisting of product-service interactions | Aurich et al. 2006; Sakao et al. 2008; Welp et al. 2008; Maussang et al. 2007; Maussang et al. 2009 |
| b. Fast-Track Total Care Design | Functional performance based on integrated services and products within the development of an offering | Alonso-Rasgado et al. 2004; Flieb and Keinaltenkamp, 2004 |
| c. Service Engineering Framework | A framework that integrates a product service design modelling tool with a discrete event simulation test-bench | Duckwitz et al. 2008; Baines et al. 2009; Emmanouilidis et al. 2012 ; Pezzotta et al. 2015 |
| d. Service CAD | A systematic business model design methodology to increase eco-efficiency | Komoto and Tomiyama, 2008; Komoto, 2009 |
| e. Service Explorer | Utilization of service engineering to increase the product's value via services | Sakao et al. 2009a and 2009b; Sakao and Lindahl, 2009 |
| f. Requirements Data Model (RDMod) | Clarifying and defining the requirement specifications by defining the structural principles of a PSS design approach. | Van Halen et al. 2005; Scholl et al. 2010; Berkovich et al. 2009, 2011; Berkovich et al. 2014 |
| g. Spiral Design Process | A product-service strategy and methodology that creates revenues over the whole life cycle | Tan and McAloone, 2006; Wild et al. 2009; Pezzotta et al. 2012 |
| h. Functional-Blueprint Design Approach | A merger of the service blueprint with product design's functional bloc diagram tool in order to convey a unified approach for PSS design | Maussang et al. 2009 ; Trevisan et al. 2015 |

### *a. Integrated Product and Service Design Process*

Aurich et al. (2006) proposed developing PSS solutions by integrating the modular associations of the product and service aspects of the solution's design. According to the relevant authors, three tactics exist *liability-driven, function driven and use-driven*. However, these three schemes derive from one common frame: assessing the common points between product and service design methods, aligning the latter with organizational aims based on product-service information exchange, and integration of the tangible product elements and the intangible service constituents.

The core of the process resides in adapting product design processes to service characteristics thus easing acceptability within the firm. By using the 'Unified Modeling Language', modular designs would provide more suitability and understanding for the involved actors as well as point out and address particularities of specific customer requirements and their tailored demands. The design thus seeks to model services, comprehend their realization and elaborate a product-service prototype to test the design (Vasantha et al. 2012). The modularity and personalization factors emphasize the development of actors' network to create value throughout the process' life cycle by exploiting the product-service affiliations to provide high quality individualized designs (Aurich et al. 2006). A model-based approach founded on the above took birth to support integrated product service systems (IPSS) model generation (Welp et al. 2008). The methodology permits evaluating several solution constituents from different points of view and on various levels of detail. The implementation was embodied in a software prototype founded on an IPSS object and an IPSS process which when combined form an IPSS artifact spawning a functional behavior.

Maussang et al. (2009) emphasized the need to shift from focusing on product and service elements aside to a systematic approach (Figure 6) to ensure success. They also argued that this methodology *"could support the design of PSSs starting from the design of the architecture down to detailed specification of physical objects (products). They used operational scenarios to go deeper into the description of the system once the main elements (physical objects and service units) had been identified"* (Vasantha et al. 2012).

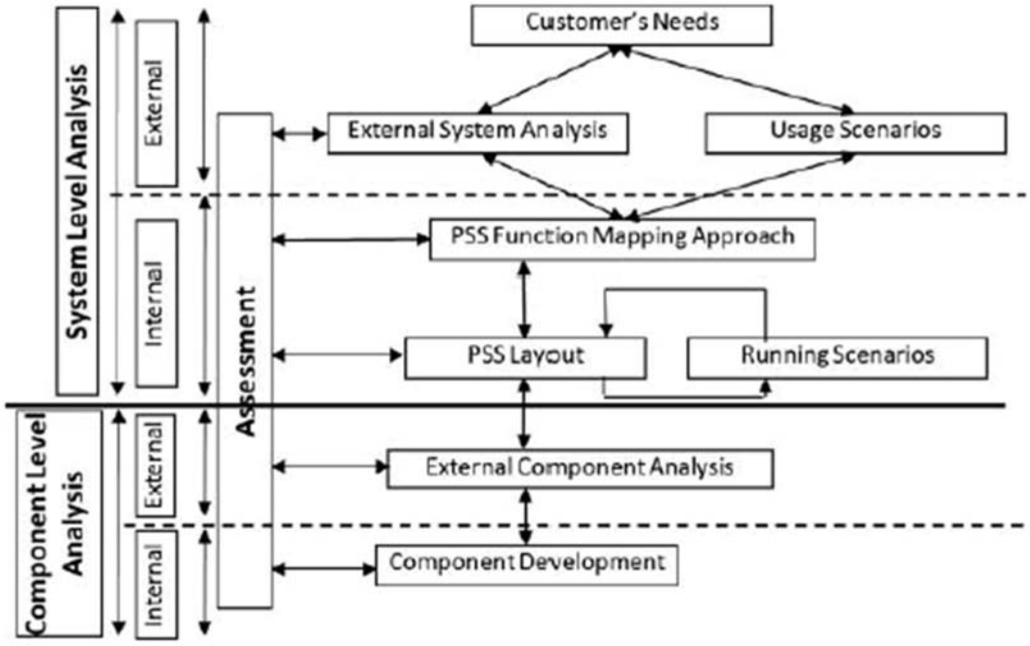


Figure 6 – PSS systematic design approach (Maussang et al. 2009)

A functional analysis approach and a Structured Analysis and Design Technique (SADT) designs consistent PSS, as they would narrow down the discrepancies between the system, product and service. AFNOR (1991) states 7 criterions to ensure the proper design development of a solution:

1. Compatibility: user-activity integration as required by the task to fulfill.
2. Homogeneity: standardized presentation of information and descriptive elements that lead to the same outcome.
3. Guidance: structured approach to outline the design components in a clear and concise manner.
4. Flexibility: the interface has to adapt to various users from different work levels, who may need to configure certain parameters.
5. Explicit control: the user must have full control of the effects and outcomes of the activities he performs.
6. Error management: identifying failure modes and assisting the user in correcting them
7. Concision: clarification and proper representation of the design.

The AFNOR norms (AFNOR, 1991) were proven internationally accredited and constitute the ISO 9241-12:2008 standards. Welp et al. (2008) relied on the latter, in coherence with Aurich et al. (2006), to portray an integrated PSS model (Figure 7).

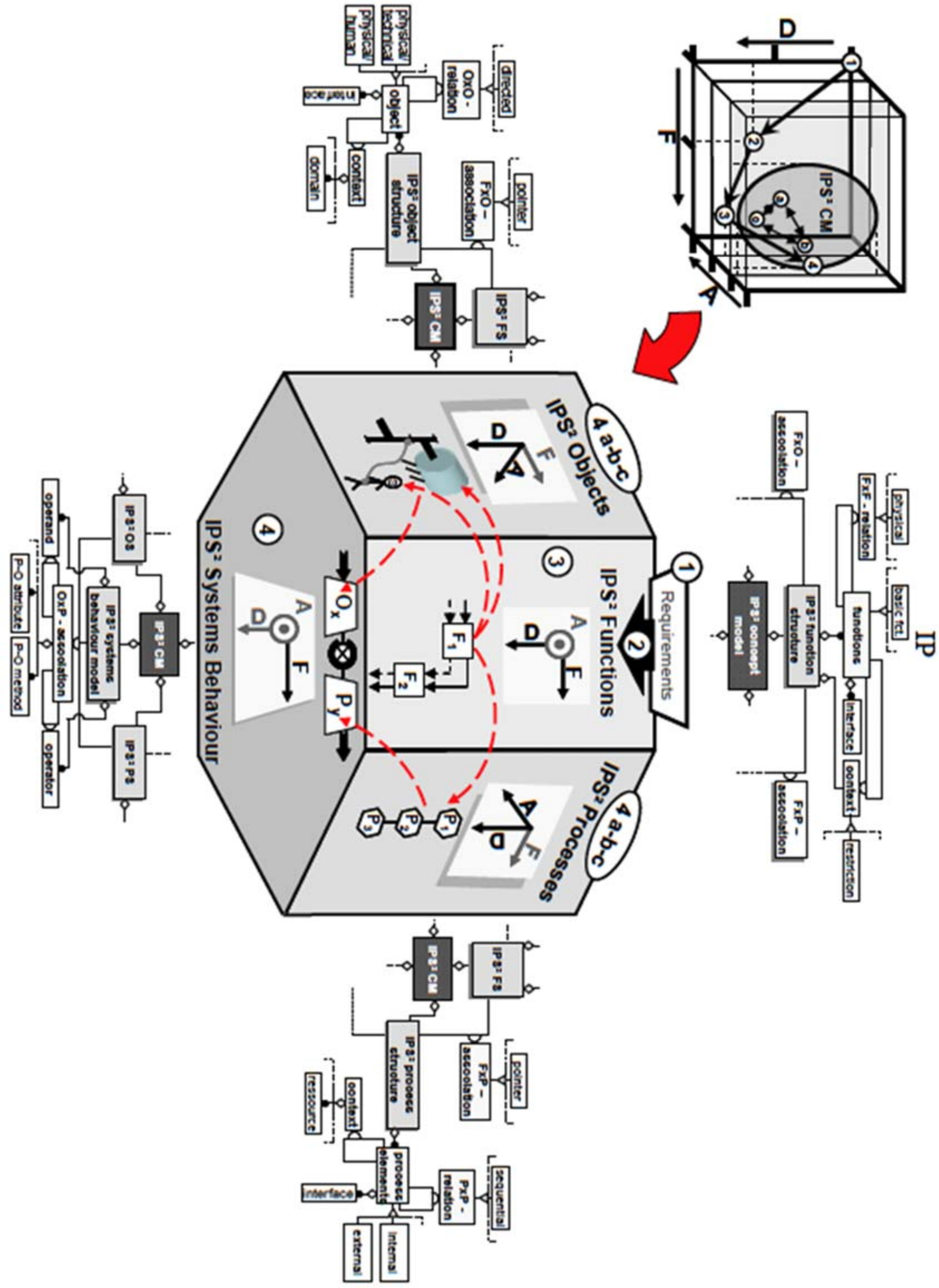


Figure 7 – Modeling an integrated product-service system (Welp et al. 2008)

Maussang et al. (2007) and (2009) utilized the SADT to propose the Agent-Based Model for PSS design. The SADT consists in representing objects, data, information and materials with the practices employing them such as operations, processes, events and activities; all represented in a diagram describing the data and activities' inputs, outputs and controls. The context covers the current operations, the problem statement and sensitivity factors. The functional specs include the proposed functions, parameters and impacts.

The design constraints embrace the resource specifications, operation conditions and costs. Sakao and Shimomura (2007) state that the utilization of functional analysis representation vis-à-vis agent-based modeling supports the development of a PSS with value as the focal point of the project: value offered by a PSS must be higher than the value of existing products and services. Value will be defined in this context as the function to cost ratio where increased value would result from increased functionality and/or reduced costs. The function should therefore satisfy clients' requirements and all life cycle stakeholders (manufacturers, suppliers etc.) and costs must enclose the intangible aspects and not just the financial ones. The PSS elements result from analyzing customer requirements, assessing the actors involved, translating the clients' needs into functions and the embedded costs and defining the technical function to achieve. The function is developed based on:

- Extracting the needs of each element/functional bloc diagram
- Translating functions into technical functions
- Detailing the solution and its components (Maussang et al. 2007)

In many cases, the customer and manufacturer are not the only actors involved and other stakeholders intervene. Consequently, it is key for all participants to find the proper value-cost balance. Maussang et al. (2009) refer to the Flow and View model to schematize the prior: provider, receiver and state parameters. Interaction functions correspond to service delivery while adaptation functions reflect constraints and reactions. An internal functional analysis helps identify the technical function to answer while brainstorming the possible solutions to answer them through the use of a Function Analysis System Technique (FAST) diagram and a functional block diagram (FBD) to represent the relations between elements and thus facilitate optimization scenarios: *"The FAST diagram enables designers to detail service functions into technical functions and then to imagine different solutions that could reach them. In the case of PSS, solution can be physical objects or technical service units. But links between those elements are very* *important in PSS and finding functions is not anymore sufficient. That is why we want to use also a FBD. Scenario model is used to describe all values and costs of agents in a specific case but it must be more detailed to specify links between elements* (Maussang et al. 2007)”.

On a detailed level, each element in the FBD will be specified and it is those specifications that dictate the design process in one particular way or another. A representation of the FBD is presented through an excerpt from Maussang et al. (2009) applying the latter on a bike-sharing scheme (Figure 8) followed by a short description of the scheme.

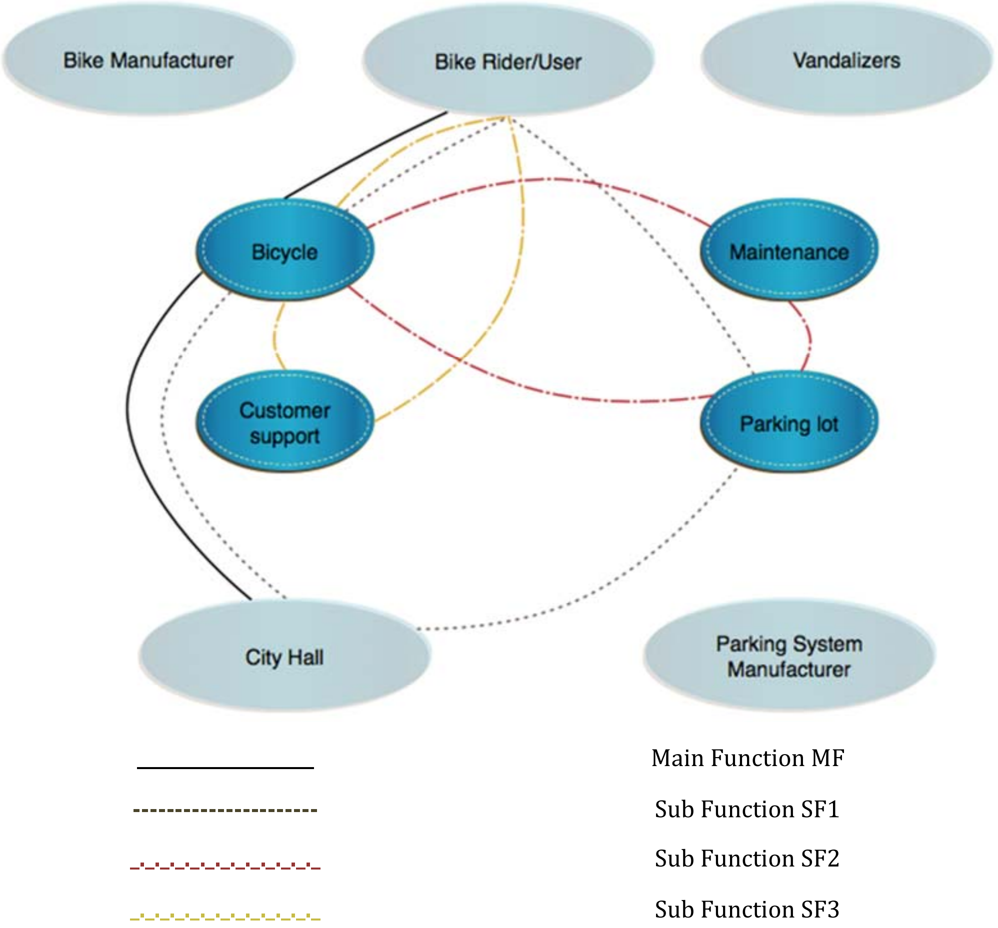


Figure 8 – Functional Bloc Diagram mapping actors’ interactions (based on Maussang et al. (2009)’s Velo’V (VV) bike-sharing example).

The product components are the VV bicycle and the parking lot.
The service components are customer support and the maintenance service.
The main function is providing the rider/user with a rentable solution to commute within the designated area while relieving him from maintenance

and ownership responsibilities.
The maintenance service includes recovering the bike from its designated parking lot, executing the needed maintenance or repairs to ensure its well-functioning and re-assigning the bicycle to its station.

Customer support consists in receiving a call or face-to-face interaction with the bicycle user, providing the client with the assistance he needs regarding the bicycle (e-card assistance, lock assistance, questions etc.) and making sure his demands are met.

City Hall provides the bicycle riders with designated parking areas for picking up the bikes and returning them after use.

### *b. Fast-Care Total Products Design*

Alonso-Rasgado et al. (2004) define an integrated product-service offering as a 'functional product' also named 'total care product' consisting of physical (product) and non-physical (service) elements. Moreover, functional products engage the client in a long-term relationship in which the provider will be in continuous interaction with the customer compared to a traditional product scheme and thus carrying several advantages for both ends such as: increased product performance knowledge, better understanding of requirements, constant cash flow, better availability, customized functions etc.

The preceding stage of this dissertation, Concept design, provides the customer requirements, their analysis, and the concept selection. The output of the former phase will now have to be developed in detail to generate a realistic solution. Dividing the system into sub-systems that can be hierarchized is the first step as it structures the approach and allows better understanding of the required interactions between the PSS elements. This subdivision is known as a FAST diagram (Figure 9).

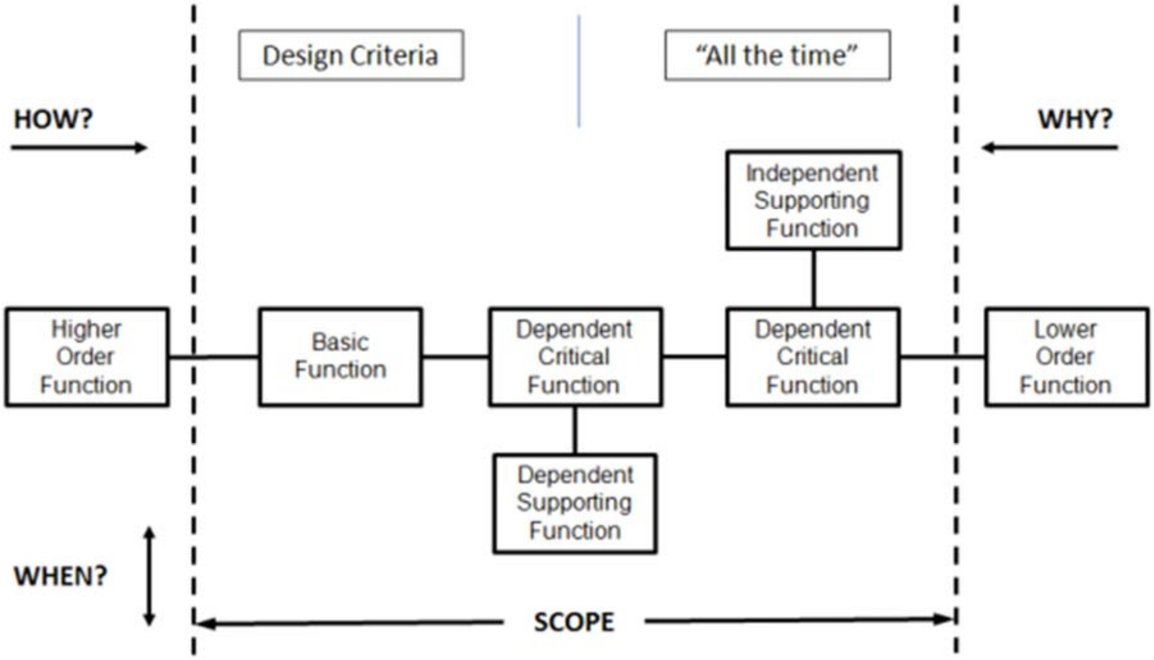


Figure 9 – FAST diagram design procedure

According to Alonso-Rasgado et al. (2004), a service affects the product's operations, maintenance, processing, design, performance and improvement. Consequently, the first step is modeling the envisioned elements to better assess the solution's performance and optimization. Two approaches to model the task can be adopted: Molecular Modeling (Figure 10) and Service Blueprinting (Figure 11). The Molecular Modeling (MMo) approach depicts the service and product elements, identifies and shows all the fragments of the system and hints at the latter's behavior if any modification were to occur.

On the other hand, the Service Blueprint (SB) (Flieb and Keinaltenkamp, 2004) technique attempts to visualize all the intricate functions based on considering services as the cornerstone of the blueprint. A SB will thus show a time frame, the main functions and sub-functions and define the model's tolerance (Alonso-Rasgado et al. 2004). The added value of the SB vis-à-vis MMo resides in the quantitative description it offers, materialization of a service and prototyping while trying to capture human behavior as much as possible to reduce the incertitude of the service's intangibility feature.

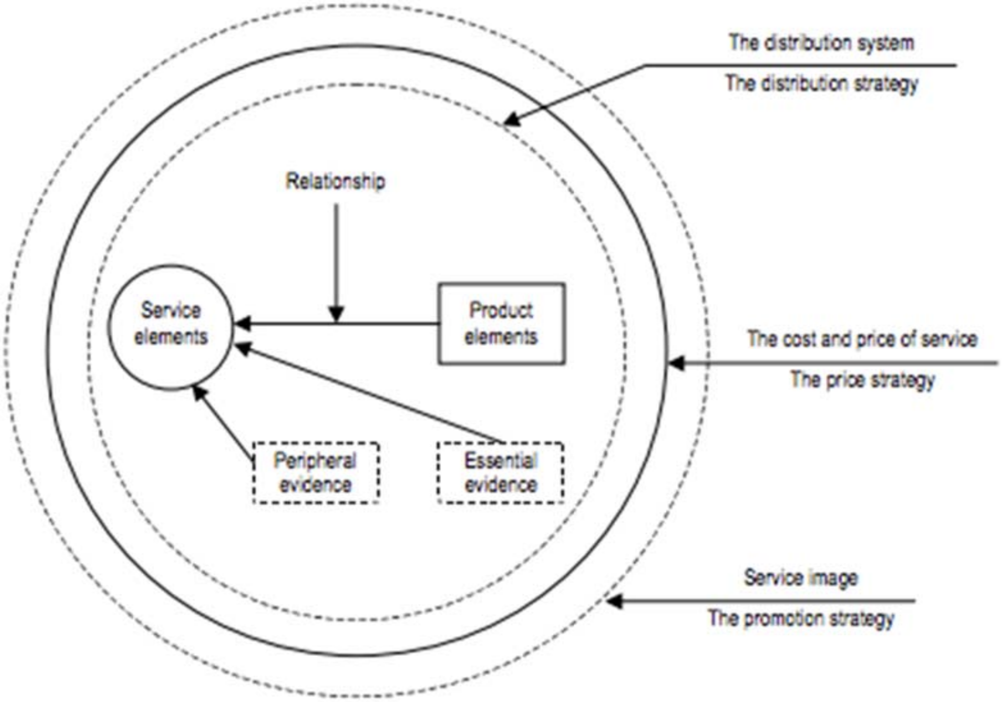


Figure 10 – Molecular modeling

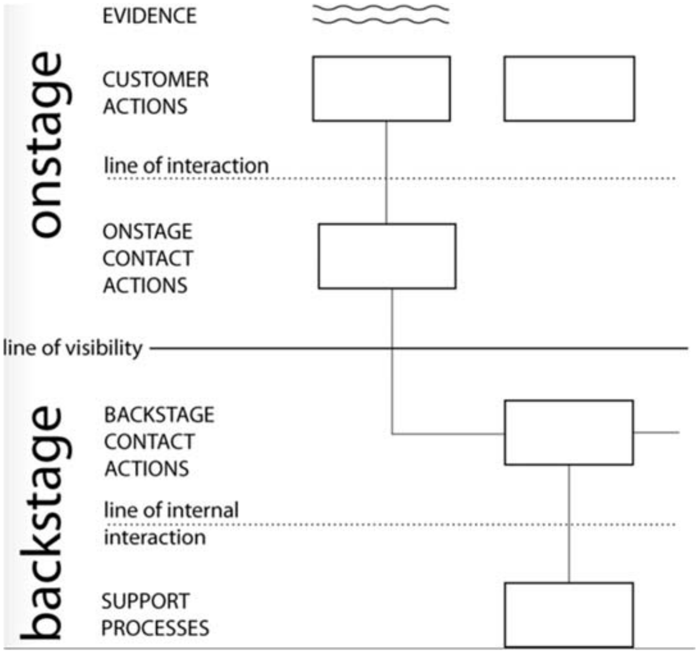


Figure 11 – Service Blueprinting

Alonso-Rasgado et al. (2004) utilize the same approach of Aurich et al. (2006): the SADT to represent the system to obtain a primary and 'static' graphical representation (Figure 12). The SADT schematic, doesn't serve as an effective tool of PSS design, but acts as an organizational tool to clarify the activities involved and as a starting point to the actual simulation.

*"The main reason for modeling is to test the functionality of the service system. In addition, sensitivity analysis can be facilitated, giving a measure of the sensitivity of the system to changes in inputs. If one or more subsystems are failing or performing poorly then the simulation will highlight those subsystems. In such cases the modeling can be taken to a higher level of detail within the problematic subsystems enabling the cause of the degraded performance to be identified. The system may then be modified accordingly and the effects of the modifications checked by re-running the simulation* (Alonso-Rasgado et al. 2004)*."*

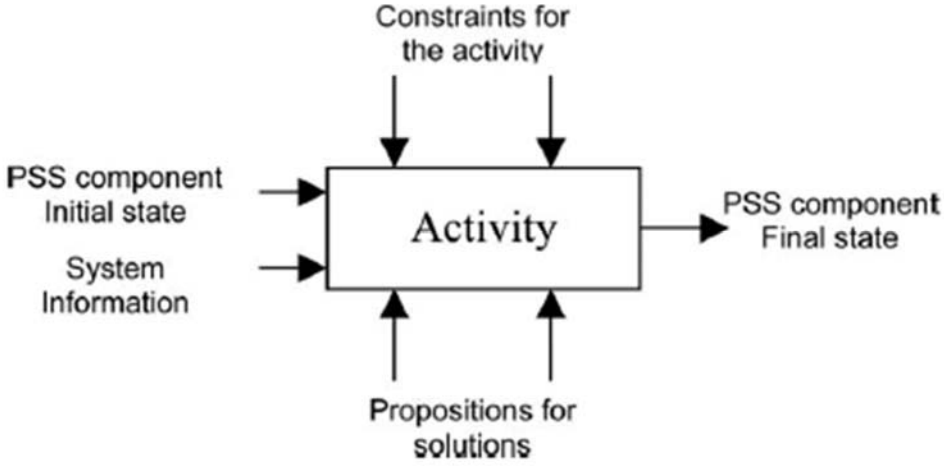


Figure 12 – SADT block (Trevisan et al. 2015)

Service modeling, after having identified the distinct functions forming the system, comes in to evaluate the holistic solution in terms of product and service performances, quality and data flow. The SB is the advised tool to apply for the prior.

The hierarchy being defined, service, functional and application testing are the next logical phase of the detailed design process (Alonso-Rasgado et al. 2004).

- Service testing includes simulating the designed scheme to assess whether the performance and intangible aims are met or not. Areas in which the service underperforms are then investigated for improvements while analyzing the risks and environment that lead to the test's unwanted outcome. Service reliability is a key component as it depends on defined resources, determined environmental conditions and contractual agreements stating each party's involvement and responsibility. Having contracts helps review the service's performance by comparing its outputs against user requirements seen that once the service is within the consumer's realm, mistakes and miss-use can occur.

- Functional testing provides a preliminary vision of the customer's reaction when encountering the service and establish a sensibility analysis to given inputs. From a product's stance, maintainability and reliability are the main features to handle as well as the product's quantitative characteristics, which will provide feedback on its performance in its working environment. Failure modeling methods such as Failure Modes and Effects Analysis (FMEA) and Ishikawa diagrams help improve the product's reliability, maintainability and serviceability and enhance the overall value. In a PSS context, service and product maintainability have to be considered equally as both will have a non-negligible influence on customer satisfaction.
- Application testing concerns the sequence of operations that will take place between the customer and the service provider. The outcome of this phase would be personnel training and an extensive knowledge base development of all the PSS features of the design. Not all activities have to be provided by the PSS manufacturer; instead some elements can be outsourced such as hardware components, decentralized 'pure' service providers etc. Constant monitoring however must take place to ensure the PSS developer's control over its offering isn't lost or jeopardized.

### *c. Service Engineering Framework*

The following framework, developed by Pezzotta et al. (2015), focuses on PSS development by viewing it from a content and provision channel standpoint. Four phases are described:

1. Value
2. Process
3. Simulation
4. Monitoring

#### Value

The discussion assumes customer requirements have been identified and evaluated in the ideation and conceptualization phase. A detailed approach stars with expanding the service idea and its provision process: the Receiver

State Parameters (RSPs) are consequently dichotomized into sub-parameters to reduce the intangibility factor and eliminate any ambiguity. In other terms, the intrinsic functionalities are to be defined, the resources allocated and *"the entities that the company can leverage in order to optimize its provision process* (Pezzotta et al. 2015)." Furthermore, the value-resource relationships will be assessed to pinpoint the impact of each resource on each aspect of the PSS's content and channel. Quality Function Deployment (QFD) assists designers in recognizing which resources have a significant impact on the client's state parameters.

### Process

Activities embedded in the service provision are modeled; a common and robust tool is the SB approach. The activities a consumer performs, the activities the involved company implements while interacting with its clientele, the activities that take place within the manufacturer's domain and the activities supporting the PSS are the core tasks to exhibit when mapping the product-service process.

Ascertaining the links between the activities mentioned above must not be eliminated with haste, but should be re-considered to verify their validity as non-value adding or whether they would be somehow involved in alternative scenarios. The same applies for service/function delivery channels.

### Simulation

The process phase matches the functions to their activities and provides a 'draft' of how the solution will be explicated. However, the prior is a static representation that is not updated with the process's dynamics and the PSS's performance is not captured. The proposed method to solve the issue is through Discrete Event Simulation (DES): ''*a technique for constructing a model that describes the behavior of a real-world system, and the resulting model can then be used to test how the performance of a proposed system alters over differing operating conditions* (Baines et al. 2009).'' Simulation shifted from production-manufacturing practices to service and PSS practices due to the complexity of the latter compared to their predecessors. A service can be qualified successful if it encompasses quality and timeliness. Thus, simulation is a method that visualizes the dynamics and variants of the service domain to constantly assess its implementation and provide credible service scenarios. DES answers the mentioned need, by playing the role of an assessment tool, a balance analyzer and a catalyst to increased efficiency and productivity.

The first step of the simulation is to formally describe a service with its detailed specifications (Figure 13). Defining predecessor-successor relationships outlines the PSS elements and resources that will be directly affected by the service. All activities are allocated to a unit and have a defined processing state set as 'organization' or 'processing' (Duckwitz et al. 2011). This first simulation step can be decomposed into three levels:

1. Task Selection: prioritizing and decision-making factors.
2. Active Negotiation: starting a cooperative task.
3. Passive Negotiation: answers to the initiated cooperative task.

The task selection step sees designers investigate all possible tasks to choose the most relevant one (high priority task) and its required resources are allocated. The activity's state then passes from 'organization' to 'processing': the undertaking is then judged as a single-worker task or a cooperative task. In a PSS context, most of the time the second option will be utilized as product and service designers must be aligned towards the same objective. Having started their chore, we shift towards 'Active Negotiation' where the realization is underway until it is fully processed and the corresponding state goes back from 'processing' to 'organization'.

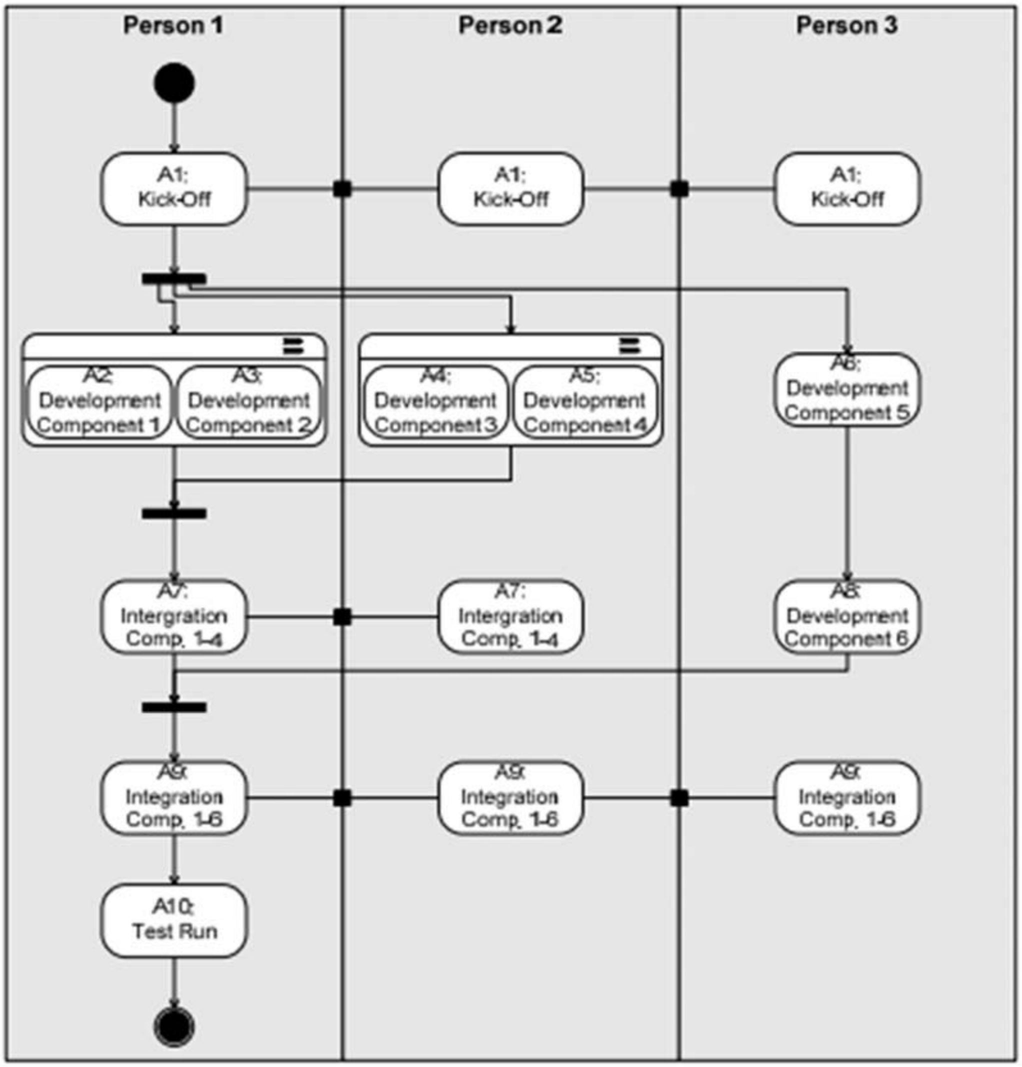


Figure 13 – PSS process modeling (Duckwitz et al. 2008)

The model relies on the following postulations:

1. Three main stakeholders are interested in the PSS's success: the manufacturer, the consumer, and the environment.
2. PSS design will answer customer needs through combined products and services where each product is assigned a service. The product-service structure relies on functionalities allowing an increased value to be obtained by the client.
3. The aim of a PSS is to generate revenues for the company by providing a high level of value versus a reduced amount of resources.
4. The environmental aspect is crucial and a PSS solution must be within the norms of the ecological legislations to gain acceptance.

The simulation is founded on the hypotheses mentioned and requires the iteration of incremental steps to upgrade the existing products and service to achieve customer satisfaction. The simulation will rely on evaluating possibilities, offerings, combinations and components coherently with changing customer needs and varying amounts of resources. Additionally, any new hierarchy must be checked for compatibility to continuously deliver win-win strategies for the developer, the customer and the environment (Emmanouilidis et al. 2012).

### Monitoring

A structured build of Key Performance Indicators (KPIs) allows the assessment of the integrated product-service solution. These KPIs must address the Critical-To-Quality attributes (CTQ), which are correlated to critical process parameters (CPP): the model presented in Figure 14 serves as a process map where each element of the process can have its impact on the PSS quality assessed; the View model serves as a guideline. Continuous monitoring is essential to ensure sustainable long-term profits.

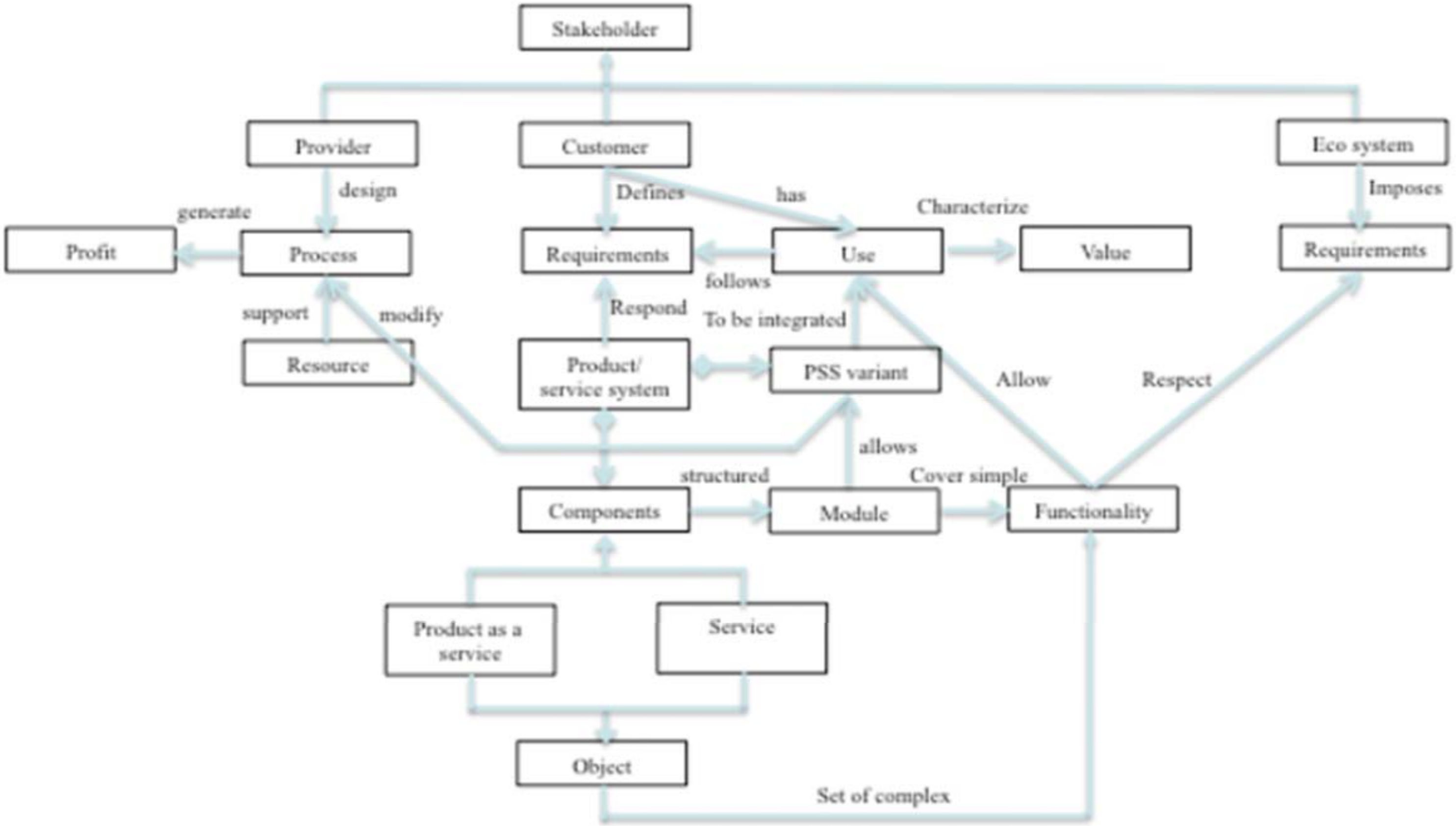


Figure 14 – Simulation modeling

### *d. Service CAD*

Systematic information with adequate informatics support aims to develop the PSS proposal process by aiding designers in evaluating the required activities, quality and the environment in which the activities would be fulfilled. The Service CAD (Figure 15) was then extended through a life cycle simulator to provide quantitative results for judging the design’s effectiveness in meeting consumer requirements. *“The model can be used as a meta-level representation in which the designer can construct a PSS model in different views (aspects) such as process-oriented (e.g. using service blueprinting), stakeholder-oriented (system map) and correspondence-oriented (Serviset). Importantly, products in a business model are individual instances rather than assuming that all products have identical behaviour in the market and end of life processes. The difficulty for designers to categorise elements as provider, receiver, channel or content was also expressed. The important limits found in Service CAD come from: monotonically increasing and decreasing functions, unrelated results of evaluations of multiple sequences of activities that partially overlap, incapacity to identify conflictive objectives among multiple stakeholders in a PSS model and difficulty in optimising timing, frequency and interrelations of services within the PSS model* (Komoto, 2009; Vasantha et al. 2012). The Service CAD architecture comprises of a model builder, a model browser, a class hierarchy builder, an interference engine, a rule builder and a rule manager. The information related to each of the latter components is saved in a model base, a class hierarchy base and a rule base. The model builder erects the PSS model based on evaluation and suggestion algorithms applied to a certain PSS model that is saved within the model base. The model browser allows the user to navigate through a range of proposed models or even parts of models which can be collected into a new PSS model. The class hierarchy builds the service goals, quality and service elements within their desired environment. These factors can be stored in sub-classes depending on the relations that may bind them or similarities. The prior will be stockpiled in the class hierarchy builder. The inference engine quantifies the relations between PSS models and class hierarchies according to set out rules, using the rule builder, according to which assessment takes place. The sequence can be executed several times to sort out the necessary and un-necessary tasks. This segregation is allowed through the implementation of the rule manager.

The initial objectives are set out as $G'_0$, the quality attributes $Q'_0$, the activities $A_0$ and the environment $E_0$. A group of PSS models are initially generated in advance prior to the utilization of the Service CAD tool. The initial model serves as the base for an ulterior PSS model that would consider the quality, activities, goals and environment inputs (Komoto and Tomiyama, 2008).

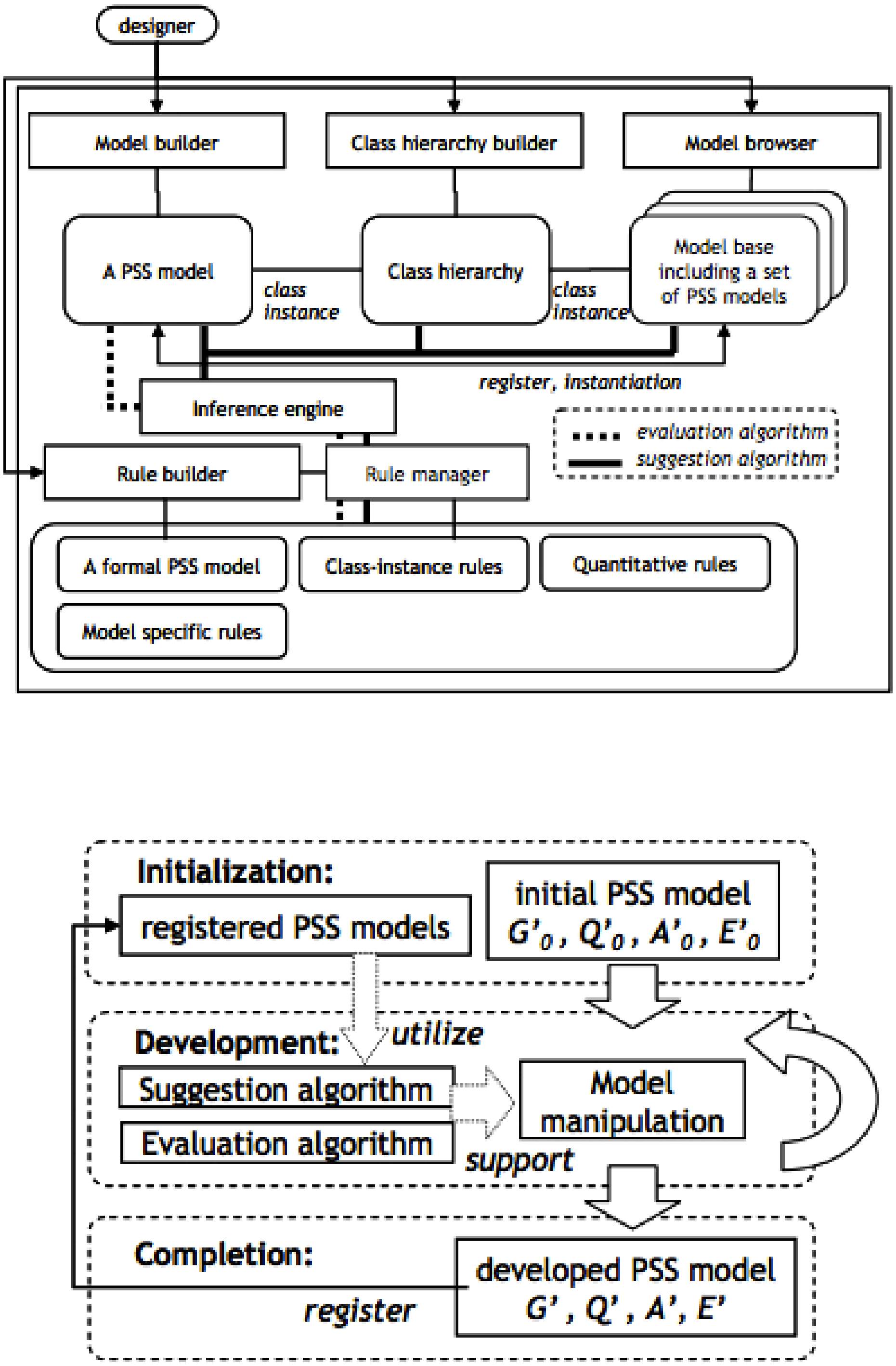


Figure 15 – Service CAD (Komoto, 2009)

Given that the tool is a computer reliant, an application is a convenient way to potraty its use for desining a PSS offering. The following extract from Komoto, 2009 handles the implementation of product-service schemes in computer embedded products such as medical diagnosis equipments:

***"Initialization***

*The designer first prepares the initial description of a PSS model and the description of PSS models registered for the suggestions. The initial description of a PSS model consists of goals, quality criteria, and members in environment* (Figure 16). *Activities shown in* Figure 17 *are not included in the initial description, because they will be instantiated on the PSS model using the suggestion algorithm. Class names, which are assigned to all elements in the initial description, and the relations between them, are defined in the class hierarchy. Parameters of the members of environment and their value do not have to be defined in the initial description, because they will be added with the instantiation of activities appeared in* Figure 16 *by executing the suggestion algorithm.* Figure 17 *lists a part of activities in the registered PSS models in the case study. Although the prepared PSS models contain an activity, a PSS model in general, can contain multiple activities. The case study assumes that the quality newness is related with the functional state of products and the relation is a monotonic function. In other words, increasing the value of functional state enhances the quality of service evaluated in terms of the newness. Since each element in PSS models has a class name defined in the class hierarchy,* Figure 17 *shows the class names of the elements instead of their original instance names. As is shown in* Figure 17*, the goals to be realized by an activity do not always correspond to the specific state transition of the environment as a result of its execution. For instance, the maintenance service improves the physical states of products by delivering the skill of engineers, while the mechanical upgrading service gives the same effect by delivering (new) mechanical components. Similarly, the software upgrading service improves the newness of products by delivering information as executables instead of the delivery of mechanical components by the mechanical upgrading service. Furthermore, an activity, which causes the similar effects on the environment, is interpreted as service that realizes the delivery of different contents. In* Figure 17*, for instance, a passenger in the service to deliver mobility (transportation1) changes his/her spatial state and he/she becomes the receiver, while goods of a receiver in the service to deliver goods (transportation2) change its spatial state and it becomes the contents for the receiver. These flexible descriptions of service do not mean that the descriptions are incomplete and that the interpretations therefore cannot be defined uniquely. Rather, service is understood and reasoned based on multiple interpretations.*

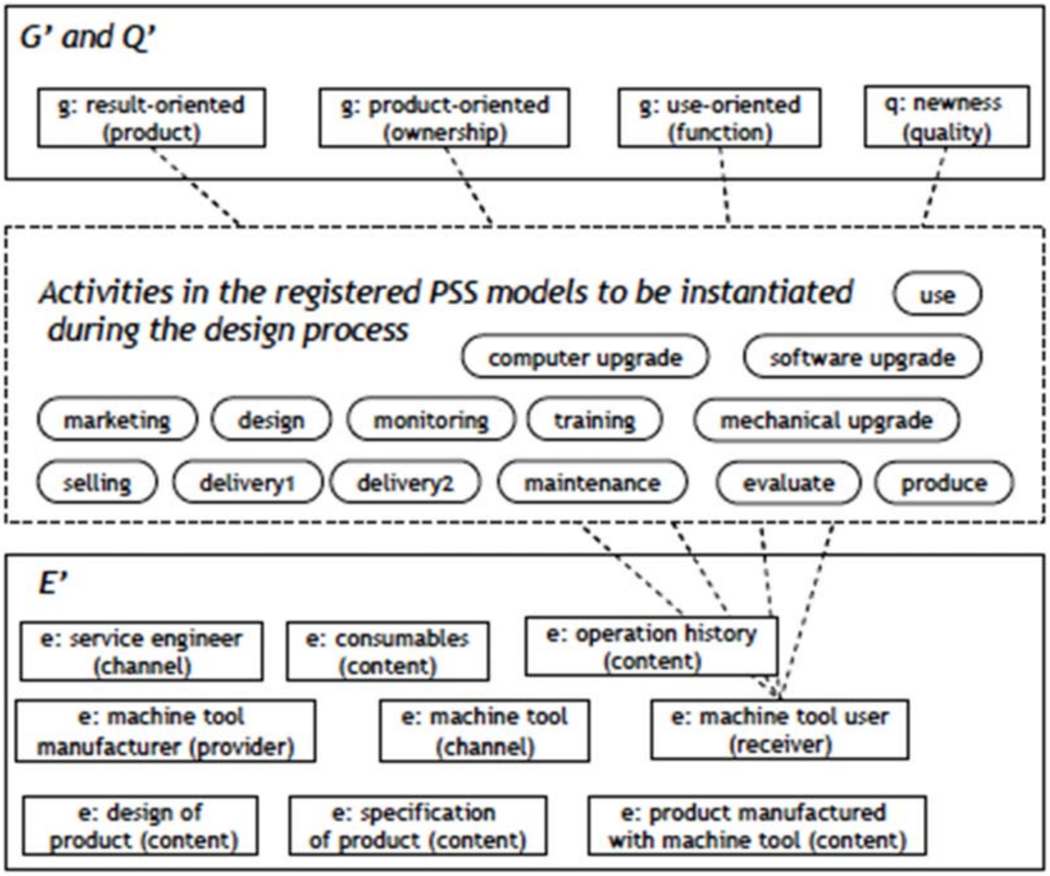


Figure 16 – Initial outline of the PSS model

| Activity *a* | Description of conditions ***cond*(*a*)** and consequences ***cons*(*a*)** |
|---|---|
| selling | *cond*(selling) = [provider, receiver, goods, own(provider, goods)]<br>*cons*(selling) = [gen(own(receiver, goods)), del(own(provider, goods)), specifies(ownership) = receiver, realize(selling) = ownership] |
| transportation1 | *cond*(transporation1) = [provider, receiver, goods]<br>*cons*(transportation1) = [gen(spatialState(receiver, goods)), set(place(goods), receiver), specifies(goods) = receiver, realize(transportation1) = goods] |
| transportation2 | *cond*(transporation2) = [provider, channel, destination]<br>*cons*(transportation2) = [gen(spatialState(passenger, destination)), set(place(passenger), destination), specifies(mobility) = receiver, realize(transporation2) = mobility] |
| maintenance | *cond*(maintenance) = [user, engineer, product, skill(engineer) = high, spatialState(engineer, product)]<br>*cons*(maintenance) = [inc(physicalState(product), healthy), specifies(skill) = user, realize(maintenance) = skill] |
| mechanicalUpgrade | *cond*(mechanicalUpgrade) = [engineer, product, newParts, skill(engineer) = high, spatialState(engineer, product)]<br>cons(mechanicalUpgrade) = [inc(physicalState(product), healthy), inc(functionalState(product), updated), realize(mechanicalUpgrade) = newParts] |
| softwareUpgrade | *cond*(softwareUpgrade) = [server, channel, product, executables, informationConnection(server, channel), informationConnection(product, channel)]<br>*cons*(softwareUpgrade) = [inc(functionalState(product), updated), realize(softwareUpgrade) = information] |
| use | *cond*(use) = [user, product, consumables, spacialAccess(user, product), physicalState(product)=healthy)]<br>*cons*(use) = [dec(physicalState(product), malfunction), del(consumables), realize(use) = function, specifies(function) = user] |
| produce | *cond*(produce) = [producer, production facility, product design]<br>*cons*(produce) = [gen(product), gen(own(producer, product)), set(place(product), producer)] |
| evaluate | *cond*(evaluate) = [user, product, spatialAccess(user, product)]<br>*cons*(evaluate) = [specifies(newness) = user, *eval*(evaluate) = newness, newness = monotonicallyIncreasingFunction(functionalState(product)] |

Figure 17 – Activity instances in the stockpiled PSS models.

***Development***

*The designer develops both a sequence of activities to realize the goals and specify environment to meet the execution conditions of the developed sequence of activities. To do so, the designer manually modifies the description of the PSS model and employs the evaluation and suggestion algorithms. Using the evaluation algorithm, the designer identifies the unrealized goals, unevaluated and unenhanced quality, and (un)necessary elements in the service environment. After the identification, the suggestion algorithm is employed to search for activities instances to improve the PSS model in terms of the evaluation criteria.* Figure 18 *describes how activities in the registered PSS models are inferred from the PSS model starting from the initial description. First of all, activities to realize the delivery of contents specified by each*

*PSS types are instantiated (realize). Selling, use, and product delivery activities deliver the ownership of the machine tool, the function of the machine tool, and the product manufactured with the machine tool, respectively. These activities are chosen by the designer among other alternative activities. For instance, production (by the customer) is an alternative activity of product delivery from the machine tool manufacturer to the customer for the result-oriented PSS. In terms of the quality newness, the designer first generates activities that evaluate the quality, and finds the related parameters in the environment. After that, the designer finds activities that enhance the quality through the related parameters. In this case study, the model base includes an activity evaluate for the evaluation of the newness of a product, mechanical upgrade, computer upgrade, and software upgrade activities to increase the functional state of a product in the registered PSS models. Especially these upgrading activities are different in terms of their execution conditions and consequences of the execution.*

*To enable activities to realize the goals, evaluate the quality, and enhance the quality, other activities are necessary to cause the state transitions of the environment. For example, the delivery of a machine tool is necessary for the customer to use the machine tool. Furthermore, to enable the continuous use of the machine tool, consumables should be delivered to the customer and the physical state of machine tools to be recovered. The process to generate the enabling activities for all the instantiated activities is performed iteratively until the conditions of the generated activities are satisfied by the initial state of the environment.*

*In parallel with the development of activities, the descriptions of existing constituents, relations, and parameters are specified, and new elements are introduced to the environment. For instance, the machine tool does not have any parameters when selling is instantiated to deliver the ownership of a machine tool.*

*It obtains its physical and functional parameters when use and evaluate activities are introduced, respectively.*

*The newly instantiated activities and elements in the environment from the registered PSS models are unified with existing elements in the PSS model during the execution of the suggestion algorithm. The possibility of unification between two activities is evaluated by comparing the delivered service contents and execution conditions in new activities with those in the existing activities. For instance, computer upgrade is unified with consumable delivery, because both activities deliver products. Mechanical upgrade is unified with maintenance, because both activities require the skill of engineers. Furthermore, new parts in mechanical upgrade are delivered together with the service engineer at the delivery of engineer. Software upgrade is executed with monitoring,* *because both activities deal with the delivery of information contents (operation history and executables).*

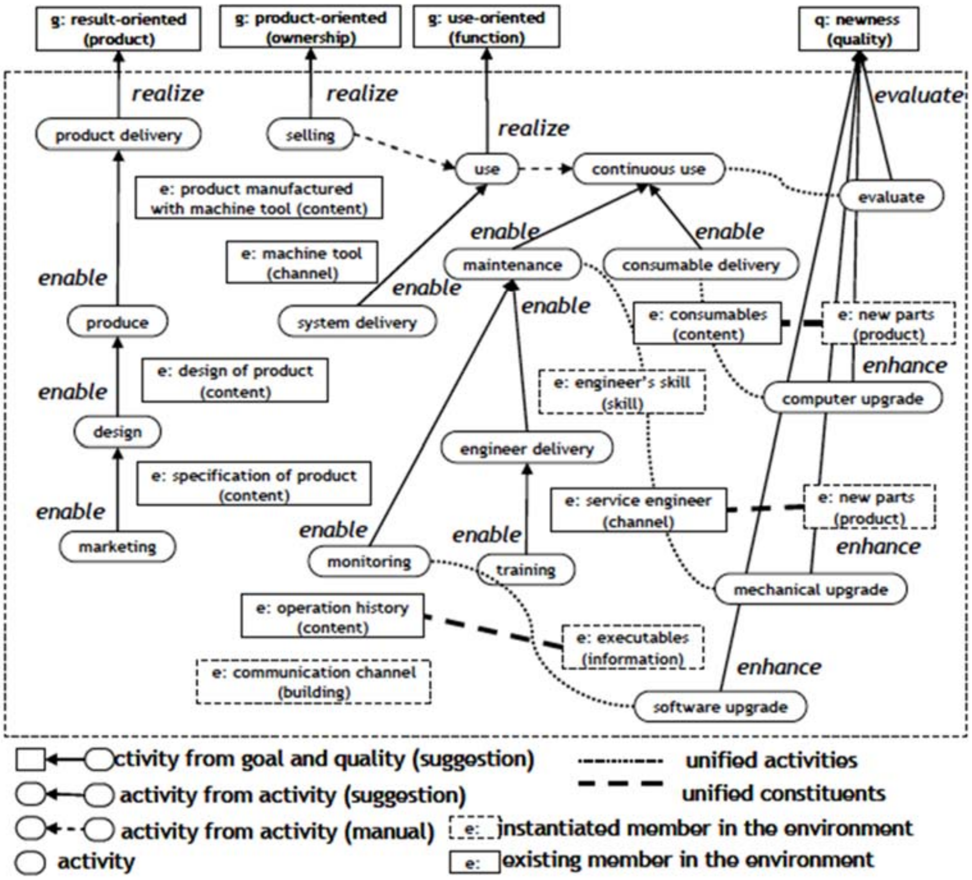


Figure 18 – Acitivity generation flow (Komoto, 2009)

### *Completion*

*The designer completes the design of a PSS when the evaluation algorithm does not find unrealized goals, unevaluated quality, unexecutable activities, and unnecessary elements in the environment* (Komoto, 2009)*".*

### *e. Service Explorer*

Sakao and Lindahl (2009) argue that the Service CAD can be utilized to store several instances of PSS design with various rules and constraints in each. The second would create a history of cases that can be applied in new occurences thus decreasing the time required for the newly pursued services: *"one of the methods to design a new solution is to apply various sets of design rules to existing service cases* (Shimomura and Tomiyama, 2002, 2005)*."* The amalgamation took birth under the name 'Service Explorer' (Figure 19) which offers new horizons in relation to its predecessor:

1. Allowing the designer to input and edit a pre-existing model: This feature is the key function of the proposed Service Explorer: a graphical interface allows the user to navigate through service exmplars for an efficient design. Nodes and arcs provide a schematic similar to one of a network.
2. Exhibit design elments requiring the designer's attention and focus. The engineer's requirements should be translated in an effective manner showing the focal components which would simplify the understanding of the solution, its function and sub-functions, parameters and boundaries.
3. Cataloging specimens for future review or to serve as a reference for future models. The service explorer utilizes the XML format to ensure readability across various operating system platforms. The database/catalog eases the user's search for his inquiries by decomposing high-level entities into modular elements/inputs. The service explorer has thus been extended to a Java platform for added flexibility and 'robustness'.

The notable addition in the Service Explorer with comparison to its predecessor is the utilization of the flow-view model and service blueprinting to maximize customer value while considering the effects services and products will have on each other – synergies and interactions between the human and physical processes embedded in the offering. Sakao and Shimomura (2007) expressed the change of state for a customer through receiver state parameters (RSPs), which represent customer value. They proposed a view model to handle functions and attributes to represent RSPs. They argued that the lowest-level functions are associated with real entities, such as hardware, humans and software. They extended service blueprinting to include physical processes to connect with view models representing service content and employed the business process modelling notation. Merging the flow-view model and service blueprinting concretize the product and the service's intra-connected roles. The setback resides in the Service Explorer's exposure to subjectivity, limiting the selection of services, service activities and service channels, which could refrain improvements and developments due to the high dependency on the client's state parameters.

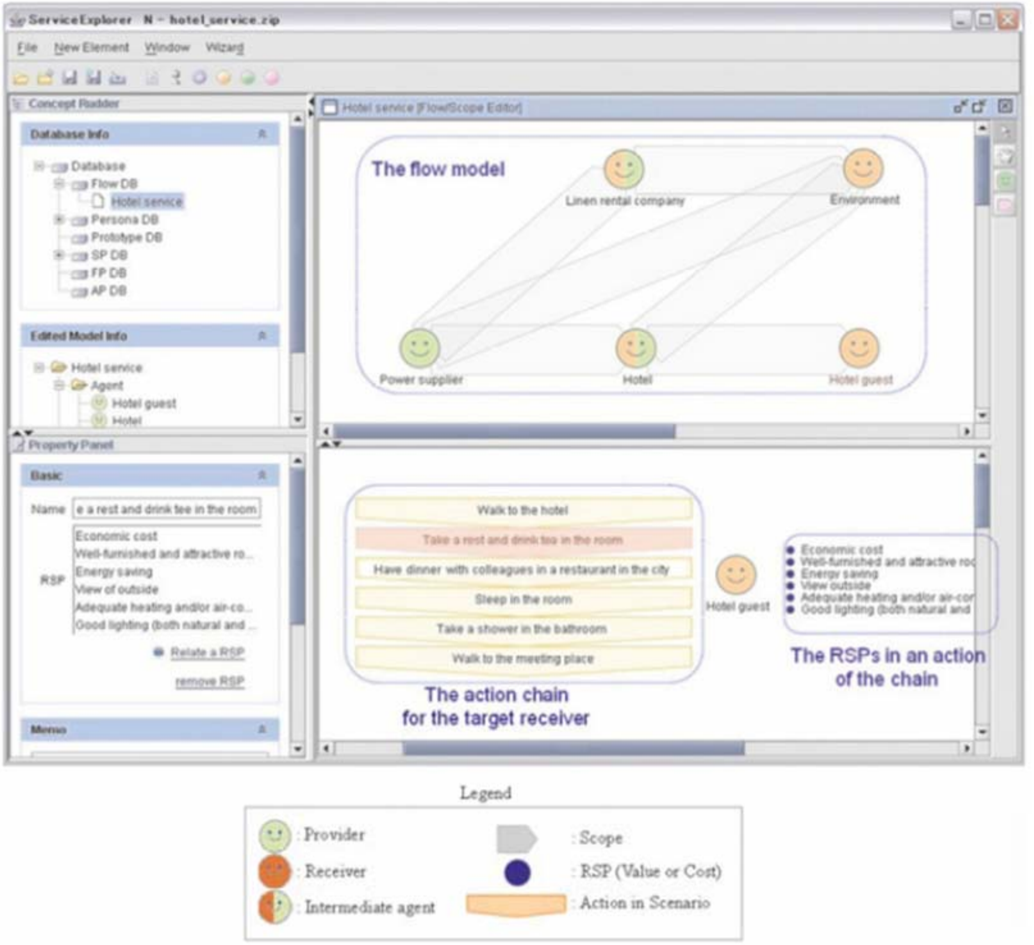


Figure 19 – Service explorer (Sakao and Lindahl, 2009)

### *f. Requirements Data Model*

A PSS creates value to its clients by offering added flexibility and personalization compared to classical product offerings. The product in a PSS context is a combination of hardware and software arranged in a manner to meet customer requirements. A recurrent characteristic throughout the literature as well as this dissertation is modularization where each module is a sub-functionality of the holistic offering designers seek to provide. The Requirements Data Model (RDMo) approach to designing integrated products is founded on Requirements Engineering (RE) to translate customer requirements into PSS components (Figure 20) (Berkovich et al. 2009; Berkovich et al. 2014). The key documents stand out as the user requirements and the functional specifications. Identifying the requirements, the challenges are the initial step taken.

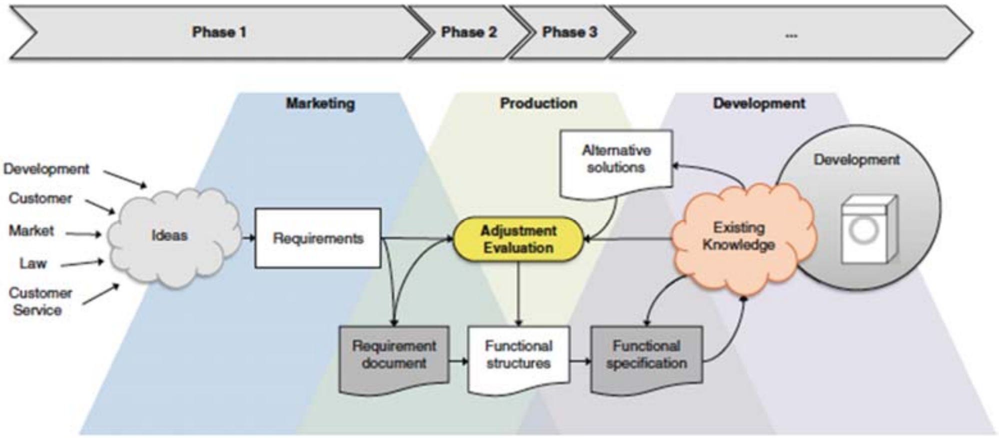


Figure 20 – High-level view of the RDMo (Berkovich et al. 2014)

Having identified the requirements, the initial objective is to identify the stakeholders (customer, developers, providers etc.) using the customer-oriented department to capture the entire picture and consequently verify that all requirements are distinguished. The prior have to described in quantitative and qualitative fashion to minimize risks of misinterpreting them, especially when the intangible service components are concerned. The requirements of the RDMo are vital for PSS acceptance as the solution's response to stakeholder requirements is the base of design. Thus, requirement engineering states that in order to develop the solution, the following must be satisfied:

1. Requirements must be communicated to the customer and within the PSS team during all life cycle phases. Specific information is mandatory to derive precise physical and non-physical elements.
2. Step by step implementation to address conflicts and inconsistencies between product elements and service components.
3. Constraints must be solved within a single domain, as well as between several domains, thus guaranteeing the homogeneity of the proposal. Berkovich et al. (2014) emphasize the determination of interdependencies to facilitate tracing and rerouting during any development phase. Change management, and the use of change control forms manage upcoming changes and impacts.
4. Requirements are to be validated, and compared with design specifications to ensure compliance before entering the prototyping/testing phase.

At a system level, this phase consists of the conceptualization phase where ideas and suggestions are embodied in preliminary sketches describing general functionalities and goals without delving much into details. Moreover, the solution is investigated from a business stance to assess the PSS's feasibility and profitability while respecting environmental and ecological guidelines and laws.

At a feature level, the commodities and services are specified and characterized according to design requirements while keeping note of the possible interactions and the influences they may have on one another:

1. System Design: the tangible and immaterial components of the PSS belonging to the setting/environment are included in this section. "*The system design represents the cross-domain concept for the realization of the requirements to the PSS, which describes the features of the PSS. Thus, it indicates the technical products, the combination of hardware and software elements, and services of which the PSS consists* (Berkovich et al. 2014)".
    a. The system context identifies the PSS setting and margins.
    b. The functional structures express the functionality of the solution, divided into sub-fragments.
2. Product Oriented requirements comprising of:
    a. Technical functions and performance: technical functions, safety, resources, user interaction etc.
    b. Legal requirements: regulations and legislations, warranty period, contracts, property rights, patents etc. (Van Halen et al. 2005)
    c. Financial requirements: price, cost, risk, NPV, etc.
    d. Quality: availability, reliability, serviceability, efficiency and reusability (Boehm, 1996)
3. Result Oriented requirements: the deliverables have to be defined given that they depend on the customer's personal needs and desires. A categorization at this stage cannot be defined (Scholl et al. 2010).
4. Process Oriented requirements conveying data on the service and its respective activities. The following is noted:
    a. Process design: the required activities to fulfill a task outlined by the sequence to follow, the inputs and outputs, operational conditions, efficiency, flexibility, customization etc.
    b. Interaction: between the client and the service and between the client and the service provider; interfaces, language, information, support etc.

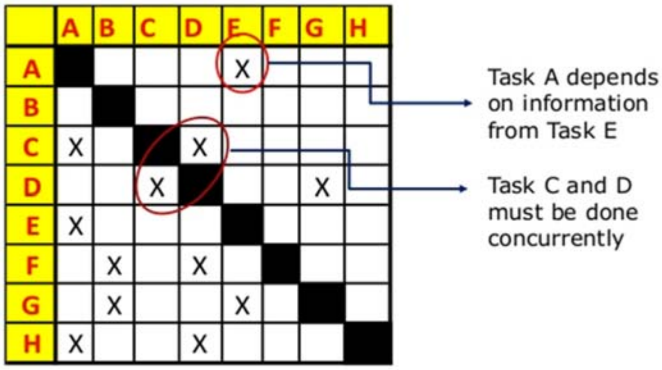
    c. Timing: guaranteeing a minimum level of availability, response time, delivery time, transaction time etc.
    d. Reliability: in other terms quality management to ensure consumer satisfaction and sustained value.
5. Resource Oriented requirements such as the necessary human and technical resources to realize a certain task.
    a. Human resources: capacity, skills, remuneration and training and skills desired to deliver a service.
    b. Facilities: locations, companies, service centers etc.
    c. Equipment: the technological resources to provide the needed resources for a successful service outcome.
    d. Material: auxiliary and raw materials.
    e. Information: infrastructure to ensure data transfer and sharing as well as the methodologies to adopt in developing a service.
    f. Capital: monetary funds and estimated costs.

At a function level, the hard and soft parts of the offering are described, vis-à-vis the structure, specifications and requirements of each.

1. Functional structure: a systematic decomposition of the functions to recognize the specific products and services needed to realize that function.
2. Functional structure requirements: *"The function level represents the concretization of the design requirements related to the feature level for the single functions of the functional structural design. Consequently, the function-structure requirements comprise the functionalities of the domain-specific components, such as hardware, software, and services, and thus establish the basis for the complete identification of these components on the component level* (Berkovich et al. 2014)." Detailed information is the core of breaking down functions at this level and assigning specific tasks that each mean must accomplish. The product's specific requirements (adapted from the previous phases in addition to tactile specs such as stability, geometry etc.) are recapitulated as well as the service's.

At a component level, the focus is the development of artifacts with respect to their assigned environment occurs, finalizing the design task and completing the PSS architecture. Moreover, supporting activities are to be described in order to address constraints and conflicts of interest which become a significant concern when the system becomes more complex, involving additional restraints: a design structure matrix (DSM) (Figure 21) is a useful approach to analyze and manage complex systems by simulating, portraying and analyzing dependencies within a solution. Additionally, prioritization can take place to figure out the correct order of mapping out the functions and the measures to realize each one of them. Several iterations can occur in order to optimize the design.

The RDMo is summarized in Figure 22 eliciting the various steps described earlier.



| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| A | ■ | | | | X | | | |
| B | | ■ | | | | | | |
| C | X | | ■ | X | | | | |
| D | | | X | ■ | | | X | |
| E | X | | | | ■ | | | |
| F | | X | | X | | ■ | | |
| G | | X | | | X | | ■ | |
| H | X | | | X | | | | ■ |

Figure 21 – Design Structure Matrix (Berkovich et al. 2014)

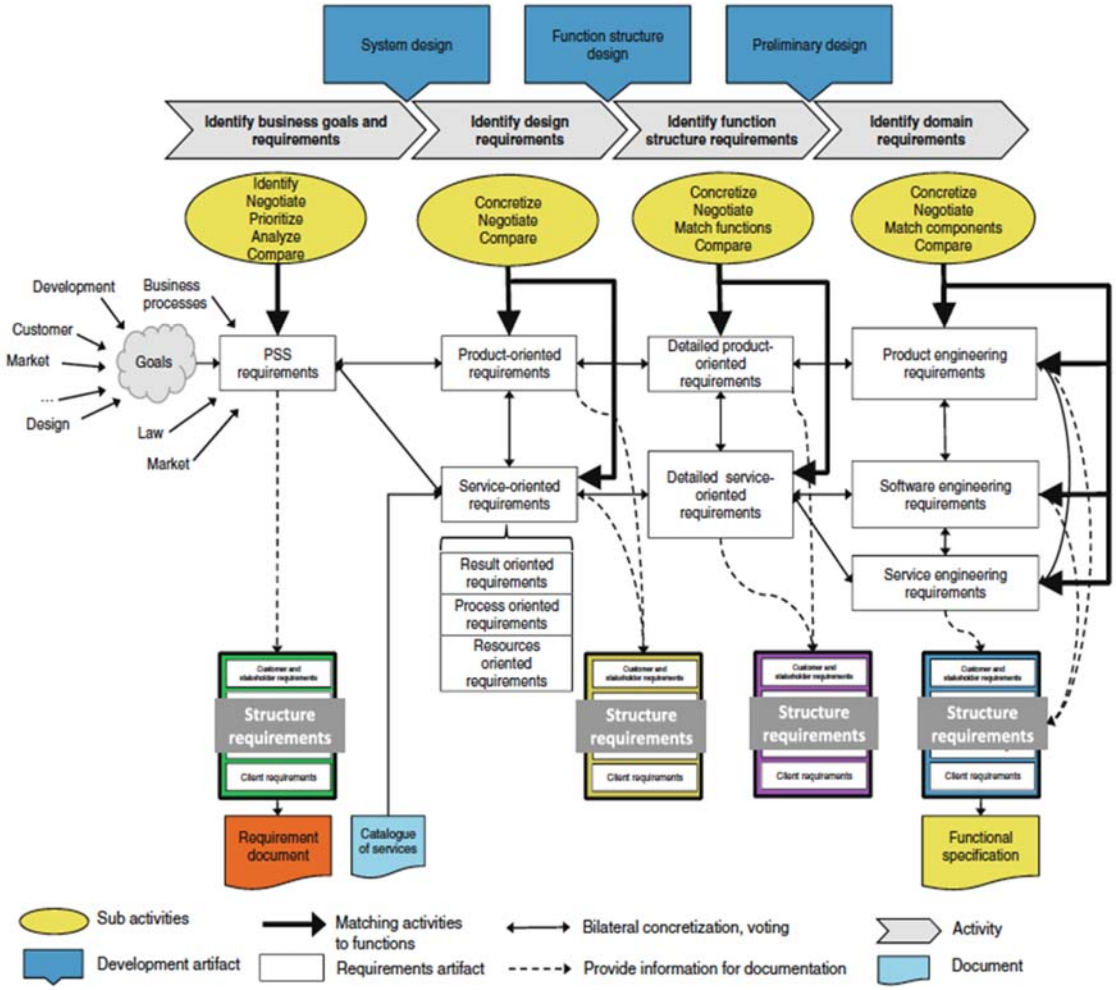


Figure 22 – The Requirements Data Model (RDMo) (Berkovich et al. 2014)

### *g. Spiral Design Process*

The Spiral Model (SMo) (Pezzotta et al. 2012) derives from the *V-model* founded in *2004* (Figure 23) and describes the needed activities from a life cycle point of view when it comes to designing solutions. The SMo guides PSS design by adopting a risk-driven approach to generate valid systems. Two notable characteristics of the prior are its incrementally cognitive method to define a system's components and complexity, and the establishment of milestones to ensure that each step has been covered to its full extent before proceeding with the following activity (Figure 24).

The noticeable value of implementing the SMo instead of the V-Model is the re-iteration at the end of each completed design/task to assess its validity and the possibility of testing and re-designing the concerned step and/or its predecessor before reaching the next level.

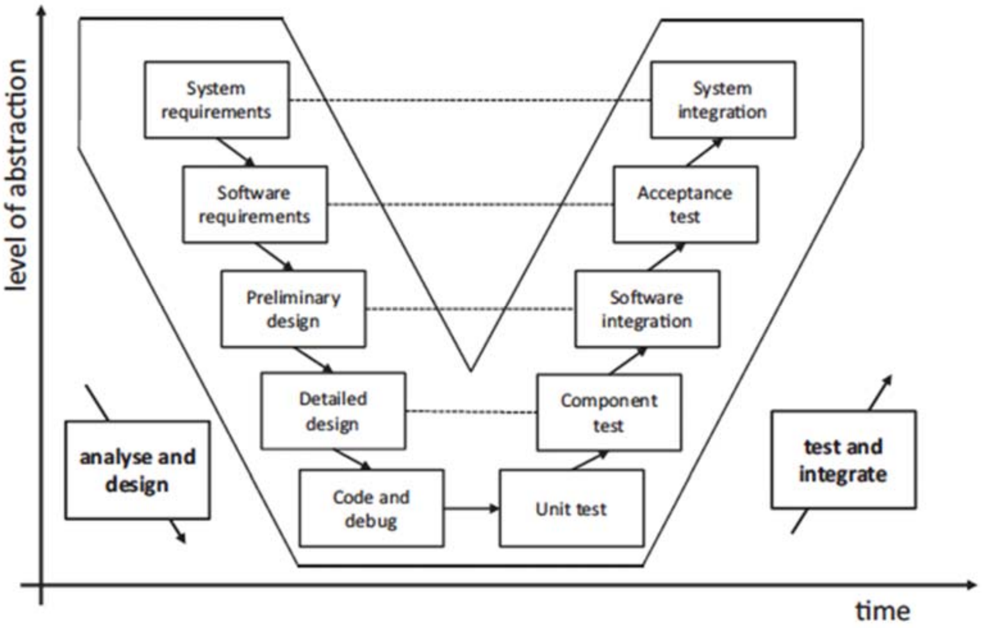


Figure 23 – V model

The core criteria rendering the SMo a legitimate tactic to propose PSS designs are summarized by Andreasen (2002) and Tan and McAloone (2006):

1. Product and service integration level is proportional to complexity of the customer's expectations and requirements
2. Covering all the life cycle phases: beginning, middle and end.
3. Involvement of all the needed functions and stakeholders to realize the offering.

4. Incorporating the customer in the value creation process.

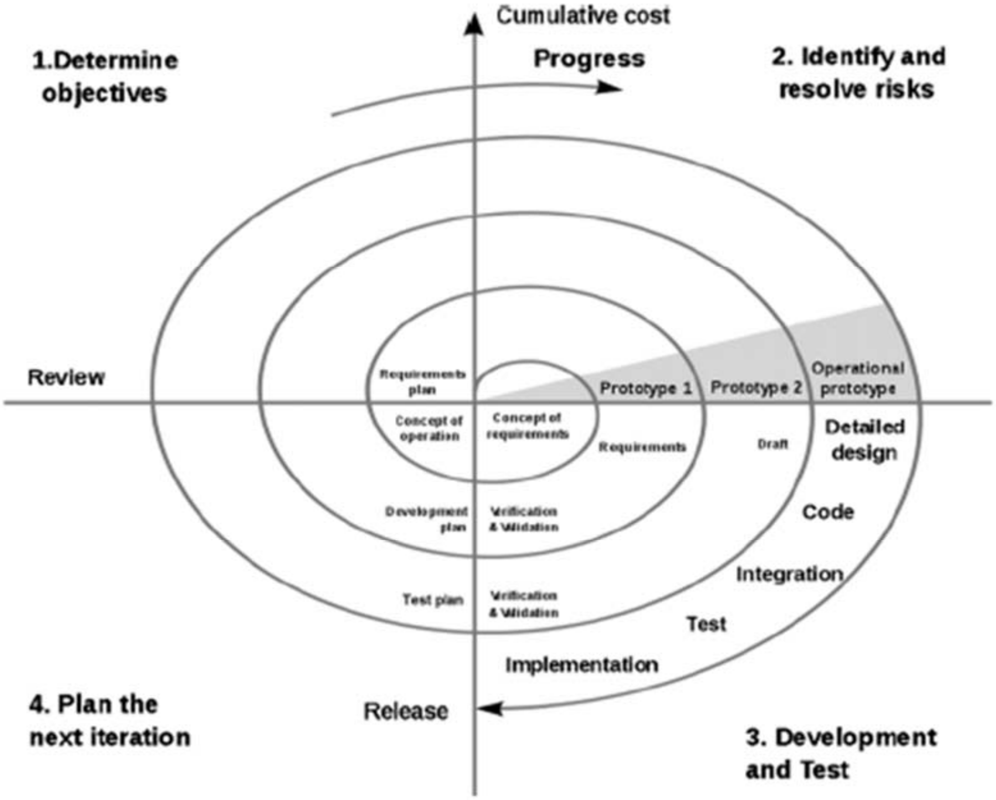


Figure 24 – Spiral model

Supporting processes to the SMo are the Design Foci Activity Phase Perspective and Participation (DFAPPP) classification (Wild et al. 2009) and the xCOR technique to engineer the relations between the DFAPP phases. The DFAPPP hierarchy considers an element as a jack-of-all-trades: a component doesn't exist on only one level, but can be present in other stages of the PSS pyramid.

Five fundamentals define the DFAPPP (Pezzotta et al. 2012):

1. Design Foci: defining the specifications of what is being designed such as the domain, the product, service, information, stakeholders, objectives, enablers, knowledge and skills. The domain is mainly composed of an artifact and information objects such as the value of the latter to its user/client. Consequently, the strategy is to increase the value-adding functions and optimizing costs by keying vital activities that facilitate the task and increase customer satisfaction. Client contentment is the guiding line of the decomposition of the general task, and the extent of the service user's involvement dictates the complexity of the sub-modules to fulfill.

2. Activity: the features required to establish the tactic to follow to implement the sought-out design. Centralizing the customer guides the product and service designers in their task to analyze the needed task to achieve from a product and a consumer's point of view to produce a successful offering.
3. Phase: macro- and micro- analysis of the life cycle stages and activities (design, implementation, sales, use, upkeep, reuse...). Three distinct phases can be outlined:
    a. Beginning Of Life (BOL): *"Referencing to the dCOR* (Figure 29) *representation, an in-depth work is performed during the Plan phase in order to align the requirements coming from all the functions involved in the process. There is also a well-framed Research phase, which aims to transform the requirements coming from the Plan phase in order to develop a consistent PSS prototype* (Pezzotta et al. 2012)*."*
    b. Middle Of Life (MOL): concerns the post-market release of the integrated product-service, which mainly revolves around the use of the solution and gathering feedback from the customer regarding the main aspects of the solution such as satisfaction, personalization, product performance and possible openings for add-ons and future solutions which would be evaluated in the re-iteration loop when the solution is scrutinized again: vital feature of the SMo.
    c. End Of Life (EOL): the solution, once it has fulfilled its purpose is subject to its EOL scheme. In product-oriented PSS, contractual obligations may oblige the manufacturer to retrieve the product or have the client return it when considered obsolete (similarly to recycling). In use-oriented and result-oriented PSS however, the provider is always responsible for its solution once the consumption phase ends: re-integration, re-furbishing, re-use etc. are highly emphasized to not compromise the environmental advantage characteristic of the PSS.
4. Participation: the participation of customers, users, designers, engineers, technical staff, marketing personnel and other stakeholders to explicit their involvement in the design process. Engineers, marketing staff and service personnel are all part of the PSS development, and it is their collaboration from the BOL to the EOL of a PSS that influences the prior's outcome: engineers cover the tangible specs while the customer-oriented team handles the intangibilities. The latter can be described as

a ‘multifunctional team’ realizing their respective tasks in coherence and alignment with each team’s respective goals. Adapting those specs in a subtle manner is crucial for the company’s goals to be reached. Pezzotta et al. (2012) mention ‘the clinic test’ as a way of introducing a prototype to the customer while hiding the motives behind the prototype as well as the manufacturing brand to attain feedback on the perceived value and consequently run analysis and further considerations to improve the solution.

5. Perspective: the point of view taken when assessing a design. Involving the customer and understanding what he sees and feels guides the project since surveys and feedback are not as effective as in a conventional product design environment given that personalized features aren’t as easily quantifiable and assessable. Moreover, customization abolishes mass manufacturing and establishes personalized solutions in a similar way to Lean manufacturing where product manufacture is triggered by customer demand.

The xCOR mapping technique (Figure 25) visualizes the process as a whole to identify gaps and weaknesses that have to be amended. The drawbacks to alter via xCOR emerge unifying the intrinsic chain links that form a PSS:

1. mCOR: marketing chain related activities, notably product-portfolio and plausible services information acquired from market segments analysis.
2. dCOR: design chain activities to engineer and develop a product.
3. sCOR: supply chain activities (purchasing, production, logistics, distribution, recovery) amongst the concerned parties
4. cCOR: customer-oriented activities, mainly customer relationships and support management.

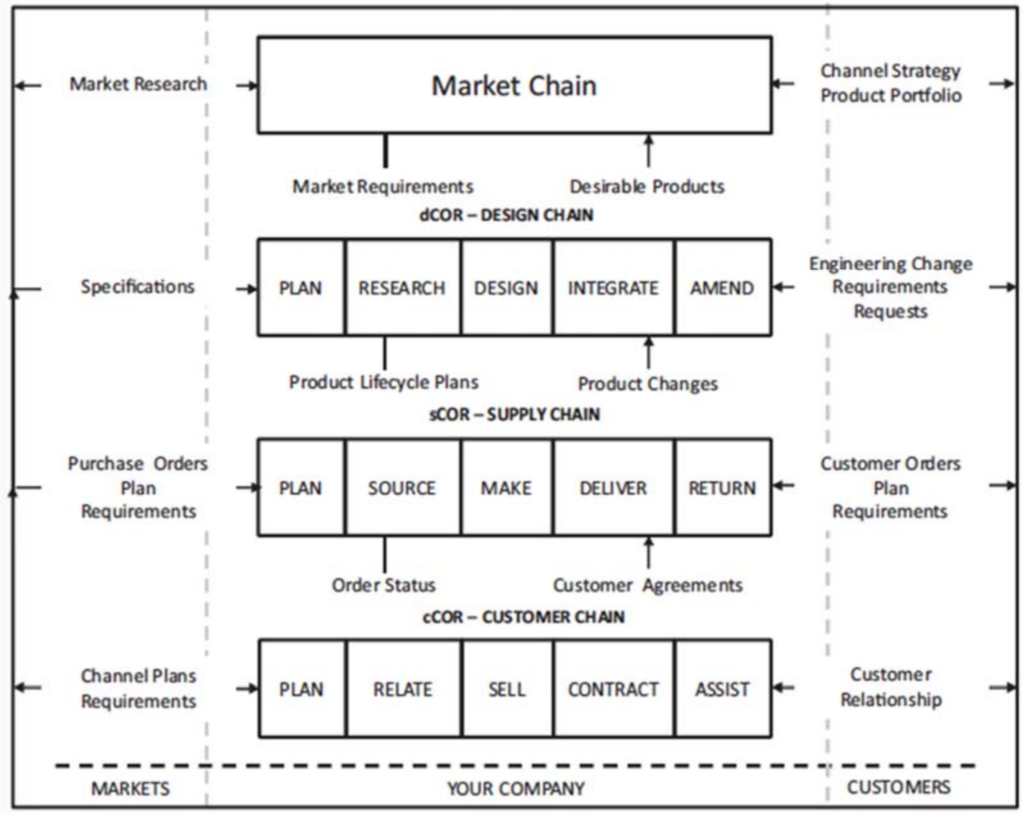


Figure 25 – xCOR technique (Pezzotta et al. 2012)

### *h. Functional-Blueprint Design Approach*

Trevisan et al. 2015 propose merging service and product design methods to construct function, process and structure layers for PSS development. The infrastructure defines the components which can be new or pre-existing within the company. The structure matches the product and service instances to fulfill the desired activities. Notably it combines Maussang et al. (2009)'s FBD approach (Figure 26) with Luczak et al. (2007)'s service flow-chart method to generate a 'functional blueprint' design process. System limitations, internal and external components and stakeholders are identified and modeled via the FAST and SADT procedures to portray the sequence of tasks required to realise a function or sub-function (Figure 27).

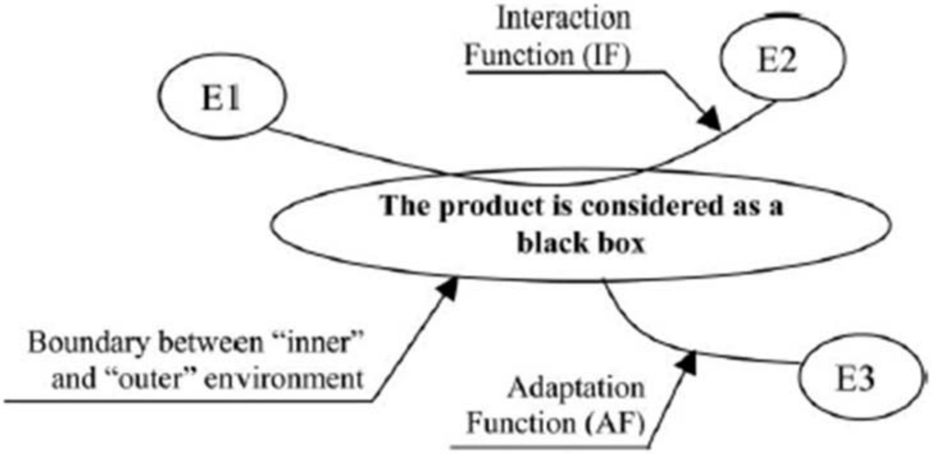


Figure 26 – External functional analysis (Maussang et al. 2009; Trevisan et al. 2015) - *Interaction functions (IF) symbolize the product's function relative to the exterior (outer) setting). Adaptation functions (AF) represent constraints and reactions by the exterior setting (E1, E2, E3).*

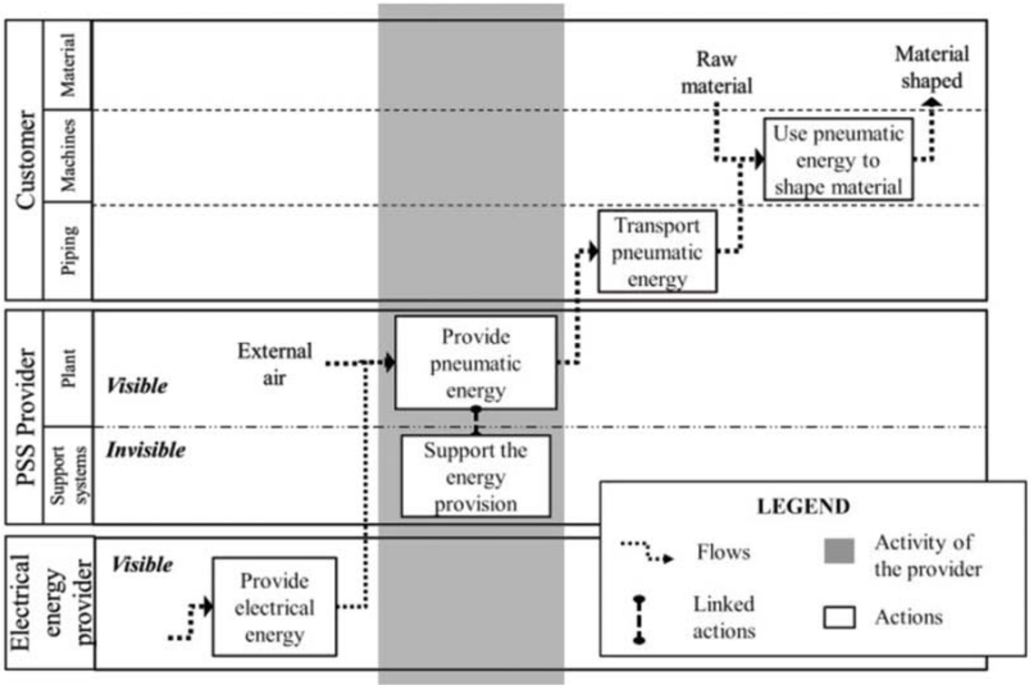


Figure 27 – Example showing the merger of the FBD scheme with a service flow-chart tactic. (Excerpt from Trevisan et al. 2015): *The activities are laid out in a manner that elucidates their sequence alongside the supporting processes needed to fulfill them.*

## 2.4 Main outputs of the literature review

To summarize the analysis carried out in previous sections, it can be underlined that a remarkable problem these days concerns the need of a large number of companies, to integrate their production of goods with related services in order to keep their market competitiveness. Such a transition, well discussed for instance by Oliva and Kallenberg (2003), Baines et al. (2009) and Vezzoli et al. (2015), differs from the ones based on the perspectives of service providers (Yoon et al. 2012; Pigosso and McAloone 2016). While the design approaches of a PSS highlighted in the literature are diversified and varied, it emerged that most of the existing methodologies are case-specific and personalized to circumstances and specific needs when it comes to developing a PSS. These strategies targeted the interrelations and connections between tangible artefacts and intangible services aiming towards the joint development of eco-efficient, value-enhancing offerings. However, given the intuitive nature of the PSS development scheme, the above-mentioned approaches can be hardly qualified as "generic". In this context, in accordance with Vasantha et al. (2012), we intend to define as "generic", a robust methodology applicable to various types of integrated product-services, covering all the PSS components: stakeholders, the environment, support objects, life cycle stages, processes, assessment the criteria, customer requirements, business models, products and services. Based on this, the analysis showed that the key goal of a framework is to build a "path", valid to more than one application, to develop product-service integrated solutions, to catalyze the cultural shift and to ease communication and interactions within the firm (Isaksson et al. 2011).

Accordingly, this motivated the author to carry out further research targeting the models that provide a structured procedure to guide engineers in PSS development from a producer's point of view.

The selection of frameworks as above defined is exposed in Section 3, taking into account the product manufacturers' perspectives on developing integrated solutions, mainly morphing their existing stand-alone artefacts into service-integrated solutions, also known as PSSs.

# 3. PSS Frameworks

## 3.1 Overview from the literature

The following chapter analyzes the most dominant PSS frameworks to obtain a better understanding of the activities they embed and how their implementation can lead to an integrated product-service offering.

### 3.1.1 Framework for PSS design for manufacturing firms

According to Alix and Vallespir (2010), manufacturing objectives can be reached by replacing traditional offerings with an integrated value-adding solution comprising of a product and an associated service. Designing this integrated offer involves four dimensions: the product, the service, the process and the organization. These dimensions need to be developed with specificity to achieve an efficient operational PSS level:

1. Strategic management of the organizations' goals and principles.
2. Understanding the customer and adjust to his requirements to offer a high-end service.
3. Defining value from both a client and a manufacturer's perspectives.
4. Integrated value horizontally and vertically.
5. Cultural spread towards a more commercial/customer-driven focus instead of solely traditional technical skills.

*Wild, 2009* emphasizes the need of inner cooperation between product and service departments as well as between segregate service disciplines to combine all views and deliver a competitive offering. "*The challenge is then to propose a method to support firm core competence widening taking all the dimensions and changes into account, analyzing how they are linked and how they allow to design the coherent value adding solution using the most appropriate methodologies and tools whatever the discipline is concerned* (Alix and Vallespir, 2010)." Development of integrated product-service solutions should therefore take place within a project management view to embrace the firm's culture, capabilities, processes, expenses, profits and value.

Four progressions are utilized to delineate the project (Table 8).

The first consists in analyzing the customers' demands and measure the company's situation vis-à-vis these requirements, similarly to a SWOT analysis. The second defines the deliverables of the offering and its value from a provider and a customer's perspective. The third phase handles the design and delivery processes while the fourth and last step corresponds to customer delivery.

Table 8 – Progressions to developing a PSS solution (adapted from Alix et al. 2009)

| **Sequence Number** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **Sequence Name** | **Starting** | **Definition** | **Realization** | **Closing** |
| **Sequence Activity** | Analysis of requirements and company position | Deliverables and value analysis | Defining the PSS process | Service delivery and capitalization |
| **Supporting activities** | | | | |
| **Delay** | First planning | Master planning | Control planning | Review planning |
| **Cost** | Evaluating resources | Forecasting costs | Limiting costs | Reducing expenses |
| **Risk** | Risk analysis | Risk scenario | Hazard management | Risk minimization |
| **Communication** | Providing information | Defining the communication system | Managing disagreements | Improving communication |
| **Knowledge** | Data management | Information management | Knowledge management | Knowledge control improvement |
| **Organization** | Identifying actors | Project structure | Project control | Improving the organization |

<u>The starting sequence</u> utilizes a SWOT diagram to outline the internal and external factors that affect the firm's capability of achieving its desired goals

Internal components are strengths and weaknesses found within the company such as the firm's culture and organization (brand, hierarchy, experience), its marketing and commercial features (price, promotion, market share), human resources (management, motivation, skills, training, project team), financial modules (costs, profits, stakeholders) and technical capabilities (design, innovation, research and development, manufacturing capabilities, operational potential).

External factors on the other hand arise from political, economic, social and technological sources and influence the manufacturer's position in the market. The latter requires strategic planning to negotiate with customers and suppliers and manage potential threats from similar products and rivals.

Alix et al. (2009) provide a list of the most dominant and widespread elements regarding the SWOT assessment: Project team, Manufacturing resources, Technological potentiality, Operations/ process, Partners relationship, Brand image, Cost base, Cash flow, Sales team, Distribution, Political environment, Economic outlook, Cultural changes, Technical context, Customers position, Suppliers position, Competitors position, Substitute, Product to integrate.

<u>The definition sequence</u> targets the development of the solution that will allow the creation of added value for both the developer as well as the customer to maximize its competitiveness and profitability. The core of this secondary phase relies on analyzing the suggested offer's value by benchmarking it against previous versions and competitors' actions. Value in this context is demonstrated as the difference between functional performance distinguishing between basic and supporting value/functions, and the needed costs to achieve the prior. Accordingly, value should be defined from the solution provider's point of view and then from the paying customer's (Table 9).

1. For a provider, the main focus of a solution is reaping its profits. These benefits take the form of tangible items such as rapid designs, reduced lead and cycle times, market expenditure, generated revenues, lower eco-impacts and reduced expenses, from one side, and intangible ones like customer loyalty, company image, stabilizing turnovers etc. on the other. Likewise, costs are separated into direct and indirect ones with the differentiating factor being tangibility/intangibility. "*Each benefit can be defined as expected performances that stem from a strategy and have priorities one to the other. Quantifiable criteria can be associated to each one whose level also stem from the strategy. The level really measured, that reflect the performance of the function, compared to the global cost of the service allows determining the value of the service for the firm* (Alix and Vallespir, 2010)."
2. Seen from a customer's stance, value is seen as the worth and usefulness of a given solution versus the cost of the latter. While tangible aspects can be expected and measured, implementing a functional solution

highlights the imperceptible subjective evaluation that varies from customer to customer (Hermel and Louyat, 2005). The main product remains the priority concern, product-related interactions are the secondary element and implicit/indirect functions come in third.

Table 9 – Value from a customer and manufacturer's view (adapted from Alix and Vallespir, 2010)

| | | **Provider value** | |
|---|---|---|---|
| | | **High** | **Low** |
| **Customer value** | **High** | The PS is beneficial for the company and fulfills customer requirements. | To emphasize customer retention, value is increased by lowering the price or complementing with additional services for the same price. |
| | **Low** | Synonymous of customer loyalty if the consumer is part of it or if the overall cost is not that significant | Difficulties may inhibit the delivery of the PS solution, and financial factors can be a decisive factor |

The realization sequence handles the 'value engineering' task of the process (Touzi et al. 2013). Management science has a large impact in this phase as it describes the general guidelines of the system to use and deliver the service. Setting up the milestones and the managerial aspects of project management, mainly regarding the activity network, costs and expenses, conflict resolution and facilitating communication throughout the company's structure (Zhao et al. 2009).

The closing sequence, fourth and final stage (Figure 28), portrays the provider-customer interactions regarding service delivery. "*According to the existing terminology, service delivery is a service production and service delivery process*" (Touzi et al. 2013). The interrelationship between those two ends enables supplying the service, given that the service is halted when the coupling comes to an end. The provider and the customer are the core notion in this process but can also be part of pre-and post-delivery phases. Examples of such preceding or following levels include initialization (coupling not necessary, but info regarding the service needs is vital to activate the process), customization (customized service to fit its desired context) and closing (similar to initialization but now required to terminate the delivery).

Situations dictate the product or service's capacity to fulfill its function. Similarly, when an artifact holds a need, the second may indicate various load levels.

The provider's capacity must be capable of responding to the need load. Consequently, and given the variability that may occur, an insufficient capacity indicates a non-operational state. Likewise, capacity can be compared to a continuous range of value: when an item is providing a service, its capacity decreases. When the service is delivered, the capacity can either be restored, or remains at its new level. The first scenario is known as a 'long lasting function' utilizing non-perishable supplies while the second is referred to as 'consumable function' embedding un-renewable resources (Touzi et al. 2013).

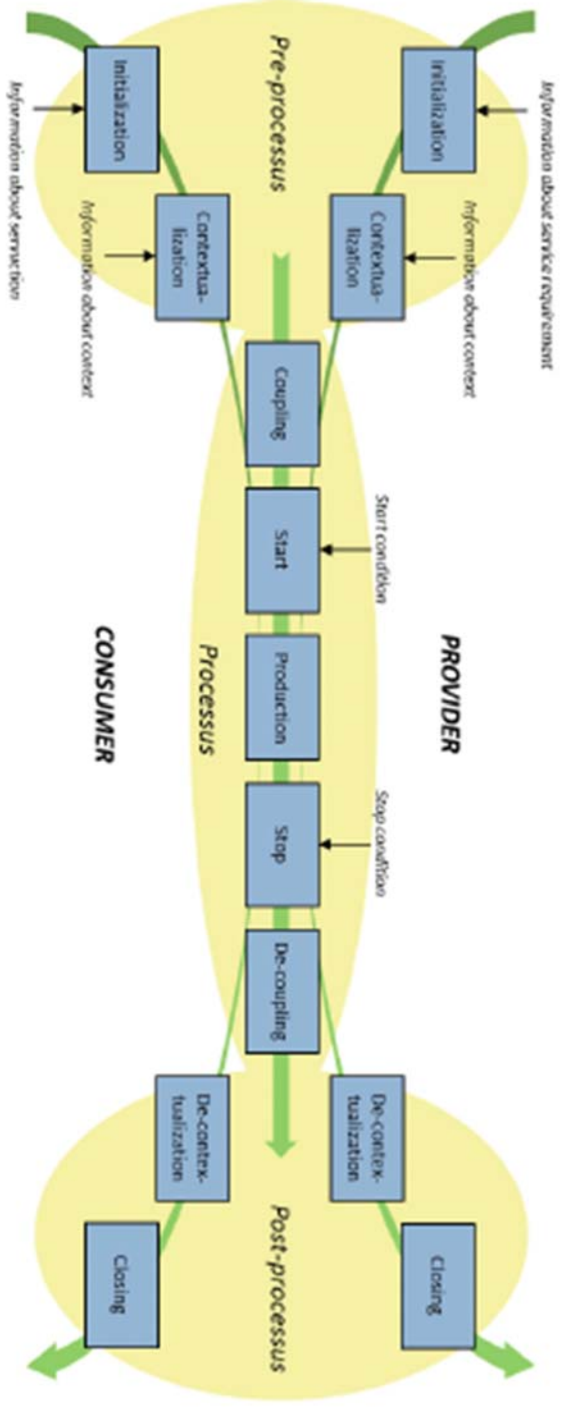


Figure 28 – Service delivery process (Touzi et al. 2013)

### 3.1.2 Innovative Product Advanced Service Systems (IPASS) framework

Lee and Abu Ali (2011) utilize two questions" Who are your customers? What do you customers really want?" as the basis to develop and generate concepts that transcend beyond the physical product offering. The concept relies generally on unsystematic approaches that need to be formalized and organized in order to understand the on-hand situation. Three tools are suggested: the application space map, quality function deployment and the innovation matrix (Figure 29). The latter represents the consumers and their requirements while differentiating explicit and implicit needs, and met and unmet desires. At the same time, customers are also separated into two categories representing the portion that is currently being offered a solution and the complementary that is not. Converging the innovation matrix's output with QFD enables a standardized manner of thinking and identifying opportunities.

The innovation matrix: conventionally established via brainstorming meetings, requires a systematic approach to narrow down the field and originate specific ideas. The procedure to establish the matrix is as follows (Lee and Abu Ali, 2010):

1. Defining needs and customers: served customers, and explicit needs that are met.

2. Evaluate unidentified customers and needs: eyeing un-served market segments and un met needs then perform a correlation analysis to assess the identified customers that are not being offered a solution and the explicit requirements that are not addressed.

3. Gap analysis: recognize latent needs and unanswered consumer segments.

4. Application space exploitation: recognize opportunities that can close the gaps and correlate the application and technological space.

5. Dominant concept generation and design: quantitative assessment of client and manufacturer needs and initiate the business plan.

Nonetheless, before applying the innovation matrix the environment of the product and service has to be outlined to identify the type of model that would allow a company to offer new services and thus generate profits. Consequently, the main target would be satisfying the established clientele and use it as a means of expansion towards new markets.

On the other hand, another approach is starting with a dominant design in terms of products and services that would consider current consumers and potential ones as a means of recognizing the needed technology and infrastructure required to implement the design. However, focusing on the established market base is not sufficient for a design to be successful, as it will fall short in terms of innovation and improvements. Technological breakthroughs are essential to obtain 'new' products and services that *"can satisfy the unarticulated needs of unidentified customers* (Lee and Abu Ali, 2010)*"*.

Figure 29 – Innovation Matrix (Pirenne, 2017)

<u>QFD application space mapping:</u> brainstorming ideas and concepts is an important step in the PSS development process but the latter intangibles have to be materialized in concrete fashion to be integrated within the company's structure. Application Space Mapping (ASM) is a catalyzer for this reaction by matching each idea into its adequate application space. A matrix shaped representation (Figure 30) similar to the Innovation Matrix above represents the quality implementation – the ASM: the application space is scaled horizontally with respect the to the used technology present on the vertical axis. All application spaces and technologies have to be identified first and the service layer is formed by connecting a physical product to its related services (Figure 30). The following step is to define the functional environment (i.e.: office, driving space, etc.) in which the offering can be applied. Afterwards, the outputs of the innovation matrix are adapted to the application spaces based on context suitability and feasibility. The final step is to check the matches between technology and application space and fill the matrix.

The role of QFD is to identify the relations between customer needs and manufacturing requirements to select the most optimal combination: the result of a QFD is a quantitative score that helps prioritize the acknowledged opportunities. More accurate and detailed results can be obtained by applying QFD twice, once between technology and customer demands, and another between technology and company needs; the latter allows a better assessment from a customer's stance as well as a firm's point of view.

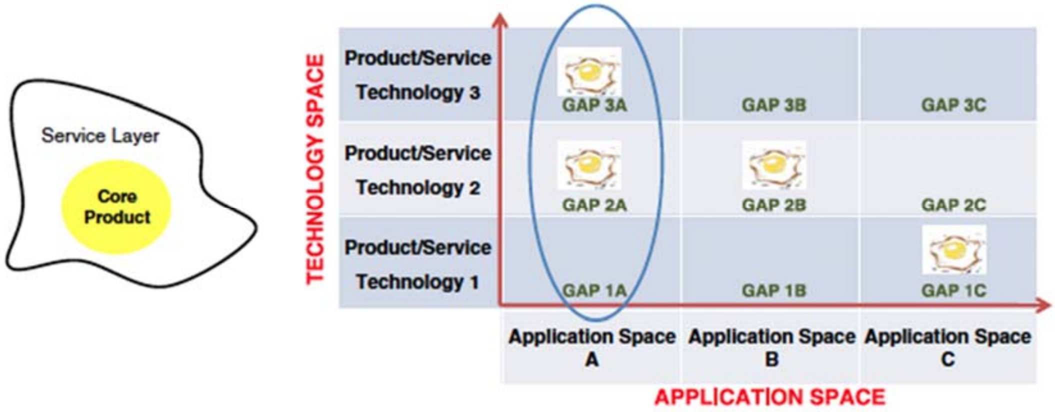


Figure 30 – Scheme of the Application Space Mapping (ASM) (Lee and Abu Ali, 2010)

The following case study helps clarify the framework shown by Lee and Abu Ali by applying the methodology of Innovation Matrix and QFD-ASM on a company operating in the field of pressure-sensitive technology and self-adhesive solutions.

First of all, the innovation matrix has to be implemented by examining the company's customer base (brand owners, governmental parties etc.) and the current product portfolio (Figure 31: lower-left quadrant).

Second, the unrevealed requirements can be concretized throughout brainstorming sessions, cause and effect diagrams or any similar tool. In this example's context, the team recognized the design of new labels embedding dynamic information such as storage information. Another idea suggested the introduction of a multi-purpose adhesive substance applicable on several surfaces (Figure 31: top-right quadrant).

After identifying the latent and explicit needs, the subsequent stage is to expand the customer base and market scope exceeding the existing ones. The firm identified here prospects related to infiltrating the logistics market with info-track labels, hygiene applications and wound protection (Figure 31: lower horizontal quadrants).

The provider also recognized the limitations of expanding in only one axis (horizontal or vertical): short-lived profits can be perceived but long-term growth would still be a farfetched objective. Consequently, developing the related quadrant is essential and the use of smart products vis-à-vis information obtainment is key for a functional and sustainable design (figure 31: upper left quadrant → latent need and unidentified customers).

An example is RFID labels that transmit data related to hygiene and protection as well as facilitate inventory control.

After the innovation matrix, the succeeding procedure is to fit the generated ideas in the company's organizational structure and technology. The current capabilities of the company revolve around coating and adhesion. Hence, innovating the coating applications presents itself as a candidate under the name 'Personal Hygiene Space' (Lee and Abu Ali, 2010). Adaptations to the context vary along individual/personal spaces such as wound treatment, personal protection and food hygiene. Protection and hygiene can be secured by using UV, wipe-on, soak, sleeve-in or spray applications (Figure 31: vertical axis).

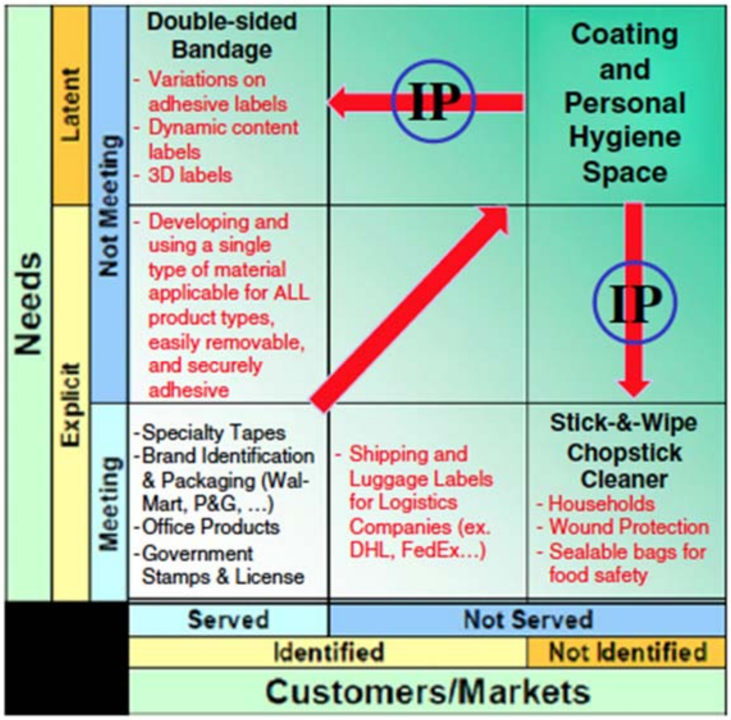


Figure 31 – Innovation matrix example/illustration (Lee and Abu Ali, 2010)

Two application spaces, (home and dining at home) circled in Figure 32, were then assessed using the QFD tool to convey customer requirements into feasible decisions. As mentioned earlier applying the QFD methodology takes place twice (Figure 33), once considering the voice of the customer and once considering the voice of the company.

Following the innovation matrix and QFD-ASM, a dominant design has to merge. In the case's context, this was in form of the 'wipe-on' method as indicated by its respective score in the QFD analysis (Figure 33). For the dining space, a 'Stick and Wipe chopstick cleaner" was born as a solution and wound treatments at home discovered 'Double-sided bandage" as theirs. These two solutions are the final result of the practical example.

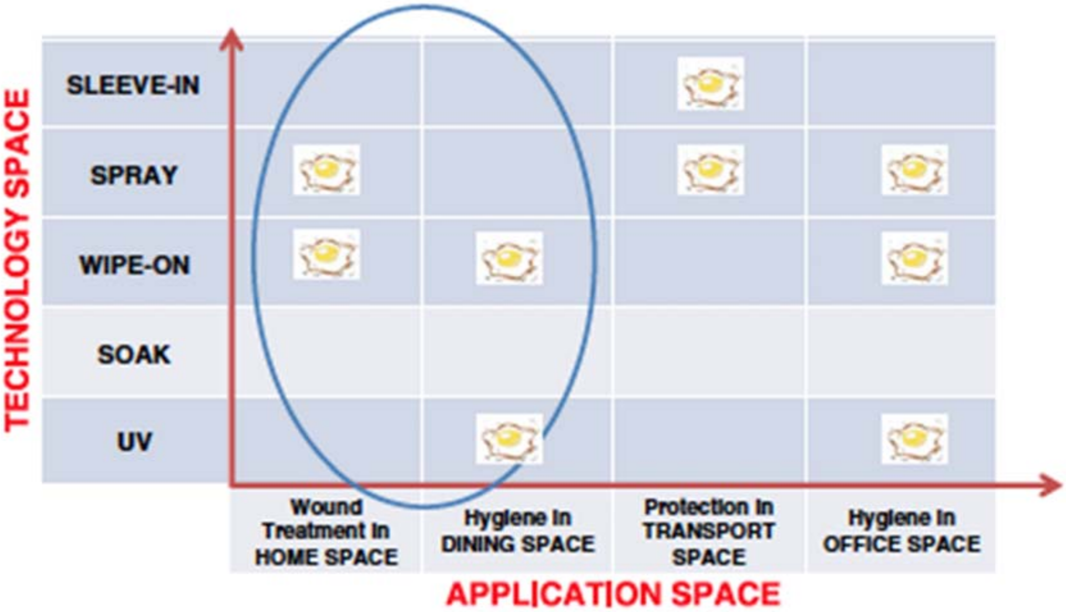
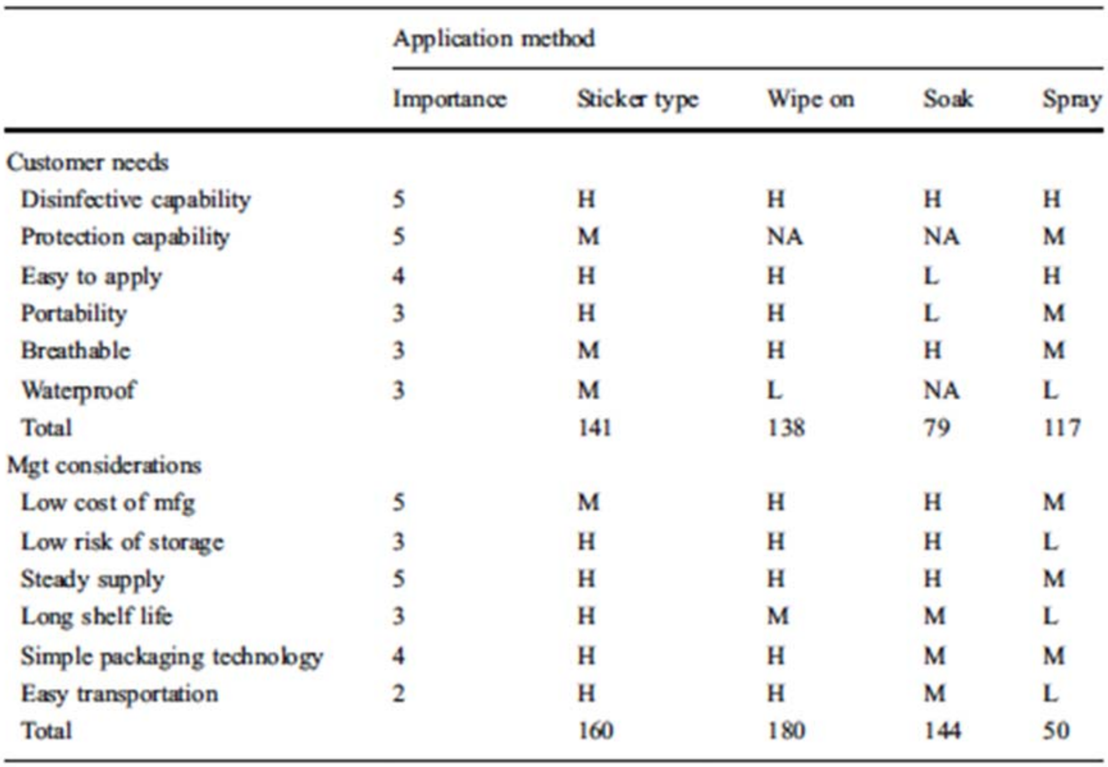


Figure 32 – ASM example (Lee and Abu Ali, 2011)



| | Application method | | | | |
|---|---|---|---|---|---|
| | Importance | Sticker type | Wipe on | Soak | Spray |
| Customer needs | | | | | |
| Disinfective capability | 5 | H | H | H | H |
| Protection capability | 5 | M | NA | NA | M |
| Easy to apply | 4 | H | H | L | H |
| Portability | 3 | H | H | L | M |
| Breathable | 3 | M | H | H | M |
| Waterproof | 3 | M | L | NA | L |
| Total | | 141 | 138 | 79 | 117 |
| Mgt considerations | | | | | |
| Low cost of mfg | 5 | M | H | H | M |
| Low risk of storage | 3 | H | H | H | L |
| Steady supply | 5 | H | H | H | M |
| Long shelf life | 3 | H | M | M | L |
| Simple packaging technology | 4 | H | H | M | M |
| Easy transportation | 2 | H | H | M | L |
| Total | | 160 | 180 | 144 | 50 |

Figure 33 – QFD example derived from ASM (Lee and Abu Ali, 2011)

### 3.1.3 Customization framework for road-mapping product-service integration

According to Geum et al. (2011), the drivers towards integrating products and service in holistic packages coincide with the manufacturing trend of converging technologies and industries using strategic innovation. The process of integration is three-phased (Figure 34) and addresses the methodology of adapting the product-service characteristics to the company's distinct situation. The first sequence outlines the technology's position as a catalyst for the product-service integration, thus shaping the architectural structure. The second handles the activities that must be performed to utilize the road-mapping methodology. The final stage concludes with the complete roadmap for P-S integration and realization.

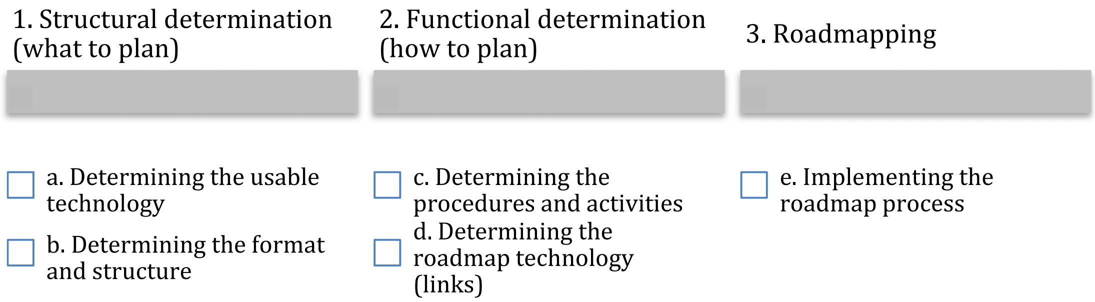
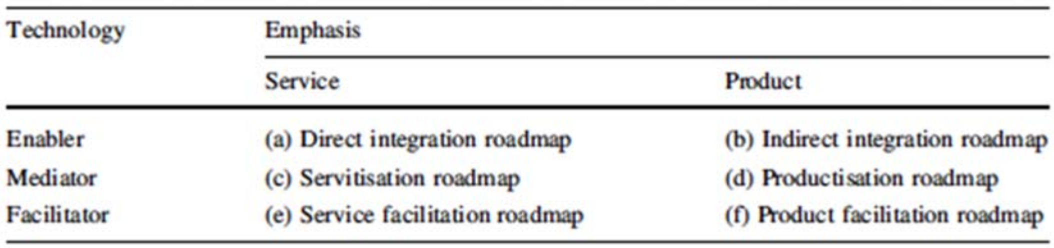


Figure 34 – Roadmap process approach (adapted from Geum et al. 2011)

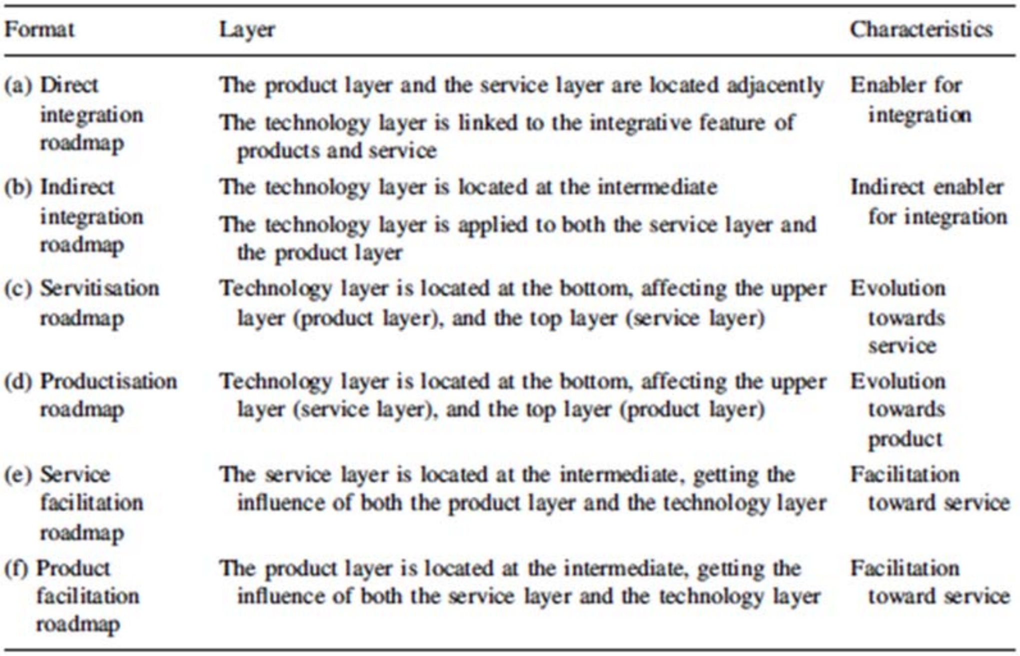
Structural determination entails two sub-activities as shown in Figure 34:

a. Determining the usable technology: the latter encompasses the product, the process and the management (Chadee and Pang, 2008). *"Technology is the 'know-how' or knowledge that improves our understanding about how to do things* (Capon and Glazer, 1987). *It allows better organization and management of products, improves communication and eases process customization in terms of direct/indirect integration and service/product facilitation* (Geum et al. 2011)*."*
b. Determining the format and structure: P-S integration can take place in different ways according to different structures and hierarchies based on the type of technology implemented and defined in the initial step. The latter can weigh more on the service component or on the product component, each with its specific enabler, mediator and facilitator (Figure 35).



| Technology | Emphasis | |
|---|---|---|
| | Service | Product |
| Enabler | (a) Direct integration roadmap | (b) Indirect integration roadmap |
| Mediator | (c) Servitisation roadmap | (d) Productisation roadmap |
| Facilitator | (e) Service facilitation roadmap | (f) Product facilitation roadmap |

Figure 35 – Format and structure (Geum et al. 2011)



| Format | Layer | Characteristics |
|---|---|---|
| (a) Direct integration roadmap | The product layer and the service layer are located adjacently<br>The technology layer is linked to the integrative feature of products and service | Enabler for integration |
| (b) Indirect integration roadmap | The technology layer is located at the intermediate<br>The technology layer is applied to both the service layer and the product layer | Indirect enabler for integration |
| (c) Servitisation roadmap | Technology layer is located at the bottom, affecting the upper layer (product layer), and the top layer (service layer) | Evolution towards service |
| (d) Productisation roadmap | Technology layer is located at the bottom, affecting the upper layer (service layer), and the top layer (product layer) | Evolution towards product |
| (e) Service facilitation roadmap | The service layer is located at the intermediate, getting the influence of both the product layer and the technology layer | Facilitation toward service |
| (f) Product facilitation roadmap | The product layer is located at the intermediate, getting the influence of both the service layer and the technology layer | Facilitation toward service |

Figure 35 – Format and structure (cont’d)

c. Determining the procedures and activities: having decided on the needed format and the enabling technology, the roadmap must have its features revealed with respect to its distinct type.

    i. Direct integration roadmap (a): product-service relations are quantified in the higher level of the roadmap and the P-S features’ associations with technology are shown in the lower level to show how the second can affect the integration process.

    ii. Indirect integration roadmap (b): relationships between technology and the P-S components have to been recognized first. Then, the integration takes place in coherence with the existing technological interface.

    iii. Servitization roadmap (c): technology and product relations come first and the service element is developed at a later stage. “*The result of the first relationship is reflected in the next analysis as technology-embedded products evolve to relevant services* (Geum et al. 2011).”

    iv. Productization roadmap (d): technology and service relations are primary and then the possible relationships with tangible products are explored.

    v. Service facilitation roadmap (e): technology and product are developed separately as any of those two layers can be the starting point of service provision. A second case would be if the focus eyes the integration period itself, then the service component can be the initial development sequence.

    vi. Product facilitation roadmap (f): technology and service tiers are planned before the product with emphasis on how these two layers can affect the product.

d. Determining the links (Figure 36): the fourth stage is selecting the optimal method for the P-S roadmap to pinpoint the impact and direction of the relationships combining the service, product and technology (Geum et al. 2010).
    i. The stepwise linking grid: is suggested in this study to identify the links between levels. The characteristics that can lead to integration are identified gradually from defining the P-S affiliation, then the integrated aspects' connections and technological resolution.
    ii. The combined linking grid: implemented to obtain integrated information from the stepwise linking grids. Its drive resembles that of a QFD matrix.
    iii. The evolutionary linking grid: applied when several linking grids upkeep the roadmap framework process. An input-output process succession is dominant as the result of the first grid is utilized as an input to the second grid, i.e. 1st grid relates to product-technology relations and 2nd grid relates to technology embedded products and services.
    iv. The independent linking grid: demonstrates the effects that independent components may have on each other (Figure 37) to classify the order of importance in identifying product, service and technology relationships.

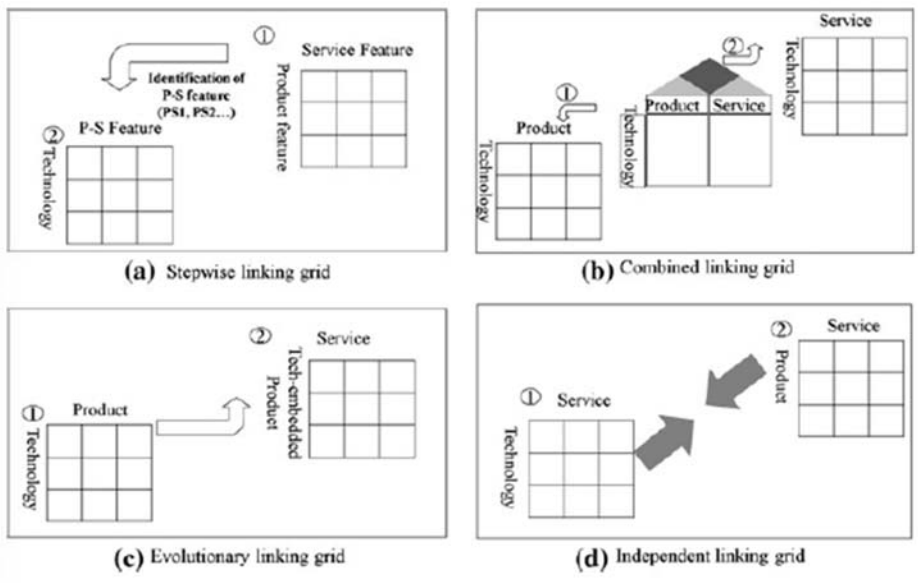
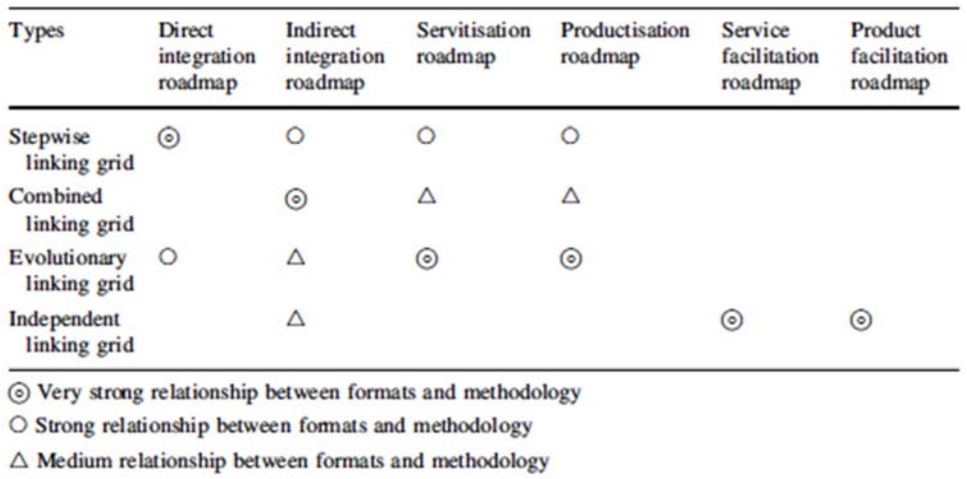


Figure 36 – Road-mapping approaches and technologies (Geum et al. 2011)



| Types | Direct integration roadmap | Indirect integration roadmap | Servitisation roadmap | Productisation roadmap | Service facilitation roadmap | Product facilitation roadmap |
|---|---|---|---|---|---|---|
| Stepwise linking grid | ◎ | ○ | ○ | ○ | | |
| Combined linking grid | | ◎ | △ | △ | | |
| Evolutionary linking grid | ○ | △ | ◎ | ◎ | | |
| Independent linking grid | | △ | | | ◎ | ◎ |

◎ Very strong relationship between formats and methodology
○ Strong relationship between formats and methodology
△ Medium relationship between formats and methodology

Figure 37 – Relation between roadmap methodologies and formats (Geum et al. 2011)

e. Implementing the roadmap process: the final phase regards linking assets and supplies to their business drivers to utilize market gaps. The approach requires analyzing the market (SWOT analysis, gaps, drivers), the product (concepts, impacts), the technology (solutions, effects) and the road mapping initiative (linking technology-based resources to prospects). After the realization of the roadmap, it has to be induced into the company’s culture, organization and operations (Gerdsri et al. 2009). Sustaining the roadmap’s results is the key point of the final phase to ensure its spread within the firm's personnel and promote future endeavors to increase profits and continuously update roadmaps accordingly.

### 3.1.4 Business model design methodology for innovative PSS

Focusing on the internal operations of the manufacturing company, its portfolio of activities and supporting hierarchy are key components to effectively capturing value from integrated product-service solutions (Lee et al. 2011). The latter are part of a business model that aims towards innovating existing ideas for competitive advantages, market leverage and additional income. The framework in this context provides strategic decisions on how to implement processes based on the firm's capabilities and resources. Linder and Cantrell (2000) define the business model framework as a merger of three main axes: perspectives, strategy and protocols.

Perspectives enclose the revenue model, customer segments, distribution channels, cost structure, partner networks, resources and client relationships. Each of these blocks can be altered and adjusted to its fitting context whether it is in a product-oriented solution, a usage-based offering or a functional result frame.

A strategy, embodied by the business model selection, is designed by the upper management tier to setup the reasoning scheme of the firm, which will be the basis of running operations. Protocols commonly referred to as tactics, present a set of standard elements to consider when implementing a model to guarantee credibility and feasibility (Table 10) (Lee et al. 2012).

Table 10 – Building blocks of strategies and associated protocols (adapted from Lee et al. 2011)

| | **Strategy** | **Protocol** |
|---|---|---|
| **Customer segment** | • Diversification<br>• NPD<br>• Segment penetration | • B2B, B2C, B2G<br>• Local, regional, national, multi, niche |
| **Customer relationship** | • Low cost access<br>• Free offering<br>• Economic advantages<br>• Awareness<br>• Education<br>• Customer participation | • Customer acquisition<br>• Client retention<br>• Transactions<br>• Relationship based |
| **Distribution channel** | • Experience building<br>• Vertical strategy<br>• Horizontal strategy<br>• Bundling/sharing | • Direct channel<br>• Indirect channel<br>• Internal, online, bundled |

| | | |
|---|---|---|
| | | Delivery |
| **Revenue model** | Conventional<br>Membership<br>Subscription<br>Free<br>Customer loyalty | Product<br>Service<br>Use<br>Functional result<br>Market |
| **Cost structure** | Outsourcing<br>Offshoring<br>Affiliations<br>Recycling/reusing<br>Modularization<br>Simplified VC | Activity drivers<br>Industrial drivers<br>Resource drivers<br>Activity and resource cost |
| **Resources** | Valuable<br>Rare<br>Non-substitutable | Humans<br>Equipment<br>Natural<br>Technology<br>Brand name<br>Consumer base |
| **Activity configuration** | Innovation<br>Lock-in<br>Efficiency | Administrative<br>Product based<br>Procurement<br>Logistics<br>Operations |
| **Partner network** | Vertical integration<br>Solution network<br>RandD<br>Flexible platform | Administration<br>Suppliers and distributors<br>Users<br>Rivals<br>Consultants |

Therefore, the first step would be match the related strategies and protocols to their according perspective (eight in total).

1. Revenue model: what type and which innovations will allow a company to reap profits from products and services. For instance, in a PSS context, a firm can indirectly receive money by emphasizing on its customer relationships, or advertisements, subsidizations, client retention, company and brand reputation etc. Examples of protocols would be the pricing mechanism, the price and the unit of payment (McGrath, 2010).
2. Cost structure: is vital to recognize all obvious and hidden costs to seek out breaks to reduce the latter. Strategies are most commonly based on outsourcing, reconfiguring activities, recycling/reusing, applying advanced production techniques such as lean and 6 sigma tools to minimize non-value-adding activities… The tactics include operational costs, acquisition costs, sunk costs and opportunity costs (Pettinger, 2012).
3. Customer segment: identifying customer groups is important to define the type of offerings to produce as well as analyze the potential of such

a solution. The strategy would thus be a mixture of the novelty of the PS offering and the acquisition of new clients. Protocols concern the classification of these segments in business-to-business, business-to-customer, business-to-government, local, regional etc.

4. Distribution channel: strategies to consider delivering the product or service vary depending on the company as well as the type of solution being offered. Integration within the plant's walls is subject to a rigorous analysis to improve the entire delivery process. As mentioned earlier, a supporting IT infrastructure is the cornerstone of such a transformation: flow optimization, channel access, ease of acquisition and recollection… The structure of the distribution channel is subject to protocols fluctuating according to the nature of the channel (direct, indirect, sharing) and depict the access point, use, disposal and types of communication contact, "*Moreover, protocols also described the value-added activity that is carried on throughout the channel in order to provide enhanced value to the customer* (Lee et al. 2011)."
5. Consumer relationship: retaining customers and gaining exposure is highly related to economic incentives and customer-oriented activities such as advertising, consultancy and education. Standardization plays a pivotal role in managing diversified products and services to strengthen the company's stance and operational strategies in this context. Objectives should be clearly defined, incorporating the client in value-creation and flexible transactions are the protocols in this sort of strategy.
6. Partner network: stakeholders perform different tasks to achieve different goals, converging all towards the efficient and effective operation of the model. Forming networks, assigning activities, outsourcing, internal and external cooperation have to be described to establish the strategy. In the latter, each network is a protocol in itself and each network involves a certain category of actors.
7. Activity design: the company may choose to design all its activities or opt for a more flexible kind of activity configuration, as focusing on core model activities and relying on specialized external companies for the others. Main activities include logistics, distribution, design, development and marketing. Secondary activities target customer management and administrative tasks. Generally, activity categories are

four when it comes to creating value: novelty, lock-in, complementarities and efficiency (Zott and Amit, 2010).

8. Resources: come in varied forms natural, human, IT, financial etc. Protocols outline the ones that can be used by the manufacturer to achieve competitiveness and enhance the overall value from the firm's point of view as well as the client's.

Designing the framework, after having defined the strategies and protocols, consists of five steps (Figure 38) that start by identifying the components of the product and service constituting the model whether the prior will be completely new or built on a pre-existing exemplar.

Second, the concept is designed by utilizing the strategies and protocols shown above. Utilizing the modular blocks facilitates the business model 'theming' (Lee et al. 2011).

The following stage specializes in the value related aspects of the model: value creation and value exchange: illustrating the resources' flow, stakeholders and PSS elements allow an easier description of the actors and their inter-relationships (similar to Customer Value Chain Analysis (CVCA), Donaldson et al. 2006). The value creation mechanism consists in identifying the actors and flows of the current model; applying the 'new' concept by adding PSS elements and required actors and finally applying the concept by adjusting the flows at hand.

In fourth comes the value proposition of the model which encloses three types of value: economic, ecological and experience (Cho et al. 2010) that arise from analyzing the value flows to concretize the stakeholders' benefits, value stream mapping of generic values and detailing the aspects of value present in the value proposition.

The ultimate step, entitled 'business model implementation', relates to the detailed activities fulfilling the value proposition according to the model's theme.

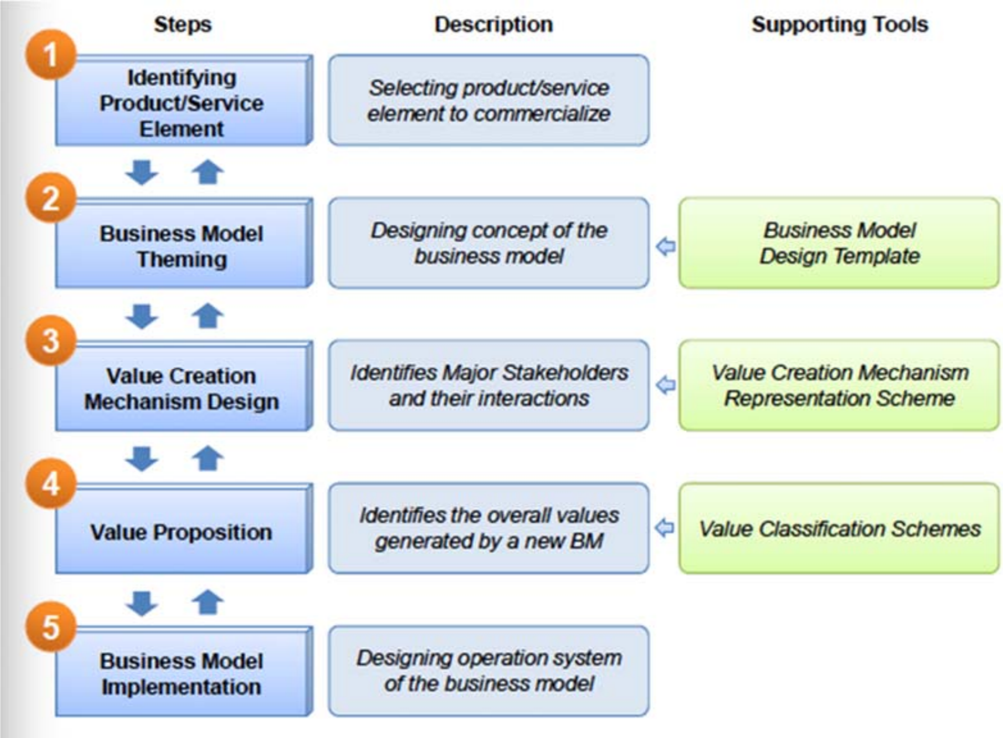


Figure 38 – Framework design steps (Lee et al. 2011)

### 3.1.5 Business Model Framework for PSS (BMFPSS)

Bonsfills (2012) presents the Business Model Framework (BMF) for PSS (BMFPSS), incorporating the essential elements of a product-service system as a guideline to strategically develop a PSS offering. Four elements differentiating structural features, yet all converging towards a sustainable result, are presented and detailed in the following (Figure 39).

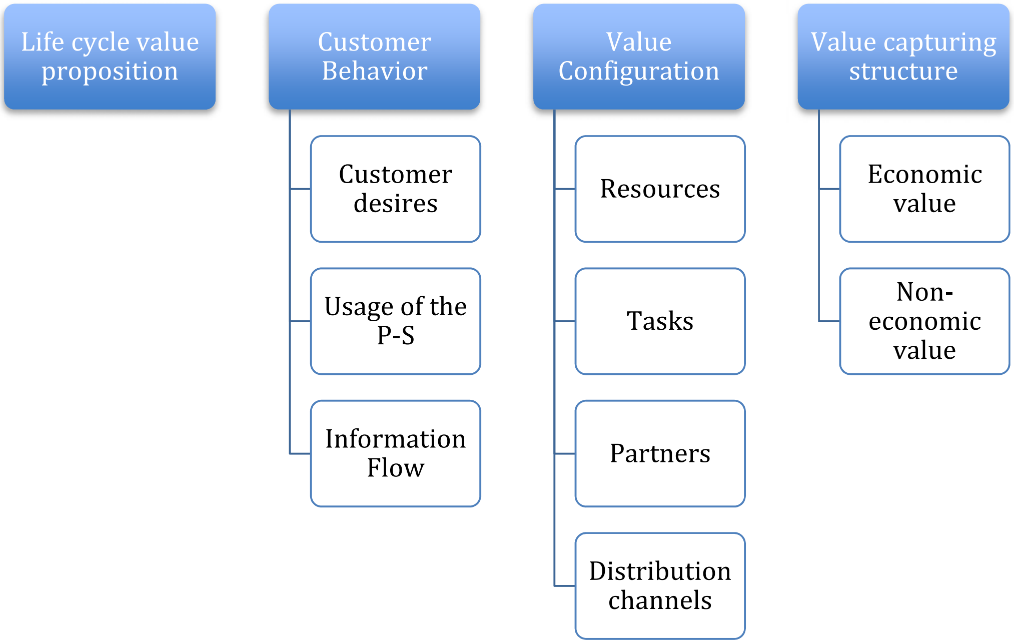


Figure 39 – Elements of the BMFPSS (adapted from Bonsfills, 2012)

<u>Life-cycle value proposition:</u> the conventional literature disregards the connection between the VP and LC considerations. However, in a PSS context, the VP is considered when designing the product's life cycle. As mentioned earlier, value in PSS is embodied in a holistic solution thus making all the life cycle stages containers of value. Moreover, a PSS is characterized by its adaptation to various and varying customer needs, thus the design, maintenance, repairs, upgrades and reuses are creators and holders of value.

<u>Customer behavior:</u> the consumer is at the center of a PSS offer from defining the needs, to being a vital part of the PSS's success or failure. Customer tastes and likings can only be truly grasped when PSS designers are in touch with the prior. This will also facilitate the manufacturer's role in identifying its market segments and allow reaching new customers by placing itself in the purchaser's shoes and feeling it what he feels when operating a P-S offering. The latter can be clarified by breaking down customer behavior into three subcategories:

- Customer desires: understanding the client's needs (present and future) is essential to allow a PSS to be versatile and dynamic enough to adjust to constantly changing customer interests, innovate instead of copying and identify then seal gaps that would translate into higher profits and better client relationships.

- Usage of the P-S: consumer behavior has a non-negligible impact on the life cycle phases of a product. Each client will be handling the PS in a different fashion than another. Therefore, each user will have a different effect and thus impact the LC differently.
- Information flow: important in the sense that marketing personnel are responsible for presenting the PSS in an attractive and appealing manner that would attract customers from one part, and strengthen communication between the consumer and the PSS provider on the other.

<u>Value configuration:</u> value is of no significance unless delivered to its receiving end. Value configuration is defined as the resources, tasks, partners and channels that allow the conveyance of value.

- Resources: the financial, human, natural… resources needed to elaborate a solution, create value and deliver it to its destined targets. These 'key' resources can be found within the company itself or outsourced if not.
- Tasks: utilizing the resources for the proper operation of the business model consists in 'key activities' that need to adapt to each situation (problem solving, FMEA, management etc.)
- Partners: PSS offerings are characterized by their holistic approach when delivering solutions. The latter is replicated in the supply chain organization where suppliers and distributors need to be part of the cultural change to maximize profits, minimize risks and block out competitors. This form of extended partnership benefits the customer by tying the connecting bonds with the manufacturer and building trust for a mutually beneficial future.
- Channels: logistics need to be accommodated to facilitate the delivery of value to the customer and have to be adapted to the life cycle phases of the PSS. Distribution and delivery and communication channels can be combined within a single entity (Bonsfills, 2012).

<u>Value-capturing structure:</u> "*just because a firm devises a strong value proposition and successfully creates and delivers that value does not mean it will earn superior returns, or even be viable* (Bonsfills, 2012)." Similarly, to the tangible and intangible aspects of PSS, value falls under two types: economic and non-economic.

- Economic value can be simplified as the difference between the profits made and the costs incurred to deliver the solution. Therefore, the profit and costing model need to be developed to define the profit margin by identifying the WTP and the pricing structure (pay per use, per allocated time, per unit…). As for costing, operation, manufacturing, delivery and related expenses need to be detailed to obtain a credible analysis and forecast of the expenses. In addition to economic terms, environmental and life cycle costing may come in handy when faced with certain legislative regulations i.e.: penal costs for greenhouse gas emissions surpassing governmental limits.
- Non-economic value represents social and ecological value that can be translated into income opportunities. Strengthened customer relationships, social status and enhanced brand name are examples of non-financial benefits.

### 3.1.6 Systematic design framework for PSS and its implementation

According to Kim et al. (2013) the elements making a typical PSS are a systematic (service) design including stakeholders, economic and ecological values, life-cycle evaluation, mapping the enabling activities and services, and identifying function sub-function relations.

<u>Systematic design:</u> This first part of the framework comprises four fragments regarding the service design process: modeling value, designing activities, service touch-point design and experience management (Kim et al. 2013).

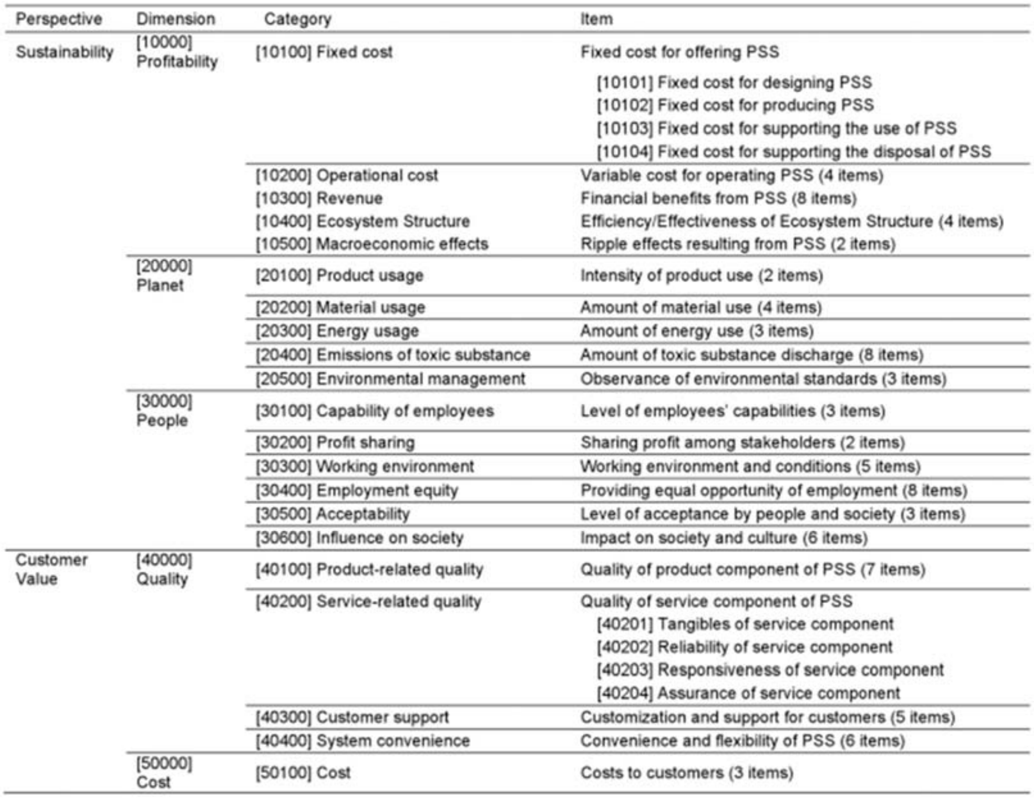
Value is to be perceived from an economical, ecological and customer experience point of view (Cho et al. 2010). Economic value is the needed return from sales after deducing costs and taxes to provide the solution: the value itself is projected as the amount of money the paying customer is willing to spend in return for a product, a service or an integrated product-service offer. Ecological or environmental value on the other hand is measured by the benefits/damages that the design would produce. PSS have long been associated with positive environmental effects compared to conventional methods, yet rebound effects are always present and a proper analysis should be carried out to minimize eco-drawbacks. Customer experience value discusses the client's interaction (also referred to as touchpoint) with the organization and its solution, when making the purchase as well as during the post-acquisition stage. It relates to the quantifiable aspects of the product and the subjective features depending on the consumer's perception, experience and judgment.

Activities need to tackle various elements of the supply chain as their consequences can affect preceding and following components thus leading to diversified consequences and therefore a different overall experience (Kim and Lee, 2011). "*Then stakeholder experiences are to be assessed and managed to close the loop so that designing of services can be evolutionally developed. The experience values include functional, social, emotional and epistemic values. Emotional values are further distinguished into active and reactive emotions. Active emotions such as happiness, anger, love, fun, control, and trust are of particular interests in service experience design. Those value themes and their attributes are associated with value driving activities in service design* (Kim et al. 2013)." Experience value denotes the user's attractiveness or averseness vis-à-vis his needs, requirements and criticism. Value is accordingly subject to two drivers, a pulling driver and a pushing one. The pulling plays on the pleasant desires of the client while the pushing describes the opposite (Kim and Lee, 2011; Kim et al. 2012).

Life-cycle evaluation: Kim et al. (2015) consider two perspectives for evaluating a PSS's lifecycle. The first concerns sustainability from an ecological, profitable and people-oriented point of view while the second relates to customer value in terms of quality and cost. Evaluation requires criterions, distinct methods and a procedure to analyze the PSS model in a most comprehensive manner. Figure 80 presents the criterions covered by the framework to assess the strengths and weaknesses while choosing the adequate and applicable modules to each case. As for the evaluation technique, it necessitates a visualization method first to understand the components and envisage their inter-relationships, i.e. PSS board (Lim et al. 2012). Kim and Yoon (2012) emphasize the use of a radar chart to assess the advantages and setbacks from a PSS model compared to a conventional product based model, or even amongst several PSS model suggestions to choose the most profitable one to develop. Obtaining feedback is the last step in order to implement a PSS improvement plan and details on which characteristic to improve or review have to be provided to continuously enhance the model.

Enabling activities and services: The service blueprint method, discussed earlier in this dissertation is utilized in the context of this framework to design and plan consumer activities and pinpoint the actors' activities related to the service in question. Existing tasks can be redesigned on one hand, and new activities can be implemented, all within the common frame of providing added value to the customer and manufacturer.

Functional relations: While developing PSS approaches, the latter's inclusion of the use stage of the solution is vital to involve customers and external actors in the development process. The firm's role, given its extension from production to production and use stages, provides added responsibility, notably on an ecological scale. Thus, it is the provider's obligation to dictate the functions and liabilities of the purchaser. *"With PSS approaches, knowledge and competencies can be aimed directly at the customer's activities, e.g. through the education and training of the customer. Value is attained through this close interaction with the customer during a product's use phase, as new insights about the product and a better understanding of customer value may be gained. If captured and integrated into the providing company's organization, these insights can be a vital source of competitive advantage* (Tan et al. 2007)*."* Once the latter is achieved, PSS can then propose new types of relationships and tamper with the actor network map while comparing scenarios with the existing ones that have by now been classified as stable, viable and thus credible enough to be used as a benchmark for analyzing how arranging new networks can give birth to new value to the client (Manzini et al. 2004) (Figure 40).



| Perspective | Dimension | Category | Item |
|---|---|---|---|
| Sustainability | [10000] Profitability | [10100] Fixed cost | Fixed cost for offering PSS<br>[10101] Fixed cost for designing PSS<br>[10102] Fixed cost for producing PSS<br>[10103] Fixed cost for supporting the use of PSS<br>[10104] Fixed cost for supporting the disposal of PSS |
| | | [10200] Operational cost | Variable cost for operating PSS (4 items) |
| | | [10300] Revenue | Financial benefits from PSS (8 items) |
| | | [10400] Ecosystem Structure | Efficiency/Effectiveness of Ecosystem Structure (4 items) |
| | | [10500] Macroeconomic effects | Ripple effects resulting from PSS (2 items) |
| | [20000] Planet | [20100] Product usage | Intensity of product use (2 items) |
| | | [20200] Material usage | Amount of material use (4 items) |
| | | [20300] Energy usage | Amount of energy use (3 items) |
| | | [20400] Emissions of toxic substance | Amount of toxic substance discharge (8 items) |
| | | [20500] Environmental management | Observance of environmental standards (3 items) |
| | [30000] People | [30100] Capability of employees | Level of employees' capabilities (3 items) |
| | | [30200] Profit sharing | Sharing profit among stakeholders (2 items) |
| | | [30300] Working environment | Working environment and conditions (5 items) |
| | | [30400] Employment equity | Providing equal opportunity of employment (8 items) |
| | | [30500] Acceptability | Level of acceptance by people and society (3 items) |
| | | [30600] Influence on society | Impact on society and culture (6 items) |
| Customer Value | [40000] Quality | [40100] Product-related quality | Quality of product component of PSS (7 items) |
| | | [40200] Service-related quality | Quality of service component of PSS<br>[40201] Tangibles of service component<br>[40202] Reliability of service component<br>[40203] Responsiveness of service component<br>[40204] Assurance of service component |
| | | [40300] Customer support | Customization and support for customers (5 items) |
| | | [40400] System convenience | Convenience and flexibility of PSS (6 items) |
| | [50000] Cost | [50100] Cost | Costs to customers (3 items) |

Figure 40 – PSS evaluation criterions for sustainability and customer value (Kim et al. 2013)

### 3.1.7 A methodology for PSS development

According to Marques et al. 2013 the development of a PSS requires designing physical products and intangible services in parallel activities to define a reliable integrated product-service development scheme, aligned with the company's business model, culture, vision and goals. Such innovative strategies, focusing on service integration, require the definition of a new model, organizational changes, emphasized customer collaboration and accentuated sustainable quality (Tischner and Tukker, 2006; Aurich et al. 2006).

PSS development is a process ranging from the identification of the clients' needs, manufacturing the solution, marketing it, delivering it to its segment and retrieving the profits. Maussang et al. (2009) outlines service development as the following phases: identifying needs, feasibility analysis, concept development, modeling, realization and testing. Cooper (2006) on the other hand, summarizes product development as the compilation of needs' identification, assessing planning and customer requirements, conceptualization, initial design, prototyping and large-scale implementation.

The differences and resemblances lead to an integrated methodology framework comprising of four steps (Figure 41):

1. Organizational preparation
2. Planning
3. Design
4. Post-processing

Organizational preparation concerns the firm's adaptation to change its business model towards the integrated development of service and product components. It is a pre-design step during which the company's hierarchy is re-structured to adapt to the new approach: design processes will have to be rethought, design services and implementation should be reconsidered and modular processes introduced in order to sustain the 'mass-customization' criteria of PSS offerings.

Planning initiates by identifying an idea that could be a customer requirement or an innovation that could satisfy unmet/future demands. "*Typically, one starts by identifying needs and then develops ideas for the new PSS, on the basis of external and internal inputs, in order to define objectives that aim to represent lifecycle perspective. Internal inputs result from the customer needs and all the players involved in the value chain* (Marques et al. 2013)." Analyzing the former inputs is vital to visualize how the new offering will be added to the company's portfolio and how it will interact from a cost and benefit perspective. At an early stage, solutions are to be conceived vis-à-vis the technical capacities of the firm, consumer behavior is to be reported to the customer-oriented personnel through surveys, interviews and feedback, the solution should be evaluated and assessed relatively to customer desires and in the end business models should be adapted to fit the customer as well as the manufacturer's life cycle views.

Designing a PSS begins by evaluating the current resources and performances present on the factory floor. Concerning the product criteria, identifying the customer needs will help establish a concept to work on that meets functional and non-functional requirements (Marques et al. 2013). The selected concept would then go under a developing period for evaluation and validation. A preliminary design follows and the product starts to take shape where characteristics are specified and the assembly structure takes birth (technical specs, materials, suppliers, resources needed etc.). Prototyping the product is the logical sequence and if the model can be validated, it will go through production. Regarding the service part, a preliminary design and detailed design are needed analogously to the product axis of a PSS: an outline, eyeing state parameters, utilizing flow and scope models (Sakao and Shimomura, 2007). The final stage before approving the service model is testing it with selected customers to pursue improvements before the final launch.

Post-processing: the PS project team, after developing the solution, has to make sure that the manufacturing activities, resources and infrastructure are ready to produce the offering within the cost and time constraints and answering all customer demand. This stage of the framework concerns the finalization of the product in terms of production, marketing and validation. The outcome of the design now becomes a tangible part of the company's portfolio. The latter implies providing the necessary documents and manual, passing safety checks and verifying the solution's capability of answering all the needed requirements. In some cases, services can be outsourced, as mentioned earlier, and thus those third parties will also require proper training regarding the appropriate use and implementation of the PS solution. Technological characteristics are required to ensure a comprehensive level of integration between the provider, the client and the outsourced service provider (Marques et al. 2013).

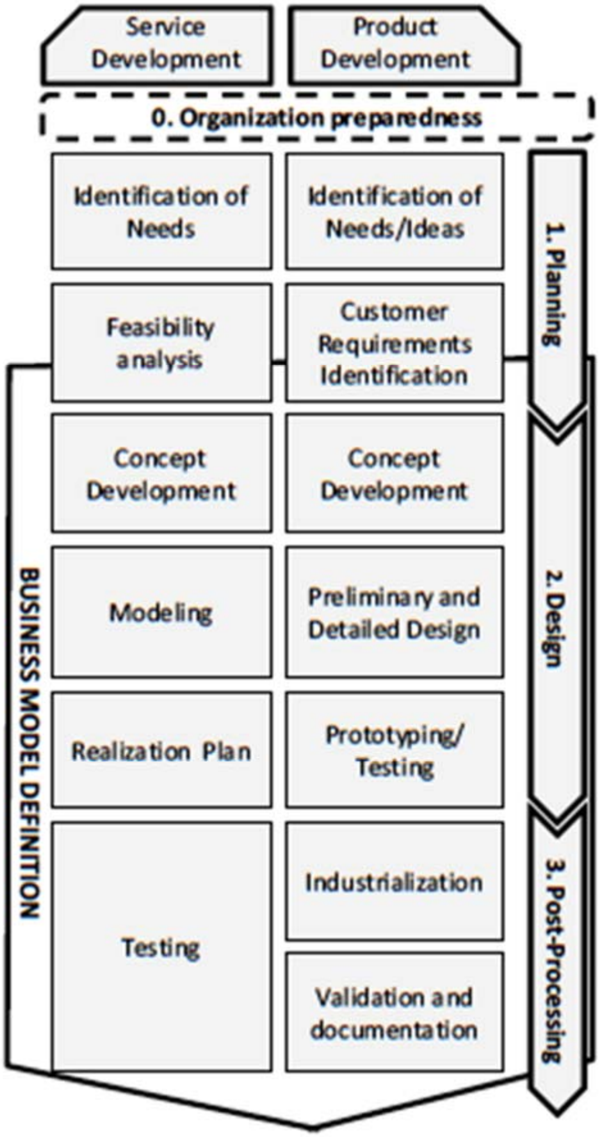


Figure 41 – Proposed framework for PSS development (adapted from Marques et al. 2013)

The following, presents an example extracted from Marques et al. (2013) on the framework above, regarding the development of a "Mobile Care Vehicle (MCV)" under the supervision of Volkswagen.

1. Organizational preparation: the MCV has a purpose of providing service to distant and isolated clients needing their payments to be processed, licenses to be handled and manage municipal related affairs. The concept behind the MCV lies in decentralizing services and personalizing them in order to adapt to each customer's requirements. "*Thus, both two entities defined the product-service concept. VW Autoeuropa*

*supplied the vehicle and Autovision, recognizing the importance of incorporating external design competencies, acted as a project integrator, assuming the management role in the all project, incorporating in the product VW MPV, the design changes executed by the Engineering Center for Automobile Industry (CEIIA), assembling and finishing the product with its integrated services. Several meetings and workshops were performed between the stakeholders and a detailed project plan was prepared* (Marques et al. 2013)."

2. Planning: identifying the clients' needs from a product and service's point of view make up the initial phase of the design. A service desk to process the requests will have to be fitted within the MCV, as well as two spaces for the operator and customer to process the latter's application. The common services were identified via consumer surveys and obtain feedbacks, based on which the required infrastructure was acknowledged (internet connection, fill-out form, printer, laptop etc.) and the training the operating personnel should follow (key issues, competences etc.). The vehicle thus constitutes the tangible product, and the services are equally defined up to a certain level of customization.
3. Design: based on the planning stage's outcomes, the functions were identified and alternatives were brainstormed to evaluate the most adequate design of the MCV: how the interior should be shaped, what materials to use, how can the interactions be simplified etc. The design eventually took birth as follows: A diesel powered vehicle, two rotary seats, back-up battery, 230V power sockets, lighting with a 300 lux output (Marques et al. 2013).
4. Post-processing: this ultimate stage handled testing the design by setting up several stopping points and was applied to a limited segment of householders in several regions and utilizing real-life circumstances.

To conclude this framework, PSS frameworks are synonym to time exhausting but of high-relevance as they provide a formal and standardized path to incur innovation with a key feature in mind that the more time spent at the beginning, the less adaptations will be required further on in terms of customer-personalization and service association. Marques et al. (2013) diagnose their methodology as beneficial in accurate definition of services and reduced marketing times.

### 3.1.8 Canvas Business Model framework

This high-level framework is based on the Canvas Business Model (CBMo) to analyze the requirements and characteristics for PSS adoption. A business model gives birth to practices that allow a company to smoothly shift from a current way of doing business to a newer one (Osterwalder and Pigneur, 2010; Barquet et al. 2013): in the case of this dissertation the shift is towards product-service systems. Nine elements constitute this framework (Figure 42):

1. Market segments: the target of the company.
2. Value proposition.
3. Distribution channels: the company-customer interface.
4. Client relationships: relationships between the company and the consumer.
5. Revenue streams: profit gained from market segments.
6. Key resources: supplies needed to deliver solutions.
7. Key activities: tasks realized to offer and deliver the elements above.
8. Key partners: suppliers and distributors that support the supply chain.
9. Cost structure: the model's costs.

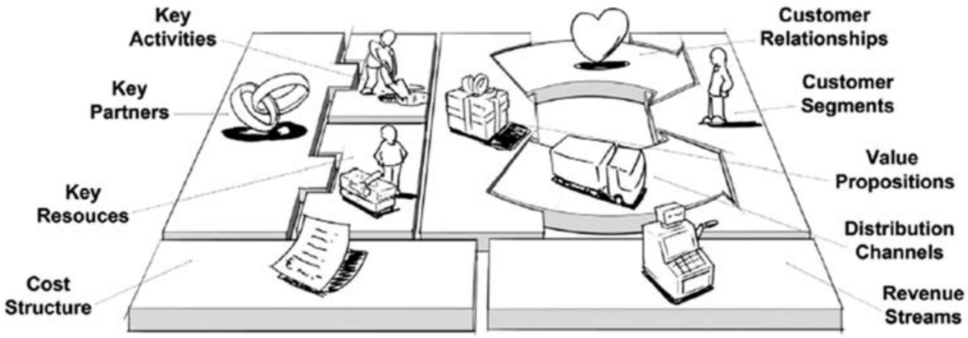


Figure 42 – The nine elements of the CBMo (Osterwalder and Pigneur, 2010)

The framework itself comprises three main axes: the business context, PSS types and PSS characteristics (Barquet et al. 2013). The first consists in evaluating the current model to see its capability of meeting PSS requirements and the internal and external obstacles that may arise. The second fulfills an identification technique between the model and the characteristics. The last tackles the detailed features needed to design, develop and offer an integrated solution to the customer.

**The business context:** Before choosing the type of PSS and defining the PSS characteristics to be considered, a company needs to understand its business situation and forecast how it should work after the implementation of PSS.

Adaptation to the current business is most advised since it would allow benchmarking against the existing solution to foresee the obstacles, costs and benefits that a firm may encounter. In some cases, the company may seek new openings to implement PSS versus morphing the existing model (Mont, 2004).

**The PSS types:** three main categories are defined as product-oriented, use-oriented and result-oriented and eight sub-categories within the three can also be perceived (Figure 1). A more detailed framework will be explicated in the following section.

**The PSS characteristics**: described as the subsequent by Barquet et al. (2013).

1. *"Value propositions: relates to the value provided by the integration of products and services. Examples of value are as follows: lower responsibility for product lifecycle; functional guarantee* (Isaksson et al. 2009)*; and reduced cost of manufacturing operations when the client is another company, since the PSS provider may be responsible for services such as maintenance and repair* (Alonso-Rasgado et al. 2004)*. Customization can also be a value proposition, since PSS enables the combination of product and service elements* (Tukker and Tischner, 2006)*. These perspectives of value indicate the shift from traditional products to PSS, which does not have embedded value, but creates it by enhancing the customers' satisfaction* (Tan, 2010)*. Stakeholders notice differently the value, depending of their roles, responsibilities and product experience. For example, the perception of a product value changes when it is sold or leased, as does the trade-off between incurred costs and liabilities for the customer* (Fishbein et al 2000)*. A particular perspective is the value of the relationship with customers during the role lifecycle of products* (Tan, 2010; Wise and Baumgartner, 1999)*. Finally, value has also a subjective dimension, for example, trust, commitment and attraction* (Grönroos, 2011).
2. *Customer segments: indicates the presence of different target groups with distinct ideas about product ownership* (Tukker and Tischner, 2006)*, caused by cultural and regional differences and sets of consumer habits, behavior and values* (Manzini and Vezzoli, 2003)*. A common option to define the customer base is to consider different types of user behavior, since PSS involves changes in ownership, responsibility, availability and cost* (Matzen, 2009).
3. *Distribution channels: sales and retail areas should promote the PSS offer, making it more attractive than a product-based option* (Tukker and Tischner, 2006)*. The adoption of PSS often requires training of the retail and sales staff, as well as other changes* (Mont, 2004)*. Another important aspect is to "sell the*

*idea" through marketing campaigns* (Tukker and Tischner, 2006) *that highlights the advantages of PSS* (Mont, 2004).

4. *Customer relationships: involves the creation of added value and its delivery through direct relations and intensified contacts with customers (Mont, 2004). This enables the development of long-term relationships, instead of short-term and transaction-based relationships typical of the traditional "product sale" context* (Mont, 2004; Williams, 2006). *The "relational" path can be achieved by building closer relationships with customers through increased operational links, information exchange, legal ties and the establishment of cooperative rules* (Matthyssens and Vandenbempt, 2010).
5. *Revenue streams: PSS can bring opportunities for augmenting companies' revenue through the enlargement of functions offered by the PSS provider* (Mont, 2002). *Instead of one-off payments, companies can structure their sales to customers in different ways* (Tan, 2010). *The long-term nature of the relationship between a PSS provider and its clients implies that companies must create new revenue models based on performance-based pricing* (Matthyssens and Vandenbempt, 2010). *However, in a network, i.e., when more than one company is involved, revenue distribution must be well managed to avoid misunderstandings. Payment may be based on the availability of the product and/or service, on how often the product and/or service is used, on the end result of the use of products and/ or services, or even on collateral for other valuable entities* (Tan and Mcaloone, 2006). *Therefore, new earnings options based on the integration of products and service can be created* (Grönroos, 2011).
6. *Key resources: PSS providers must make considerable investments in human assets* (Tan and Mcaloone, 2006). *New competencies to deal with customers must be developed, people trained and sometimes additional personnel recruited* (Cook et al. 2006; Mont, 2004). *A fundamental shift is also required in the organizational culture and market engagement, which necessitates time and resources* (Cook et al. 2006; Tan and Mcaloone, 2006). *In addition, an efficient infrastructure is required for the cooperation between customers and suppliers* (Meier and Massberg, 2004).
7. *Key activities: PSS providers must focus on the key activities of their customers, rather than concentrating efforts on activities related to physical products. With PSS, a dependency is created between company's (providing) operations and customer's (receiving) activities. Even when the product delivers a core function, essential activities are performed before, during and after the product's usage phase* (Cook et al. 2006; Tan and McAloone, 2006). *In fact,*

*the most important activities take place during the usage phase, when PSS providers can monitor the product performance through sensor technologies and also. In this sense, they can identify when maintenance should be done, supplying preventive maintenance to clients* (Schuh et al. 2008, 2009). *Additionally, the integration of operations and activities must be managed carefully, both tactically and strategically, since business processes require a new orientation to support PSS* (Meier and Massberg, 2004). *An example of this is the decision about whether or not to integrate the new product development to the service development process* (Isaksson et al. 2009). *Further examples of activities and processes that PSS providers should address are: order taking, deliveries, installing, maintenance, invoicing, complaints handling and service recovery. Correspondingly, order making, storage, installing, using, maintaining, paying and cost control, and resolving problems are examples of customer's activities to be incorporated by the PSS provider* (Grönroos, 2011).

8. *Key partners: the proposition of value through products and services embraces a complex network of suppliers and competencies* (Tan, 2010). *The establishment of a PSS network requires the identification of actors and of the core competencies they can provide* (Mont, 2002). *Furthermore, when designing partnerships, it is important to specify each partner's value throughout the product lifecycle* (Sakao et al. 2009a). *In this sense, the scope of the relationship between the manufacturer and the PSS network affects the PSS lifecycle and customer's activities* (Mont, 2004; Tan, 2010).
9. *Cost structure: cost structure management and price definition are challenges to the success of PSS* (Sundin et al. 2009). *The new logic of value creation requires new value-based pricing models, which include products and their associated services* (Grönroos, 2011). *Financial and accounting practices need adaptations, since the time scale of financial flows changes considerably from an almost immediate return of capital to an extended usage period* (Mont, 2004). *This means that the PSS provider must have the financial resources or receive support from its financing partners to bridge this period* (Mont, 2002). *In other words, when function is sold rather than ownership cost structures should be arranged to support a new demand of cash flow. In PSS, the payback period of the value delivered is often longer than the payback period of physical product sales."*

The framework, after defining the three main points (business context, PSS types and PSS characteristics) can be seen in Figure 43 below.

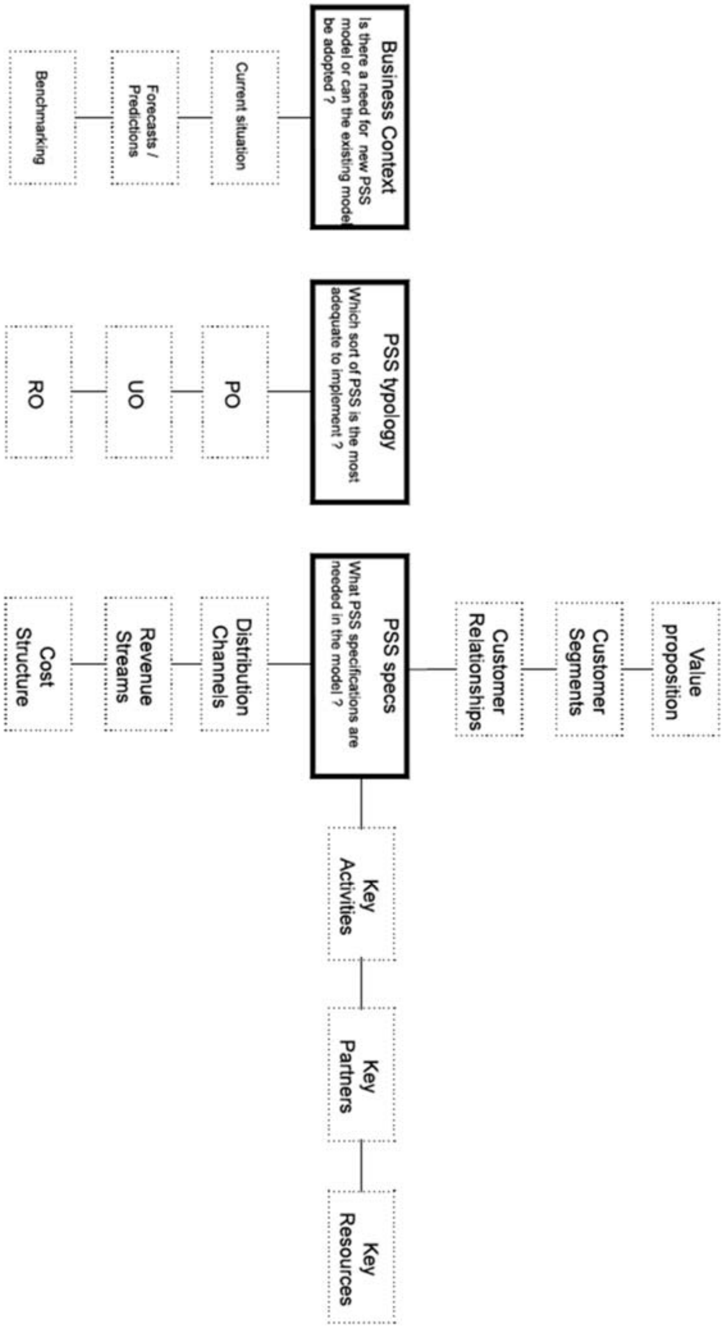


Figure 43 – Canvas business model framework

### 3.1.9 A practical design framework

Regarding PSS models, three main categories can be differentiated as being purely product related (PO), purely service related (RO), and a mix of product and services (UO) (Tran and Park, 2014).

Product oriented offerings rely on the physical product to provide the core value and services are value-additives. Use-oriented solutions consist of partial dependence on products and partial dependence on services with the ratio conditional to the PSS solution in question. As for result-oriented PSS, the customer is asking for a service/result to be achieved: the service provider is the sole actor responsible for choosing and implementing the adequate service, with a product considered as a means to fulfill that service. Based on these distinctions, product and service design priorities vary according to the PSS model adopted: in PO models, product development precedes service development while in RO models, service development is prioritized and in UO offers service and product development are subject to the ratio of reliance on the product or the service.

Based on the sections discussed above and earlier, regarding PSS models, actors' involvement, product lifecycles, stakeholders, consumer activities and customer relationships, a design framework can be conceived according to Tran and Park (2014) as seen in Table 11 and Figure 44.

The design steps enumerated from 1 to 7 in Table 11 are shown as the key steps in Figure 44 (schematic). In each step, design activities occur and need to be defined accordingly and the stakeholders' involvements also need to be described to verify the validity of the design step in consideration.

The diamond shaped figures in Figure 44 represent the tollgates/checkpoints G1-2-3-4 present in Table 11.

The arrows represent the sequential order to follow.

The feedback loop represents the most optimal case where the products at the end-of-life stage would be re-integrated (cradle-to-cradle view) in a new PSS offering and would take part in a new solution thus reducing the amount of natural resources extracted.

Table 11 – Design framework (adapted from Tran and Park, 2014)

| Design Step | Design Activities | Stakeholder Involvement | Checkpoint |
|---|---|---|---|
| **1. PSS ideation** | • Opportunity scanning<br>• Business model<br>• PSS type and idea | • User: idea generation or evaluation<br>• Others: same as user | G1 – Validity of PSS ideas |
| **2. PSS planning** | • Resource allocation<br>• Team formation<br>• Market segmentation<br>• Scheduling | • User: PSS portfolio evaluation<br>• Supplier: support | G2 – Feasibility of the PSS plan |
| **3. Requirement Analysis** | • Identifying needs<br>• Analyzing needs<br>• Benchmarks<br>• PSS specifications | • User: requirements and evaluation<br>• Others: specs evaluation | G31 – G32 – G33 – Consistency of PSS elements and structure |
| **4. Design and integration** | • Concept and detailed design<br>• Integration | • All actors: evaluation of the concept | G41 – G42 – G43 – Compatibility of the PSS elements |
| **5. Testing and refinement** | • Testing<br>• Feedback | • User: testing and feedback | PSS ready for full scale implementation |
| **6. Implementation** | • PSS delivery<br>• Usage<br>• Support | • User: utilization and feedback | Delivery channels ready |
| **7. Retirement and Disposal** | • PSS retirement / EOL<br>• Disposal | • User: disposal<br>• Provider: disposal plan | End of life. |

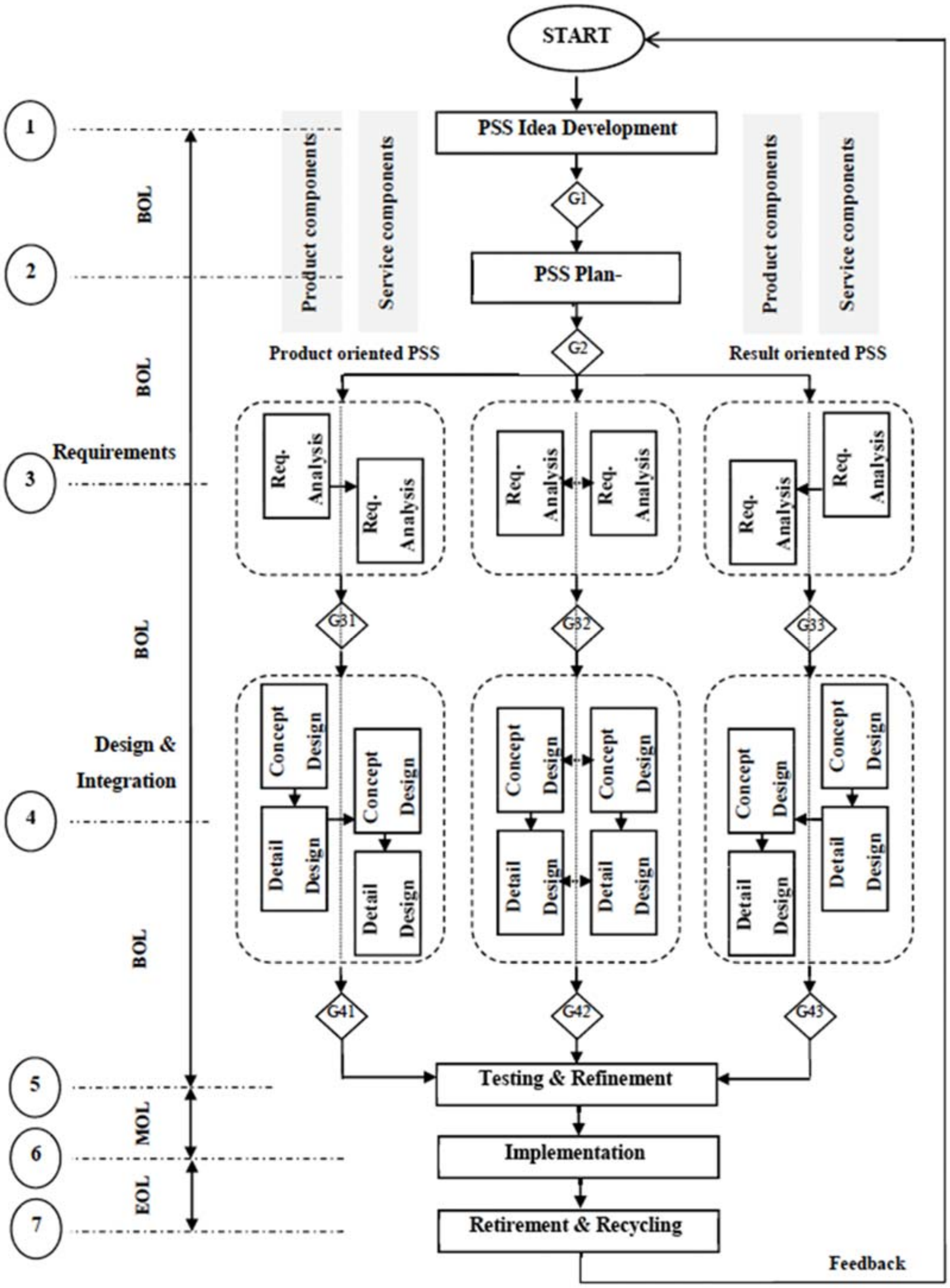


Figure 44 – Design framework representation (Tran and Park, 2014).

### 3.1.10 Generic Competitive Process framework

Reim et al. (2014) propose a framework based on the Generic Competitive Process framework established by Casadesus and Ricart (2010) to determine the value a firm can generate based on its operational and strategic tactics. A framework is thus needed to describe the design or architecture of the value creation, delivery and capture mechanism (Reim et al. 2014). Regardless the type of model implemented (PO, UO or RO), five generic categories highlight the main aspects of a PSS model: contracts, marketing, product and service design, sustainability and networks.

<u>Contracts:</u> used to portray the rights and responsibilities between the actors involved over a pre-defined period. PSS activities need to be clarified for all concerned parties and cover any miss happening that can occur to ensure consumer awareness and provider accountability. Formalized contracts are to be used with attention, as they tend to sway away from customization and thus customer-manufacturer can be jeopardized. Risks and liabilities have to be addressed on a case-by-case basis to bolster the relationship and preserve each end's right. "*To maximize the captured value of the PSS offer, it is essential to align the PSS business model categories with the contract-related aspects of responsibility and terms of agreement, contract formalization and complexity, and incentives and risk level* (Reim et al. 2014)". Activities and their intricate details must lead to a clear output in terms of level of service, payments, additional costs that may arise, availability, service costs etc. Moreover, in UO and RO model, product usage and result delivery are subject to consumer decisions; it is therefore mandatory to outline which decisions can be carried out by the customer and how the information exchange regarding the prior should take place. A risk adverse environment is implicitly present in PSS models as the deeper the shift is from product-based solutions to result oriented solutions, the more the provider is burdened with additional responsibilities that could result in excessive costs when delivering results. Table 12 represents a summary of the main contract highlights differentiated according to the PSS type applied.

Table 12 – Contract differentiation (adapted from Reim et al. 2014)

| | Responsibility and agreement terms | Formalization and complexity | Risk Level |
|---|---|---|---|
| **Product based** | Accountability for a defined service.<br>The agreement targets activities, compensation and info. | High formalization and low complexity | Reduced risks.<br>Services are harder to implement and generally a risk-adverse attitude is taken. |
| **Use based** | Accountability for availability.<br>The agreement eyes accessibility and supervising. | Medium formalization and complexity | Risks are at a medium level and reduced when responsibilities are clarified and distributed with mutual understanding. |
| **Result based** | Accountability for a result.<br>The agreement's main aim is the result's features | Low formalization and high complexity | High risks as the realization of the result lies solely within the solution provider's hands. |

<u>Marketing:</u> this aspect describes the PSS's vision vis-à-vis market and customer perspectives (Table 13). A proper marketing technique can allow entering a new consumer segment as well as offering simultaneously different customer groups customized value (Mont and Tukker, 2006). Services act as indirect marketing tools to bolster relationships with customers and help retain their loyalty, which implies a different marketing approach is to be followed in a PSS context. Three key points form the marketing pillar: communicating value, customer interaction and customer insights (Azarenko et al. 2009, Reim et al. 2014).

Communicating value revolves around differentiating the firm from its competitors such as emphasizing durability of the physical artifact, influencing the market towards ownerless satisfaction, targeting fewer tasks to be performed by the client etc… Such actions will result in higher market reach, higher sales, positive environmental effects, and in short will achieve the objectives the PSS was set to complete. Customer interactions have a tendency to increase proportionally to the extent of servitization the offering includes. For PO models, interactions take place on a 'pull' basis, i.e.: maintenance, repairs. Secondly, for UO offers, the service provider must ensure availability and usability, which cannot be realized without the customer's cooperation. Moreover, in general, UO users can always switch to alternate solution providers which burdens the company towards making additional efforts to bolster its relationships with its clients to preserve their loyalty. RO types require the highest level of interaction as the PSS provider is solely responsible for delivering value and meet the clients' satisfaction criteria (Kindstrom, 2010). Consumer and market insights consider "*the increased possibility of collecting 'product or service in use' data through increased interaction with customers* (Reim et al. 2014)." These perceptions concern the functionality of products and services, consumer activities, feedback and information, co-creation of value and innovative approaches.

Table 13 – Marketing components (adapted from Reim et al. 2014)

| | **Value communication** | **Client interaction** | **Insights** |
|---|---|---|---|
| **Product based** | Information related to functionality and durability | Relations established on 'pull / on demand' basis | Functionality, reparability and durability of the tangible product in addition to the efficiency of add-on services |
| **Use based** | Thriving towards a functional-ownerless economy while reaching out for new market niches | More frequent interactions to earn the client's trust. | Data collection regarding client habits and how well the design is homogenous with customer requirements |

| | | | |
|---|---|---|---|
| **Result based** | Reduced effort from the customer and additional responsibility for the PSS provider | High level of interaction to establish long-term trust | Holistic data collection and customer feedback to innovate methods to seal market gaps. |

Network: this area denotes the use of external partner affiliations to guarantee the successful outcome of a PSS application (Table 14). Some services cannot be handled by the primary company, whom therefore seeks exterior collaboration. Partners run through a selection process as a means of reducing risks when outsourcing in order to not jeopardize the outcomes. Extra effort intervenes in the form of collaboration and coordination based on the types of services proposed (Schuch et al. 2008). Partners, relationships and coordination are the three building blocks of the network tactic and need to be adapted adequately to each model.

In PO types, services are generally maintenance, repairs or take-back agreements: the concerned party for delivering the service is consequently one of the company's partners (Azarenko et al. 2009). Hence customer-company liaisons are subject to indirect interactions, which stresses the urge to secure a clear flow of information from the company to the customer and vice-versa. On the other hand, UO models are characterized with third-party providers for PSS delivery (Tukker, 2004). Profits are generated throughout the contracting period and not at the conventional sales point. Finally, in RO PSS the actors are in direct interaction, which requires a different approach than the preceding two sorts of PSS approaches.

Regarding relationships, it is preferable for external dealers and partners to deliver the service when considering PO or UO categories. Nonetheless, the manufacturer/provider should reinforce its contact with the sub dealers to ensure gaining proper feedback and insights towards future needs that may arise. Including those actors within the early phases of the PSS development procedure facilitates the establishment of the network (Maxwell et al. 2006). Meanwhile, in a RO nature, services are preferably offered to existing customers who are trustworthy to simplify supply chain management and enhance effectiveness by considering the client as a collaborating innovator (Baines et al. 2007, Shuh et al. 2008).

As for coordinating network activities, information sharing is vital for all three PSS types: online-based and network-based forms are of the most common ways for providers to obtain feedback for a better execution of the PSS.

Table 14 – Network components (adapted from Reim et al. 2014)

| | Partners | Relationships | Coordination |
|---|---|---|---|
| **Product based** | Dealers are catalyzers in the manufacturer-customer relation | Sub-dealers handle relationships. So, manufacturers need to have reliable bonds with those parties | Activity coordination while keeping note of standardization and legal measures |
| **Use based** | 3rd party providers | Dealers and partners assist in delivering the service. Manufacturers should have strong relationships with the latter | Coordinating tasks with the actors involved |
| **Result based** | Direct contact with the customer and 3rd party interventions are limited | Vertical integration and trust-built relationships are vital for success | Implementing new ways of collaboration and strengthening personal communication |

<u>Product and Service design:</u> services are always varied depending on the type of PSS implemented and technological advances offer new types of products. To meet the design requirements of product and service features, product and service characteristics will have to be aligned and converge towards an integrated P-S design. Likewise, improved customer relationships will facilitate the design path to deliver customized value adapted to their needs while achieving functionality and customization. The first part considers seeks outs ways to increase value from a consumer's point of view. In PO business models, serviceability, reparability, modularity, supportability and

maintainability are the focus areas of functionality; while in UO systems, usability, upgradability and availability are the lone liabilities of the provider as well as the paying customer. However, the biggest room for breakthroughs lie within the field RO structures: delivering value in a most efficient and effective manner is the PSS provider's main task and thus this means the latter has all the interest and benefits to reap in optimizing design, development and implementation.

Customization on the other hand mainly requires adapting an offering to specific and personified needs. For PO services, customization is limited, in UO types services can be customized to fit large client categories while in RO models, customization is at its highest due its integration with consumer operations. Furthermore, decentralization and flexibility become vital parts of a firm's operations (Table 15) (Tukker, 2004, Azarenko et al. 2009).

Table 15 – Product and Service design (adapted from Reim et al. 2014)

| | **Functionality** | **Customization** |
|---|---|---|
| **Product based** | Maintainability, re/use-ability | Limited |
| **Use based** | Maintainability, durability, upgrades and service provision. | Customization applicable to large consumer groups |
| **Result based** | Large opportunities and flexibility | Highest degree of customization to address person by person needs |

<u>Sustainability:</u> this is a vital component of PSS models that seek out methods to decouple economic profit from material consumption to reach sustainable targets while offering products and services that satisfy given requirements and applications (Manzini and Vezzoli, 2002; Baines et al. 2007). Nonetheless, if not managed and addressed correctly, PSS can have 'rebound' effects and cause detrimental consequences from an ecological stance, leaving only economic profits as outcome. Consequently, integrating sustainability factors in the PSS early design stages with an aim of intensifying material usage and incorporating changes within the production process with a sustainable output in mind are vital to prevent 'rebounds' (Tukker, 2004, Tukker and Tischner,

2006). Drivers towards sustainability in a PSS context are legal and market conditions, greater value in business operations and innovative technologies/solutions (Maxwell et al. 2006; Kriston et al. 2010; Bocken et al. 2014). Each of the drivers differs according to the type of PSS implemented, nonetheless two general schemes can be classified as common to all schemes: resource utilization and the scope of innovation (Reim et al. 2014).

Resource utilization can be summed up as the maximized combination of efficiency and lifetime vis-à-vis a higher usage intensity to reduce the number of physical products employed. Regarding PO models, maintenance and information sharing are the key features as they inform about product performance and guide recycling/reuse strategies throughout efficient take-back arrangements (Tukker and Tischner, 2006). In UO structures, as stated earlier in this work, sustainability is optimal when prolonging the lifecycle of highly used products given precautions regarding careless consumer behavior which would lead to unwanted disadvantageous results. While in RO examples, where the manufacturer is the only accountable party for delivering a result, the enhanced resource utilization will lead to higher profits and better revenue generation.

The scope of innovation relates to the amount and range of innovation that can be used to improve solutions. In PO and UO configurations maintenance and remanufacturing are hot topics as well as incremental upgrades being add-ons to a constant product purpose (functionality, re-integration, innovative design etc. are examples of value-adding options). Whereas RO systems are more open to radical changes since delivering the solution lies solely within the provider's realm: the manufacturer is more motivated towards exploring new routes for the same result while improving the way resources are used. Table 16 summarizes the sustainability axis.

Table 16 – Sustainability tactic (adapted from Reim et al. 2014)

| | **Resource utilization** | **Scope of innovation** |
|---|---|---|
| **Product based** | Higher lifetime and better recycling/reuse/remanufacturing methods | Incremental innovation of the product, the associated service and the business model as a whole. |

| | | |
|---|---|---|
| **Use based** | Higher use intensity and minimizing risks of rebound effects | Incremental improvements similarly to product-based PSS |
| **Result based** | Maximizing resource utilization is of key interest for the provider | Radical innovations converging towards sustainability in all its three dimensions |

### 3.1.11 PSS Design Exploration Process

According to Morelli (2006), a PSS creates value as a result of shared objectives and scenarios between the stakeholders involved. Therefore, the design process according to the author relies on: identifying the actors involved in the PSS network, establishing the possible scenarios and eyeing the relationships between the participants, and representing the required physical items, service components, links and sequences (Figure 45). Morelli, (2006) addresses the topic by adopting a socio-technological approach to pinpoint the activities enclosed in the concerned PSS (Bijker, 1997). *"Technological artifacts and infrastructures often reveal the strong influence of the socio-technical culture of their designers/developers. Their cultural frames are intelligible through the physical and technological characteristics of the artifacts."*

Hereafter, the actors are mapped based on the relationships and technological dependencies that bind them. For the designers to engineer a PSS, the tangible product's elements have to be coupled with the new features a service incorporates, such as time, mindsets, social habits etc. An adequate tool would be the Integration Definition for Function modeling (IDEF0): *"IDEF0 is a modeling technique that allows for progressive detailing of the functions and actions in the system, while keeping the link between each element in the system* (Figure 46)*. The system is modeled as a series of boxes, representing a function of the system. Arrows entering the left side of the box are inputs. Inputs are transformed or consumed by the function to produce outputs. Arrows entering the box on the top are ''controls'' that specify the conditions required for the function to produce correct outputs. Arrows leaving a box on the right side are outputs, i.e. the data or objects produced by the function. Arrows connected to the bottom side of the box represent mechanisms, i.e. means that support the execution of the function or links between models or portions of the same model. Each of those boxes can be decomposed in a hierarchy of sub-boxes, which can be analyzed with the same logic* (Morelli, 2006)*".*

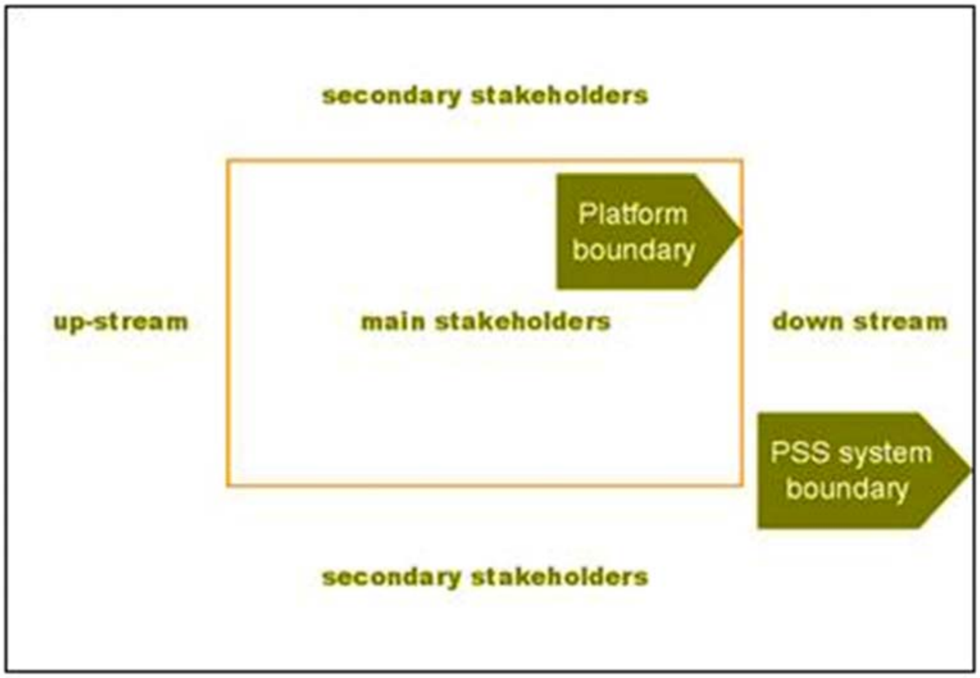


Figure 45 – Interaction map (Van Halen et al. 2005)

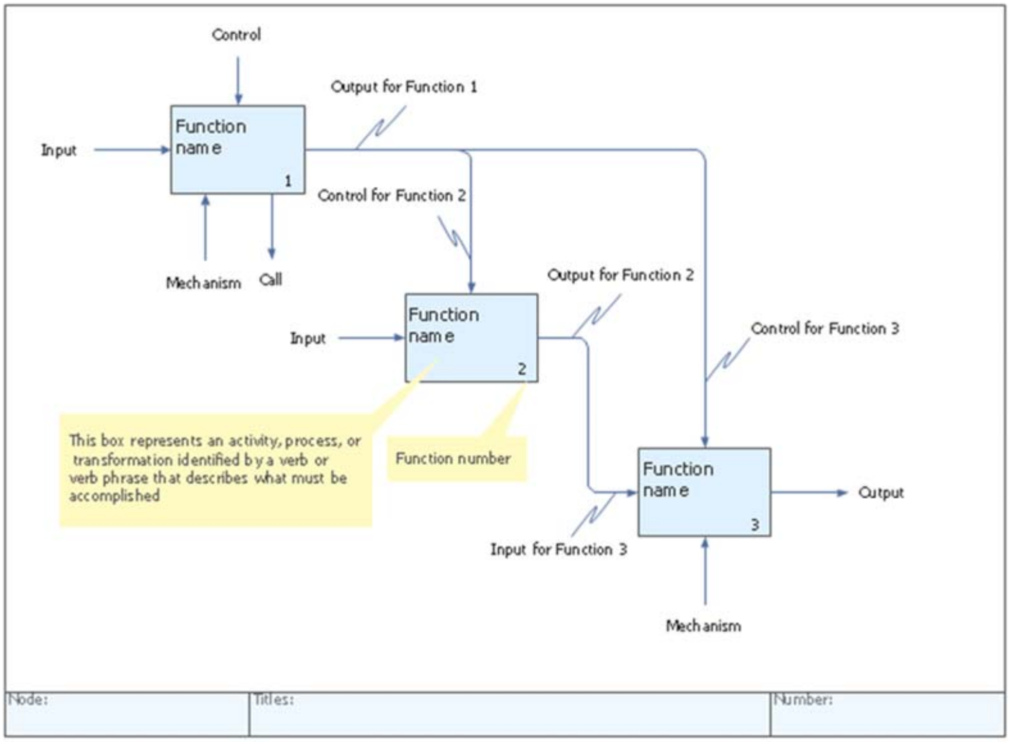


Figure 46 – IDEF0 template for PSS modeling (Morelli, 2006)

The tool is however limited to settings were customer reactions and states are predictable and subject to little variability. A more complex design embeds a higher level of unpredictability and a higher number of configurations, which can prove to be too copious to handle via this tool. To enhance the application of the IDEF0 tool, scenarios and use cases have to be envisaged to narrow the scope of the system and better delineate the needed activities to be carried out in a fashion similar to service blueprinting.

### 3.1.12 PSS Framework for intensified use

Amaya et al. (2014) provide an approach to design a PSS from an environmental perspective to emphasize its adoption rather than a conventional product-centered solution. The cornerstone of the design thus resides in the correlations between engineering decisions and ecological factors.

Gronroos (2011) targets the use phase of the product as the key objective of a PSS. Consequently, the design process will target the use phase and seek environmental enhancements deriving from the prior. In order to answer these peculiarities an extensive knowledge of the product and service components, the involved actors and interactions is required. Hence, robustness of the physical artifact is key: "*products in the end-of-use phase that are to be reused an unknown number of times must be solid enough to go through the recovery process and enter a new phase of use. Operating stability and robustness cause direct impacts on the quality of the product or system output* (Di Mascio, 2003; Geng et al. 2011; Amaya et al. 2014)." Hence, the design strategy is to increase the efficiency of the PSS and its adaptability to several use scenarios involving a customizable technological infrastructure to adapt the solution to each client's requirements. Amaya et al. (2014) seek to propose PSS solutions that improve PSS functionality and continuously deliver high-level quality throughout the artifact's lifespan and life cycle activities (Figure 47).

The use phase of the is outlined by three stages (Figures 47, 48):

- The standby stage where items are available and ready to be used. The standby time is '$t_S$'.
- The use stage where a user is using the product for a specific period of time '$t_U$'.
- The maintenance stage where maintenance occurs for a length of time '$t_M$' to ensure its readiness for another customer to use it. Normally, this falls under the preventive maintenance scheme and $\alpha$ depicts the maintenance ratio as the number of products on which maintenance is performed (Takata et al. 2004).

Manipulating the stages mentioned to propose different life cycle options requires integrating services in a strategic manner that allows comparing use circumstances and settings in order to select the least environmentally harming alternative. Supporting services include information interface, maintenance data, support centers etc. (Amaya et al. 2014).

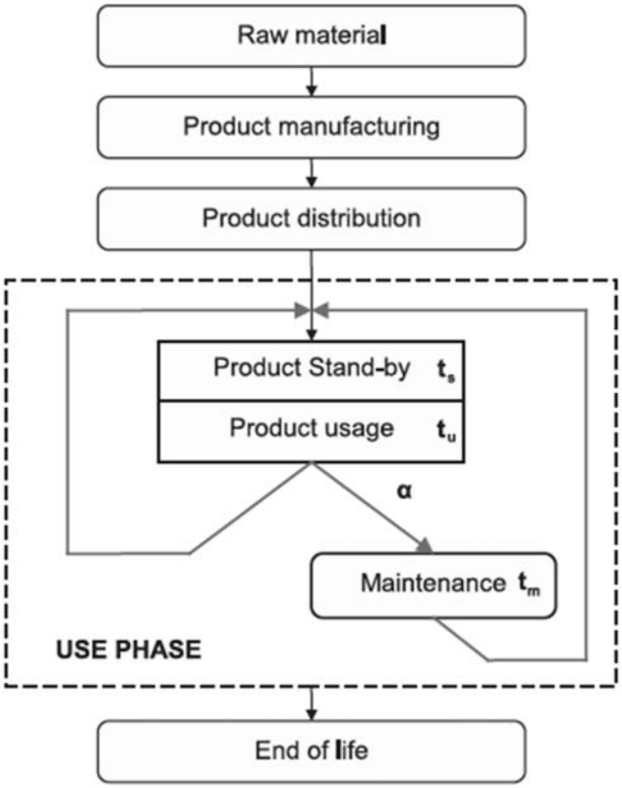


Figure 47 – Product life cycle in a PSS (Amaya et al. 2014)

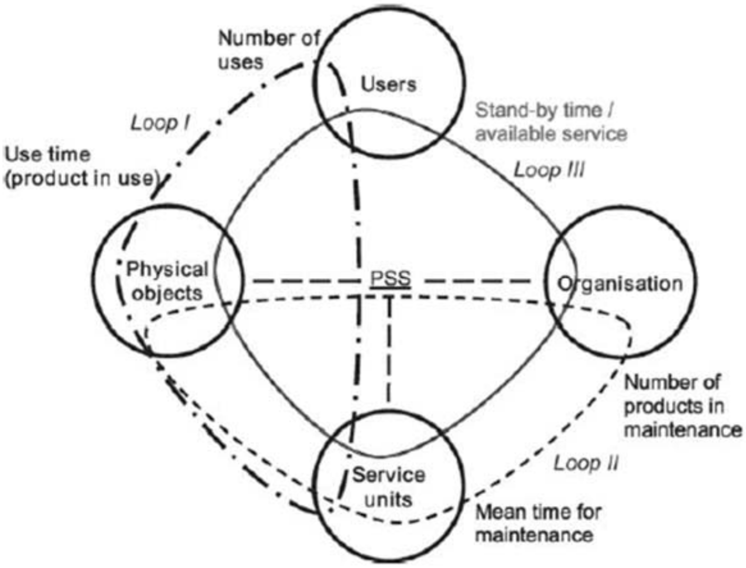


Figure 48 – PSS use phase (Amaya et al. 2014)

### 3.1.13 Kansei engineered PSS model

Carreira et al. (2013) target customer experience requirements to develop an integrated solution. Kansei engineering focuses on improving the customer's experience with products and/or services to a more pleasant state (Nagamachi, 1995). Fittingly to a PSS, a Kansei approach even when concerning a stand-alone product or service, requires a holistic stakeholder involvement. The latter led to a proposed PSS design process founded on four steps (Figure 49) (Carreira et al. 2013):

1. Choice of domain: customer feedback, questionnaires and interviews are employed to generate possible concepts to answer customer needs (Roy et al. 2009). The use of qualitative methods allows the customer to express his latent needs and requirements based on experience that cannot be constrained to numeric considerations (Sanden et al. 2006). Hence, a thorough grasp of the consumer's requirements is achieved.
2. Semantic and properties' description: once the domain is agreed on, engineers brainstorm the possible effects of the latter on the customer's impressions and emotions. Afterwards, the properties related to the domain are defined and each is assessed vis-à-vis customer perception to prioritize the properties. Novelties arise from innovative measures that experts evaluate. Quantitative tactics, such as the Likert scale are standardized to obtain credible results from the clients' assessments (Martilla and James, 1977).
3. Synthesis: the most relevant and important properties summarized as the cornerstone of the design to develop for the PSS solution. The engineers involved come from several organizations if required, with the collaboration of service providers, product suppliers and supporting actors. The extended approach helps include diversified opinions, of which some are more pertinent given the actor's close tie with the customer (i.e. versus an in-company technical designer). Additionally, simultaneous product-service improvements are implemented due to the collaboration, hence leading to a holistically amended and enriched PSS.
4. Validity testing: a batch of customers is exposed to the solution and each of them evaluates it according to specific Kansei semantics. "*Kansei engineering engages the experts and brings in the customer perspective through the whole design process, offering an approach to associate ERs with product or service properties* (Carreira et al. 2013)."

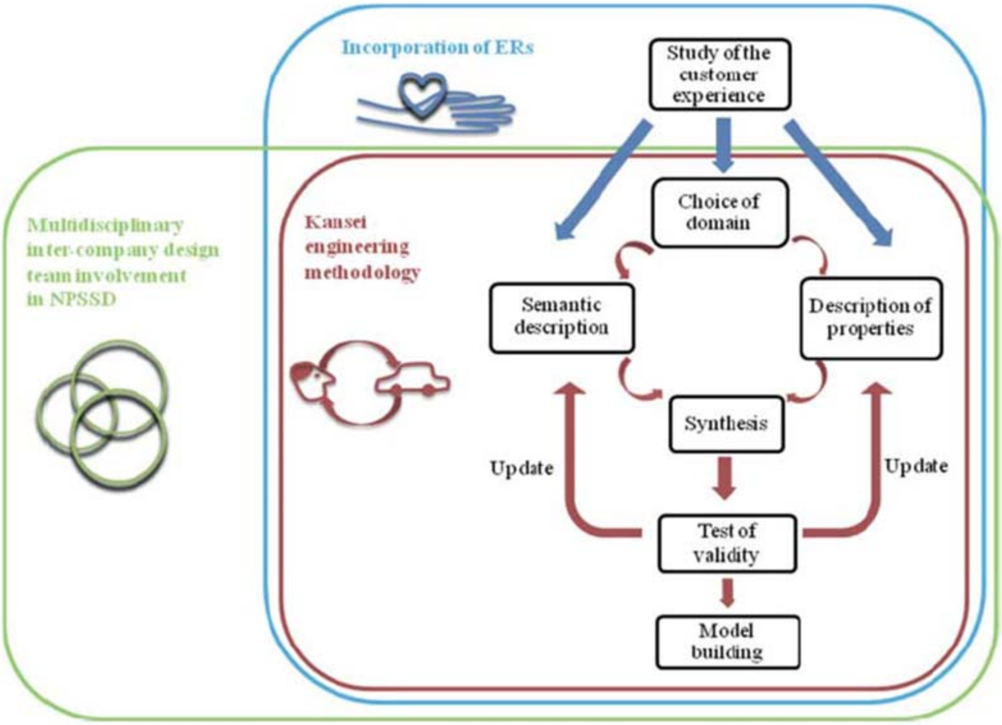


Figure 49 – PSS model based on the Kansei engineering method (Carreira et al. 2013)

### 3.1.14 Flexible PSS design framework

The approach by Zine et al. (2014) proposes the following pillars to successfully develop an integrated offering: understanding customer requirements, developing the system, validating the prior, and contract development. The sequences converge to build a PSS that is flexible, compatible with customer as well as the manufacturer's requirements, and harmonious with the firm's business model. In more detail, the process is as follows:

1. Defining stakeholders and their requirements in order to outline the required components to meet their desires (Figure 50). In a typical context: stakeholders can be end users, providers, suppliers, manufacturers and 3rd parties. Mapping out the actors clarifies the relationships that tie them, as well as the connections that may be established to deliver the service. As for requirements, customer surveys, interviews, feedbacks etc. aid designers in recognizing the market's needs. Additionally, categorizing the client sheds light on the level of quality required and market expectations.

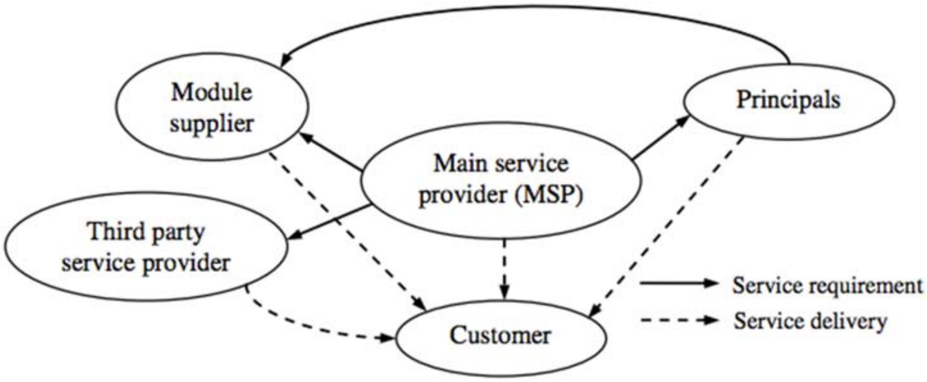


Figure 50 – Map of stakeholders and their inter-relationships

Once the participants and their needs are defined, the PSS elements to fulfill them are identified. "*The service requirements were gathered from the customers while the appropriate service components were identified, defined and elaborated based on the customers' service requirements, along with the value they would add to the customers. In the second round, the machine tool user industries were revisited to validate the service components identified and defined* (Zine et al. 2014)."

2. PSS development: portrayed in three sub-categories:
    a. Design: engineering the means to deliver the PSS elements. The second must be adapted to the clientele's requirements with adequate interaction mechanisms also referred to as touch-points (Kim et al. 2013); the added value to the customer can then be visualized (Table 17).

Table 17 – Description; comprising components and added value of PSS Activities *'from 1 to n, where n is the number of total activities included in the PSS* (adapted from Zine et al. 2014)

| Title | Component | Description | Value to customer |
|---|---|---|---|
| Activity (1) | Component of Activity (1) | Component (1) consists in… | Value that (1) provides to the user |
| … | … | … | … |
| Activity (n) | Component of Activity (n) | Component (n) consists in… | Value that (n) provides to the user |

    b. Specifying the service level: the level and frequency are to be agreed on with the stakeholders affected. These two aspects are substantial factors regarding the cost of the service mechanisms and components. Hence, a meticulous specification of the level is vital. *"A service level, in most of the services, is a commitment of the service provider to respond to the User's service demand within a certain time or it can be sometimes an agreeable quality level etc., as appropriate, with respect to a service component. For example, the service level in the case of corrective maintenance could be the 'response time' within which the Provider attends the service call (service demand)* (Zine et al. 2014)." The frequency on the other hand, refers to the rate of service demand fulfillment. Information exchange at this point is key for a proper assessment of the envisaged system and its constituents.
    c. Service blueprints: a visualization of the activities that come into play when a PSS is performed and the areas of interaction amongst the customers and providers.
    d. Determining the capabilities for service delivery: the services can be provided by the developer, the provider or a 3rd party. Thus, it is important to clarify which stakeholder possesses the optimal

competencies and is the most capable of delivering with the pre-determined required level. Table 18 illustrates a template for choosing the best delivery method.

Table 18 – Assessment of delivery actors and channels *'where the components and respective attributes are assigned from 1 to n'* (adapted from Zine et al. 2014)

| Component | Mechanism | Frequency | Manufacturer (A) | Main provider/supplier (B) | 3rd Party (C) | Lowest cost option |
|---|---|---|---|---|---|---|
| Component (1) | Mechanism (1) | Frequency (1) | Yes/No$^1$ | Yes/No$^1$ | Yes/No$^1$ | A$^1$, B$^1$ or C$^1$ |
| … | … | … | … | … | … | … |
| Component (n) | Mechanism (n) | Frequency (n) | Yes/No$^n$ | Yes/No$^n$ | Yes/No$^n$ | A$^n$, B$^n$ or C$^n$ |

   e. Product-Service integration: to ensure compatibility, the tangible and intangible elements should be designed in parallel with up to par interdepartmental communication to ensure homogeneity of the offering.

3. System Validation: prior to launch, a comprehensive review of the PSS is necessary to pinpoint possible improvement opportunities. Utilizing a blueprint/flow-chart methodology vis-à-vis an FMEA approach is a possibility for scrutinizing the design.
4. Contract development: in the context of their research, Zine et al. (2014) limited the contract development axis to the service features of the PSS. Assuming the physical product is under warranty with manufacturer and client responsibilities agreed on and concretized in a concrete agreement, the service contract development is arranged as follows:
   - *"When the User realizes a need for service, he/she would contact the Provider. Alternatively, the Provider on behalf of supplier may offer the services to the User at the time of selling the machines.*
   - *Provider thus appraises the User about the value added services and helps him/her choose the set of services from the available options.*
   - *User understands the offered services along with value addition benefits based on the services, and then chooses the services from the available options in terms of Service Components (SCos), Service*

*Mechanisms (SMs), Service Levels (SLs), and Service Frequency (SF).*

- *Based on the User's choice of SCo, SM, SL, and SF, the Provider will quote an offer of service cost.*
- *If the service cost offered by Provider is acceptable to the User, a 'contract' would take place between the User and the Provider about the service delivery. Otherwise the duo would have negotiation upon cost.*
- *If the cost were finalized after negotiation between the user and the provider, then the 'service contract' would take place. Otherwise, the process may end with a record as 'lost service opportunity' at the provider's end.*
- *If the service contract takes place, the service delivery would be executed based on terms of contract and 'service feedback' would be gathered by the provider. The process would end on termination of the service contract* (Zine et al. 2014).*"*

### 3.1.15 Integrated PSS model

The following model is founded on three visualizations: a product, a service, and an integrated view (Trevisan and Brissaud, 2016).

The product perception of a PSS is derived from Maussang et al. (2009)'s functional analysis approach where the problem is decomposed into functions resolved via FAST diagrams (Maussang et al. 2007). A service point of view employs service design tools such as the SB with specific adaptations to the setting in which it is employed to enable integrating the product with the mentioned service. The integrated view utilizes the IDEF0/SADT methodology for product-service integration. Trevisan and Brissaud (2016) develop a PSS from a 'structural organization' angle where the artifact and the service are part of an *"organizational entity that can be considered as a 'department' within a company."* Hence, arranging and categorizing the product and service components guide the path towards realizing the setout objectives. The problem and its solution constitute two design environments. The first utilizes a result model (Figure 51a) illustrating the desired interactions while the second adopts a structure model (Figure 51b) that portrays the system's sub-modules and its composition. *"The structure model then expresses the organization of the system boundaries that allow decomposing it into hierarchical levels. The resul model allows expressing the expected (inter)actions that provide value for the beneficiary. Links named 'design relations' must allow affecting the identified system* *structure to the expected result at each level of decomposition. Structural organization models* (Figure 51c) *are intermediary description that link the result to the structure models and that can be refined during the decomposition. The represent the 'sub-systems' interactions and then they are the basis for designers' negotiations about the fit of the structure with expected results* (Trevisan and Brissaud, 2016).*"*

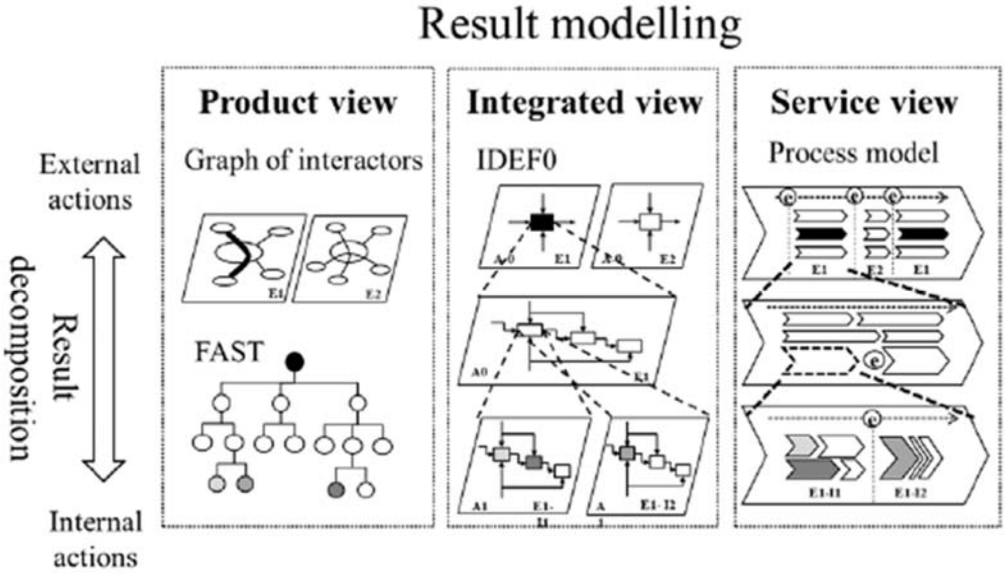


Figure 51a – The Result Model (Trevisan and Brissaud, 2016)

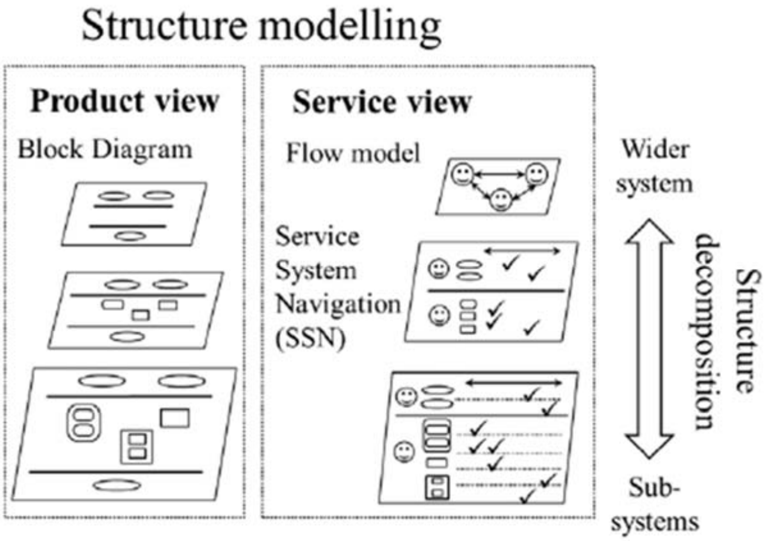


Figure 51b – The Structure Model (Trevisan and Brissaud, 2016)

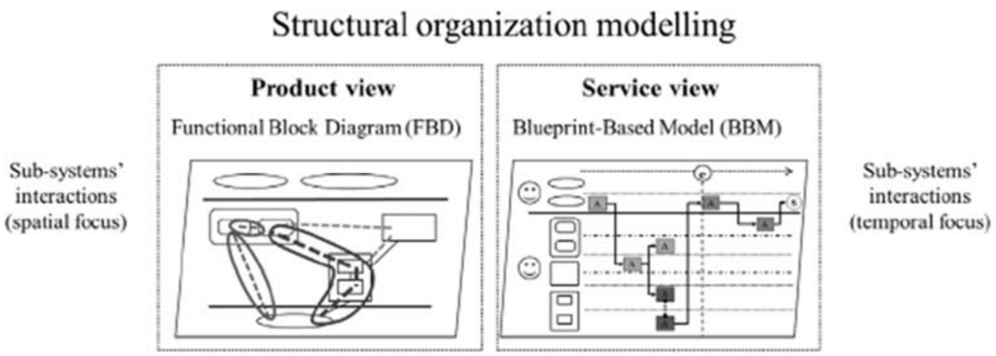


Figure 51c – The Structural Organization Model (Trevisan and Brissaud, 2016)

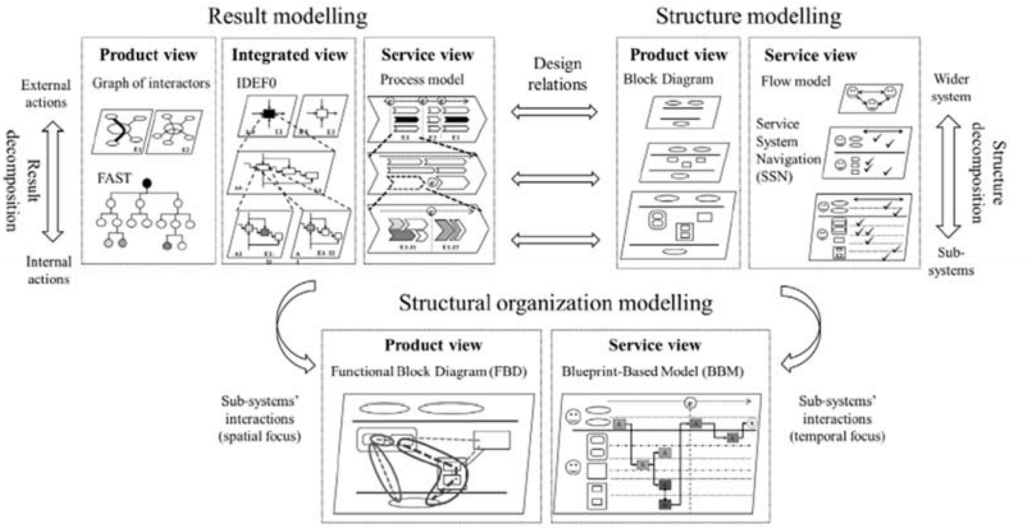


Figure 51d – The integrated approach for PSS modeling (Trevisan and Brissaud, 2016).

## 3.2 PSS framework analysis

The further step of the study consisted in a critical analysis of the above-mentioned frameworks (summarized in Table 19). Such an analysis consisted in bringing to light the main activities that are carried out when developing a PSS, i.e. what engineers need to do in practice:

1. Analyzing current business model
2. Defining PSS type and alternatives
3. Establishing the value proposition
4. Assessing customer segments
5. Customer relationships evaluation
6. Resource evaluation
7. Stakeholder analysis
8. Feasibility study (costs, benefits…)

9. Requirement analysis
10. Refinement (prototyping, testing)
11. Implementation planning
12. Product-Service integration design
13. Eco-Sustainability evaluations
14. Service delivery planning

As it can be seen in Table 20a, none of the analysed frameworks can be deemed as comprehensive.

In other words, each approach focuses only on certain activities, while a holistic approach covering all design tasks is missing. Thus, it can be noted that no clear approach is present for a manufacturer aiming to implement a PSS as mentioned by Rapaccini et al. (2013) Tran and Park (2014) and Sabbagh et al. (2016) and as explicated earlier (i.e. RQ1). In addition, the examination of the frameworks shown in Section 3.1 revealed that the understanding of the customers' requirements is intuitive and based on qualitative judgments which may hinder the proper and effective translation of these requirements into design inputs for the development of the PSS solution.

To better illustrate these issues, the analysis was carried out considering as a reference scheme, Hubka and Eder (1992)'s design process which comprises of four phases: ideation and planning, conceptual design, embodiment, testing and marketing. In other words, the frameworks were canvassed according to how they fit with the above-mentioned design process phases (Table 20b).

Table 19 - Summary of the existing design approaches and frameworks for a PSS (Haber and Fargnoli, 2017a)

| Framework type | Main characteristics | References |
|---|---|---|
| 1. Framework for PSS Design for Manufacturing Firms | The authors portrayed a framework for PSS design for manufacturing firms consisting of four stages as well: starting, definition, realization and closing; while defining the delays, risks, costs, knowledge organizational and communication aspects at hand in each of the four phases. The firm's position on the market with respect to its clientele and competitors dictate the development of a solution, its development strategy and its value delivery mechanism. Interactions within the company and between the latter and customers are pivotal in delivering an effective and satisfactory functional result. In such a model flexibility is the key attribute to adapt the company's knowledge and culture to a customized PSS solution. | Alix et al. 2009.<br>Alix and Vallespir 2010.<br>Touzi, Alix, and Vallespir 2013. |
| 2. Innovative Product Advanced Service Systems Framework | The Innovative Product Advanced Service Systems (IPASS) framework is built from the consumer's point of view by identifying the targeted market and defining its requirements. A PSS solution can be generated through innovative measures where new ideas are depicted and scrutinized to an accurate application field. Another attempt can be described by altering an existing layout into a more developed structure relying on the integration of product and services. They are then assessed to define the relations and coherency between them. The Quality Function Deployment (QFD) method is the cornerstone of this model to enable defining the space and setting of the PSS components as well as their relations with the clients' requirements and the provider's capabilities. | Lee and Abu Ali, 2010. |
| 3. Customization Framework for Roadmapping Product-Service Integration | This PSS development process is based on three sequences: structural determination, functional determination and road mapping. Technological innovation is the main factor to construct a product-service interface and identify the available protocols in which these two components can be combined. Integration can be applied simultaneously in various means throughout the design: at the product and service design stages concurrently, in separate manner where product and service development are segregated, and at the same time yet with additional weight attributed to the product or the service. Having defined the outline, process and | Phaal, Farrukh, and Probert 2004<br>Lee and Park 2005.<br>Chadee and Pang 2008.<br>Geum et al. 2010, 2011. |

| | | |
|---|---|---|
| | approach, the final phase lies in implementing the road map to identify concepts, impacts, market gaps, opportunities and implementation. | |
| 4. Business Model Design Methodology for Innovative PSSs | The structure presents a business model design methodology for innovative PSSs based on generating new ideas, such as is the case of shifting from a conventional design and development scheme to an integrated solution structure. The benefits of such a model include flexibility whereas the blocks resemble modules that can be arranged in various orders to come up with several alternatives for a certain design. The stages to be followed to align the blocks with the company goals are: identifying product and service elements, selecting the model's theme, value creation, value proposition and implementation. | Linder and Cantrell 2000.<br>Morris et al. 2005.<br>Masanell and Ricart 2010.<br>Lee and Abu Ali 2010. |
| 5. Business Model Framework | The author presents PSSs from a business model's perspective, addressing the main cornerstones of a business model's skeleton while providing an approach towards sustainability, seen its importance when considering this type of solutions. Five elements are to consider according to the author: the value proposition, customer behaviour, value configuration, value capturing and sustainability. It relies on well-known engineering and engineering management tools such as fishbone diagrams, blueprinting, causal loop diagrams, cost-benefit analysis, lifecycle mapping and analysis, SWOT matrix, and product portfolio among others. | Bonsfills 2012. |
| 6. Systematic Design Framework for PSS | This design framework comprises of four axes: value modelling, service activity design, interaction/touch-point design and experience management. Initially the requirements of the involved actors are described to obtain a picture of the sought-out value. The activities embedded to fulfil this value are designed and possible interactions between the solution and the actors are considered. Accordingly, concepts are designed within a precise context and broken down into sub-elements to develop and refine independently. Utilizing the service blueprint allows visualizing the flow of activities and functions required to process a customer request from its birth to its realization. The final sequence consists in launching the solution in its intended setting and to harness information for future refinement and improvement. | Shostack 1982, 1987.<br>Galvao and Sato 2006.<br>Kim et al. 2013. |
| 7. Methodology for PSS Development | Researchers portrayed a PSS development based on four pillars: organizational readiness, planning, design and post-processing. The core is a cultural change within the company to | Aurich et al. 2006.<br>Davies et al. 2007. |

| | | |
|---|---|---|
| | acclimatise the design and development processes to a PSS offering. This enables eyeing a solution from a customer and a manufacturer's points of view. Therefore, both life cycle stances are embedded to pinpoint the involved actors and their sought solutions. Product and service modelling allows describing the offering's features. A prototype is generated and assessed before entering mass-'production' and marketing of the functional product. The loop continues as a PDCA scheme for continuous improvement. | Tukker and Tischner 2006.<br>Maussang et al. 2009.<br>Marques et al. 2013. |
| 8. Canvas Business Model Framework | Engineers adopt a business model approach to evaluate the characteristics and requirements to shift the production culture towards PSS implementation. Three axes are described. The business context regards assessing the company's resources and market situation vis-à-vis the possible solution's pros and cons and their impact on its situation. Defining the PSS characteristics, as in the way to provide value (products and service needed), and creating value superior to that of a conventional product, the PSS delivery channels, profit streams, required activities and how to improve their performance, and specifying the actors' roles and responsibilities throughout the PSS life stages. | Alonso-Rasgado et al. 2004.<br>Isaksson et al. 2009.<br>Sakao et al. 2009.<br>Schuh et al. 2009.<br>Osterwalder and Pigneur 2010.<br>Tan et al. 2010<br>Barquet et al. 2013 |
| 9. Practical Design Framework | The following design process is reliant on the existing product and service process designs and is flexible and robust enough to be adapted to different types of PSS whilst discussing user involvement and the structural setting of an integrated product-service solution while viewing the PSS from a life cycle perspective where each respective activity needs to be described and considered during the design. | Aurich et al. 2004.<br>Aurich et al. 2006.<br>Shekar, 2007.<br>Tran and Park 2014. |
| 10. Generic Competitive Process Framework | The approach deepens the knowledge in terms of PSS operations and delineates them into five pillars: contracts, marketing, networks, design and sustainability. From one hand, customer-company relationships are described to structure the value delivery mechanism, the extended supply chain's role through suppliers and distributors is portrayed, the design method is documented and described, and the sustainability issues a PSS addresses are exposed. Customizing the use of these tactics is a trademark of each company's way of running its business thus leaving personalization and particularities of the solution in the realm of the manufacturer or developer. | Casadeus and Ricart 2010.<br>Reim et al. 2014. |

| | | |
|---|---|---|
| 11. PSS design exploration process | This PSS design approach requires converging the designer's methodology, the service provider's tactic, the consumer's perception, and the technological infrastructure to generate a value-providing solution founded on the merger of physical commodities with intangible service parameters. The developer's role relies on combining his context and stances with the client's requirements and the available technology to develop a valid PSS reliant on: assessing the needs of the customers vis-à-vis the firm's resources and market position, a personalized solution based on the customer's participation in the design process, a conceptual prototype to define the backbone of the offering, testing of the latter and final redefinitions of the solution prior to official launch. | Morelli 2003, 2006. |
| 12. PSS framework for intensified use | The PSS framework for intensified use incorporates services to maximize the value embedded in the product: accordingly, a PSS must be designed to cover all the life cycle stages of the solution in a manner that supports the environmental side of the prior. To undertake the green perspective into design, the PSS has to enclose the customer's requirements as well as the environment's by considering both points of view in the process. To do so, the authors state the product requirements have to be defined, the service requirements and its viability, a cultural shift towards eco-operations and a rigorous and thorough analysis of all the stages of the PSS. Modelling the PSS to portray the scenarios and their time occurrence are the cornerstone of the design considerations. Additionally recycling, reuse and remanufacturing amongst other green initiatives are to be carried out and adapted to the solution's design. | Mont 2002.<br>Tukker and Tischner 2006.<br>Gehin et al. 2009.<br>Gronroos, 2011.<br>Amaya et al. 2014 |
| 13. Kansei engineered PSS model | The Kansei framework accommodates the customer at the centre of the design. The PSS process begins by defining the setting of the application and the customer's demands from this environment. The prior's components such as products or services and its associated experience are evaluated to analyse missing or unfulfilled needs that the user is seeking to achieve. By understanding these missing links, designers establish the combinations of products and services to achieve them. | Carreira et al. 2013. |
| 14. Flexible PSS design framework | This approach relies on a flexible business model where a PSS can be visualized from a comprehensive point of view down to a simple modification to the existing company culture. The designers, together with the consumers, depict the service components and processes | Zine et al. 2014. |

| | | |
|---|---|---|
| | deemed focal to the PSS’s success. The tactic to adopt consists in recognizing the key stakeholders of the system, capturing the client’s requirements, defining the prior’s constituents, structuring the PSS system and designing the offering. | |
| 15. Integrated PSS model | Authors’ contributions merge towards three phases to successfully develop a PSS design. A strategic phase encloses defining requirements and assessing the firm’s position against those needs to provide a starting point for the conceptual development of a solution. The second sequence consists in the development of the concept and the detailed design of the second as well as testing to evaluate performance. The final stage is an implementation step where the PSS offering is launched on the market. | Maussang et al.2009.<br>Gronroos, 2011.<br>Trevisan and Brissaud, 2016. |

Table 20a – Analysis of existing PSS frameworks: activities involved.

| | Analysing current business model | Defining PSS type and alternatives | Establishing the value proposition | Assessing customer segments | Customer relationships evaluation | Resource evaluation | Stakeholder analysis | Feasibility study (costs, benefits…) | Requirement analysis | Refinement (prototyping, testing) | Implementation planning | Product-Service integration design | Eco-Sustainability evaluations | Service delivery planning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Framework for PSS design for manufacturing firms | | | X | | | X | X | X | X | | X | X | X | |
| 2. IPASS framework | X | X | X | X | | | | | X | X | X | X | | |
| 3. The customization framework | X | X | | X | X | X | X | | X | | | X | | X |
| 4. Business model design methodology for PSS | X | X | | | X | X | X | | | | | X | | X |
| 5. Business model framework | | | X | X | | X | X | X | | | | | | X |
| 6. A systematic PSS design framework | | | X | X | X | | | X | | | | X | | |
| 7. A methodology for PSS development | X | | | X | X | | X | X | X | X | | X | | |
| 8. Canvas business model framework | X | X | X | X | X | X | X | X | | | | | | X |
| 9. Practical design framework | X | X | | X | | X | X | | X | X | X | X | X | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. Generic competitive process framework | | X | X | | X | X | X | | X | | X | X | X | |
| 11. PSS design exploration process | | X | X | X | | | | | X | X | X | X | | |
| 12. PSS framework for intensified use | | X | X | | | | | | X | | X | | X | X |
| 13. Kansei engineered PSS model | | X | X | X | X | | | | X | | | X | | |
| 14. Flexible PSS design framework | X | | | X | | | X | | X | X | X | | | |
| 15. Integrated PSS model | | | X | X | X | X | X | | X | | | X | | X |

Table 20b – Analysis of existing PSS frameworks: compared to Hubka and Eder (1992)'s design science approach

| | 1. Ideation and Planning | 2. Conceptual Design | 3. Embodiment | 4. Testing and Marketing |
|---|---|---|---|---|
| 1. Framework for PSS design for manufacturing firms | X | | X | |
| 2. IPASS framework | X | X | | |
| 3. The customization framework | X | X | | |
| 4. Business model design methodology for PSSs | X | | | |
| 5. Business model framework | X | | | |
| 6. A systematic design framework for PSS | X | | X | |
| 7. A methodology for PSS development | X | X | | X |
| 8. Canvas business model framework | X | | | |
| 9. Practical design framework | X | | X | X |
| 10. Generic Competitive Process Framework | X | | X | |
| 11. PSS design exploration process | X | X | X | |
| 12. PSS framework for intensified use | | X | | X |
| 13. Kansei engineered PSS model | X | | | |
| 14. Flexible PSS design framework | X | | X | |
| 15. Integrated PSS model | X | X | X | |

## 3.3 PSS framework summary

The frameworks reviewed in section 3.1 portray a design sequence, in other words a design strategy, when designing a PSS solution or implementing a PSS approach, shifting from a traditional solution (production of goods) to an integrated one (production of goods and services).

According to Tonelli et al. (2009), a market analysis identifies the customer and his requirements, while a macro-evaluation of the company utilizing Strengths-Weaknesses-Opportunities-Threats (SWOT) matrices defines the scope of the PSS strategy (Alix and Vallespir 2010). In Bonsfills (2012) it is described as the value proposition where customer and manufacturer requirements are defined as the cornerstone of the PSS implementation (Barquet et al. 2013).

A feasibility study determines the firm's capabilities to verify the viability of the generated idea: estimated costs, available resources and skills are identified to assess the manufacturer's readiness to proceed with the conceptualization phase (Maussang et al. 2009). This stage consists in developing the solution by conceiving a design that allows value to be delivered. Alix and Vallespir (2010) state the conceptualization sequence as value engineering, where the product, the service and the interface between them (Chadee and Pang, 2008; Geum et al. 2010, 2011). Lee et al. (2011) argue that a feasible and promising concept requires flexibility: breaking down the idea into design blocks or modules that can be arranged in various orders to come up with possible alternatives of product and service elements (Morris et al. 2005; Masanell and Ricart, 2010).

The PSS' elements can then be laid out in a more developed structure relying on the level of integration between the physical and intangible components (Lee and Abu Ali, 2010). On one hand, having outlined a trustworthy concept, the PSS's elements have to be engineered: the infrastructure, the activities to be performed, the interactions and the network relationships. From another hand, other authors tackle the task by assimilating the PSS model to a business model where the technical specifications, materials, suppliers and resources are exemplified in a cost structure (Sundin et al. 2009) embedding the partners, activities and resources' revenue streams to relate the system's aspects to their business-oriented counterpart (Marques et al. 2013; Reim et al. 2014).

Once a PSS is developed, testing for refinement and final modifications is carried out by prototyping the solution, subjected to a closed group of customers while assessing their experience and identifying the best method for its implementation on the market vis-à-vis consumer perspectives and the required level of interaction (Azarenko et al. 2009; Kindstrom, 2010; Reim et al. 2014).

A general framework is needed to harmonize the PSS design process. Such a need, pointed out also by numerous authors, such as Marques et al. (2013), Sakao and Shimomura (2007), Vasantha et al. (2012), Tran and Park (2014) and Vezzoli et al. (2015), led us to propose a structured plan of action (Section 4) able to address designers in the development of new PSSs.

# 4. A new PSS framework proposal: The Functional-Engineered PSS (FEPSS) Framework

Analysing the various frameworks in the literature, different approaches seem to be adopted when addressing the development of an integrated offering. According to Aurich et al. (2004) and Aurich et al. (2006) PSS design is the descendant of the conventional product design structure of Hubka and Eder (1988). Both Shostack (1982) and Cowell (1988) explicated service development, before seeing its respective process formalized for the first time by Scheuing and Johnson (1989).

At the same time, further approaches aimed at the assessment of the PSS development process have been taken into account in literature. For instance, Tonelli et al. (2009) outlined the Analysis-Development-Verification-Proposal (ADVP) framework for Small and Medium Enterprises (SMEs). This four-phase approach starts with an idea generated from market analysis, the customer, marketing personnel, competition etc. with the identified demand requiring verification. Defining the probable scenarios follows and a feasibility analysis (costs, profits, resources, etc.) must be run to verify the viability of the proposed solution. The third part requires acknowledging the company's competences to develop the PSS in terms of infrastructure and to adapt the supply chain accordingly. The final sequence comprises of the marketing plan the firm should pursue to expose customers to the new solution and validate its solution. Prototyping with a limited customer segment allows confirmation of the new solution prior to full market launch. Although such an approach does not take into account the physical product part of the PSS, as argued by Schmidt et al. (2015), it well introduces the four general phases of a traditional design process, as the ones presented by Hubka and Eder (1988, 1992) and Pahl and Beitz (2007). This framework, based on the PDCA cycle principles (Deming, 1950), is widely recognized as being one of the most effective strategy tools for the management of design activities (Fargnoli and Kimura, 2007; Unger and Eppinger, 2011; Fargnoli et al. 2014a).

For these reasons, the proposed framework to unify PSS design processes is built on Hubka and Eder (1992)'s theory and consists in the following four phases: Ideation and Task Analysis, Conceptual Design, Embodiment Design, Validation and Release (Figure 52).

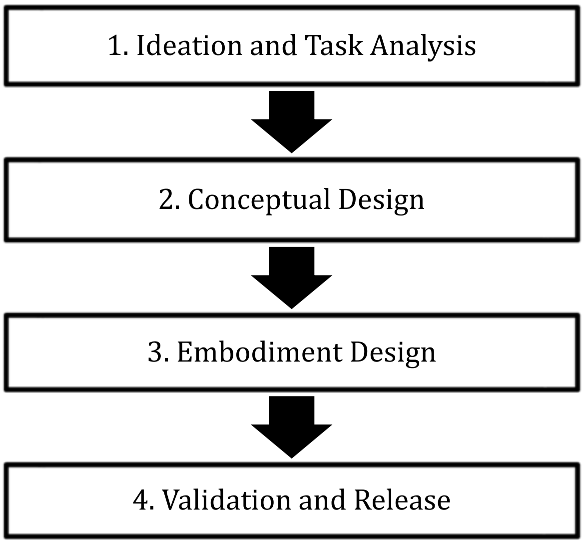


Figure 52 – General framework of the proposed PSS design process (adapted from Hubka and Eder, 1992)

## 4.1 Ideation and task analysis

### 4.1.1 Overview

The first step consists in generating a PSS idea. The latter arises from identifying and understanding customer segments and needs to create added value to the pre-existing solution. This value creation has a purpose of improving the customer's state via two general methods: optimizing and improving the current product/service provided or innovating and proposing a new solution. The adding-value mechanism must comprise of a holistic social-economic-environmental perspective while assessing it from both a manufacturer's stance as well as a client's point of view.

Regarding the consumer, the main questions to answer are "Who is the customer? What is he trying to achieve?  Which activities involve him? How is he taking his decisions? What does he feel? What do you want your customer to feel? ".

Uncovering the answers to these questions can be done using well-known engineering tools, notably ones regarding quality and quality management systems.

1. Classifying the customer: the latter can take shape of a B2B, B2C, local, national or international context. Recognizing the category oversees the scale of the buyer’s desires.
2. Existing information: old surveys and interviews (semi-structured) can hold valuable information that may have been omitted in the past as the previous questions would not have required extended data. However, given that demand has changed, re-assessing the previous data may reveal useful material.
3. Stakeholders consultations: extending the scope to include external stakeholders is beneficial as the support and sales teams are familiar with both the product and the customer since these personnel are the manufacturer’s frontline with its clientele (Vijaykumar and Suresh, 2011).
4. Ishikawa (fishbone) diagram: illustrates the primary and secondary causes of a certain outcome. This tool can be useful to target a specific subject through an organized brainstorming session to identify new areas lacking supporting information.
5. Customer journey map: the objective of the product/service provider is to place himself in the buyer’s shoes and obtain a holistic perspective on the customer’s experience. Acknowledging several behavioral stages, identifying how each goal is connected with its respective behavior, outlining the touchpoints, determining if the clients are fulfilling their goals and eyeing change opportunities for them to achieve their unfulfilled targets.
6. Critical to quality (CTQ) diagram: advantageous for considering quality drivers from the user’s perception and observing which features the user applies to evaluate the quality of the provided solution. Such differentiation also allows the firm to obtain measurable factors by which it would judge the performance of the product/service.

Understanding the business situation and estimating how changes can affect the context is a considerable topic for the manufacturer. Tan (2010) argues that assessing the PSS to consider should be adapted to the pre-PSS business model as a means of reducing risks and unwanted outcomes. Furthermore, any innovated model should be carefully considered to inhibit any unwanted negative result. Thus, a judiciously pre-conceptualization sequence is favorable and comprises in identifying the products and services to satisfy the documented customer needs, analyzing competitors' actions and setting up requirements.

1. Eliminate-Reduce-Raise-Create (ERRC) matrix: utilized to generate new value through creating a new market space to create and seize new demand. Building the ERRC matrix requires identifying competing factors that should be eliminated, which factors should be reduced and which should be raised in order to determine the factors that the industry has never offered before that would thus be the new value containers.
2. Identifying products and services: meeting requirements is achievable via products and services. The trade-off however surfaces from the needs identified earlier. For instance, if the solution requires extensive product use or whether the customer experience is the focal point, then the PSS type varies significantly (Figure 53).

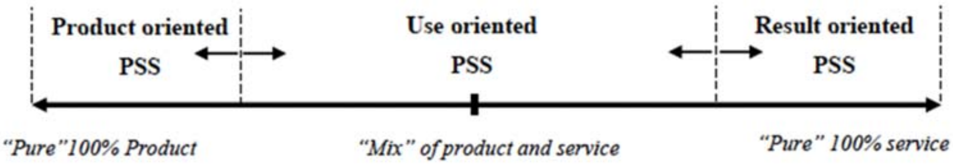


Figure 53 – Product-Service trade-off (Tran and Park, 2014)

3. Benchmarking against competitors' actions: the analysis of the industry's rivals can be utilized to visualize the competition's capabilities and resources as well as forecasting the competitor's future action if a certain scheme is applied. The benchmarking process covers specific functional areas prioritized according to budget allocation and importance. The highest benefit occurs when each functional area is compared with the company performing best in each category (lowest cost vis-à-vis highest customer satisfaction). The manufacturer would then measure his own performance and compare it to the competitor and specify the gaps that need to be filled by specific approaches that vary according to context: mimicking actions, changing company culture, innovating etc.
4. Setting up requirements: evaluating the business process is vital to capture the intangibility of an integrated product-service offering as well as the tangible features of production. Each function's characteristics must be assigned the needed resources and necessities. In other terms, the product's attributes, the service process, the resources

used and information regarding the product-service integration. The most prevalent requirements include business process specification, alternative sequences and cycles, distinction of service potential and service process, personnel skills, production and capacity constraints, quality standards, type of combination and stakeholder relationships (Becker et al. 2008).

### 4.1.2 Prioritization of the Customer Requirements (CRs)

Even when a set of basic product-oriented services are expected by customers, manufacturers have the opportunity to expand their business and generate more value and/or reduce costs from them, as pointed out by Ulaga and Reinartz (2011). Thus, they are expected to satisfy the customers' needs and expectations efficiently, by means of their "design-to-service" capabilities (Oliva and Kallenberg, 2003; Ulaga and Reinartz, 2011). To achieve such a goal, it is fundamental to understand what the customer requirements are, and more importantly to distinguish between basic and attractive requirements. Such an understanding would allow a better comprehension of the customers' requirements and hence an improvement in the quality of the offered services (Materla et al. 2017).

At the same time, once the customers' requirements are defined, it is also important to effectively transform them into design requirements (Cho et al. 2016), while avoiding possible conflicts between the service and the product attributes of the PSS. As noted by Song and Sakao (2016), it is more challenging to identify and solve the conflicts of the service attributes of a PSS since they are more intangible and harder to explicate than the conventional product attributes of a product-reliant solution. Similarly, Hakanen, et al. (2016) brought to light the need to further investigate the customer's perceptions of value associated with a PSS in order to address the manufacturer's strategies. The latter is pivotal to minimise ambiguities when designing quality into offerings (Lo et al. 2016). Additionally, different techniques for assessment of customer requirements (CRs) lead to different results, thus their comparative evaluation should be investigated to reduce inconsistencies and misleading customer information (Franceschini and Maisano, 2015). Thus, given that the services' performance and their resulting customer satisfaction are highly subjective and not easily quantifiable due to their intangibility (Aurich et al. 2010; Regan, 1963), the need for a quantitative understanding of service design through an effective approach based on a systematic procedure for developing services that incorporates customer requirements properly arises from numerous studies (e.g. in (Haber and Fargnoli, 2017a; Kim and Yoon, 2012; Rapaccini et al. 2013; Sabbagh et al. 2016)).

Based on this, a structured approach based on the QFD method and its adaptation to PSS development named QFDforPSS which comprises of two phases (phase I: to define the PSS characteristics; phase II: to define the PSS components) is proposed (Arai and Shimomura, 2005; Sakao et al. 2009). In detail, the approach adopts two augmentations to the QFDforPSS: the Kano model (Kano et al. 1984) and the Fuzzy Analytic Hierarchy Process (FAHP) (Kamvysi et al. 2014) as a means of dealing with the ambiguities of a PSS in the QFD (Cho et al. 2016).

The Kano model allows the individuation of the attractive (A) and one-dimensional (O) CRs since the attractive CRs allow more space for innovative and lucrative means for profit generation and cost reduction opportunities (Matzler and Hinterhuber, 1998). One-dimensional CRs represent the measurable technical performances of the PSS that the customer expresses explicitly. These CRs are usually ‘standard’ and specified by the customer prior to using the PSS (Madzik, 2016). In other words, the Kano model helps in filtering CRs by removing the basic ones, which are a must-be in a competitive market. This allows engineers to define the requirements that can effectively increase value for customers and, as noted by Cheng and Chiu (2007), leads to the quality strategy to follow. Generally, the Kano model denotes 5 main quality categories: the one-dimensional and attractive mentioned above, in addition to the Indifferent (I), Must-be (M) and Reverse (R) categories (Kano et al. 1984). The categorization derives from functional (if the attribute/requirement is present in the solution) and dysfunctional (if the attribute/requirement is not present in the solution) inquiries where the customer’s reactions are identified by means of specific questionnaires (Matzler and Hinterhuber, 1998). These questionnaires lead to determining the quality categories (Figure 54) through the Customer Satisfaction Coefficient for satisfaction (CSCsi) and dissatisfaction (CSCdi) which are calculated as follows:

$$\mathrm{CSCsi} = \frac{\mathrm{A+O}}{\mathrm{A+O+M+I}} \tag{4}$$

$$\mathrm{CSCdi} = -\frac{\mathrm{O+M}}{\mathrm{A+O+M+I}} \tag{5}$$

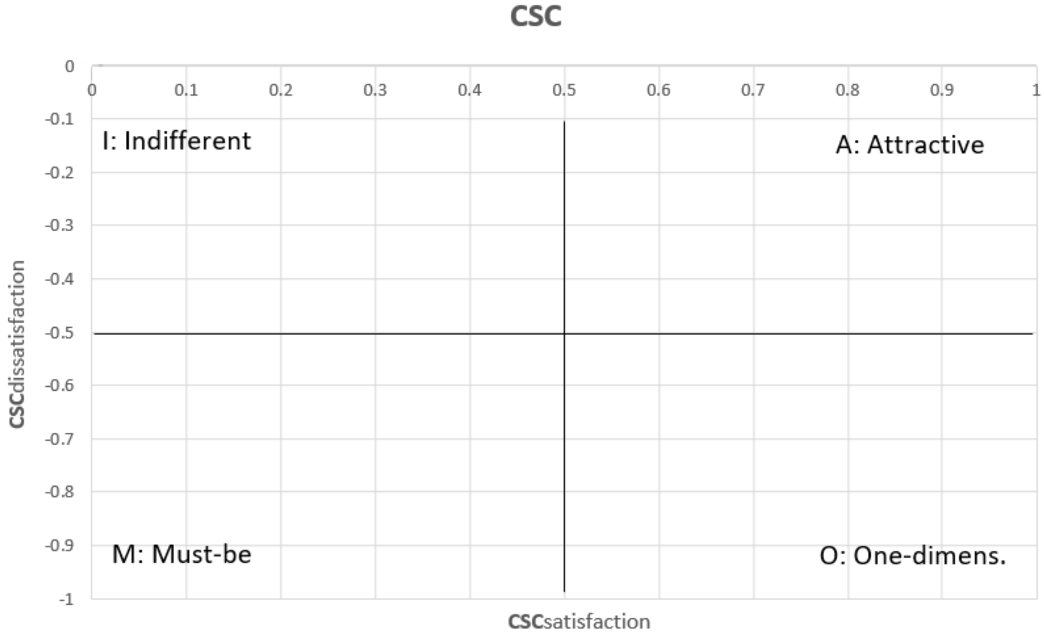


Figure 54 – The quality categories through the Kano model

The attractive requirements are then translated into Receiver State Parameters (RSPs) in cooperation with the manufacturer’s experts (i.e. marketing staff, scientific affairs manager, product specialists etc.). The RSPs are then prioritized by means of the FAHP. Ulaga and Loveland (2014), pointed out that differently from a product-centric environment, in PSSs, companies have to deal with a “fuzzy front end” to understand what customers really need and how to combine goods and services to achieve such a goal fuzzy logic and the AHP as a means of quantifying linguistic variables. The need for a quantitative understanding of service and PSS design through an effective approach based on a systematic procedure for developing services that incorporates customer requirements properly arises from numerous studies (Rapaccini et al. 2013; Sakao and Mizuyama, 2014). Consequently, in order to improve the PSS design process, notably in its early phases, we propose a QFD based approach combined with a Fuzzy Analytic Hierarchy Process (FAHP) to meet these demands

In a fuzzy logic context, crisp numbers are transformed into fuzzy numbers considered as a probability distribution, more frequently defined as Triangular Fuzzy Numbers (TFNs) since they can be easily handled and manipulated (Liu and Tsai, 2012). The use of fuzzy logic and TFNs allows overcoming the ambiguity and biasness of subjective evaluations and developing effective design strategies (Liu and Wang, 2010). Using the crisp-fuzzy AHP scale

(Chowdhury and Quaddus, 2016), the weights of the CRs are defined, enabling decision making with estimated or uncertain values. Moreover, Jiao and Chen (2006) argued that such an approach can support engineers in dealing with the vagueness and imprecision that characterize information concerning customer requirements, notably in a service-oriented context (Isaksson et al. 2011). The FAHP adopts a pairwise comparison approach where each RSP is compared to another via a 1 (equally important) to 9 (extremely more important) scale (Saaty, 1990) (Figure 55). The resulting crisp numbers are then converted into TFNs following the transformation exhibited by Kamvysi et al. (2014) (Table 21).

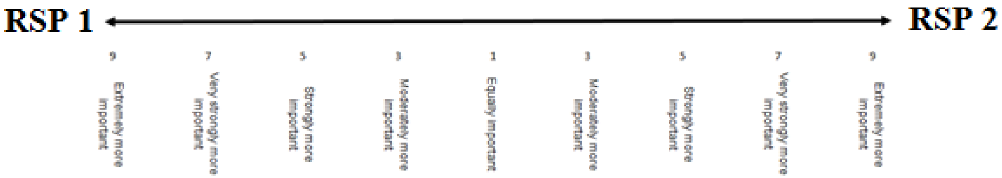


Figure 55 – Example of a pairwise comparison between two RSPs

Table 21 – Crisp to Fuzzy transformation (Kamvysi et al. 2014)

| **Linguistic variables** | **Rating Scale (crisp)** | **Equivalence in Fuzzy numbers** | |
|---|---|---|---|
| | | **TFNs** | **Reciprocal TFNs** |
| Equally important | 1 | (1, 1, 1) | (1, 1, 1) |
| Intermediate | 2 | (1, 2, 3) | (1/3, 1/2, 1) |
| Moderately more important | 3 | (2, 3, 4) | (1/4, 1/3, 1/2) |
| Intermediate | 4 | (3, 4, 5) | (1/5, 1/4, 1/3) |
| Strongly more important | 5 | (4, 5, 6) | (1/6, 1/5, 1/4) |
| Intermediate | 6 | (5, 6, 7) | (1/7, 1/6, 1/5) |
| Very strongly more important | 7 | (6, 7, 8) | (1/8, 1/7, 1/6) |
| Intermediate | 8 | (7, 8, 9) | (1/9, 1/8, 1/7) |
| Extremely more important | 9 | (8, 9, 10) | (1/10, 1/9, 1/8) |

### 4.1.3 Definition of the PSS characteristics

Having defined and prioritized the RSPs, the manufacturer's experts define the product and service characteristics (PChs and SChs) that will shape the PSS. The latter are inserted in the QFDforPSS and their relative importance vis-à-vis the RSPs is determined (Figure 56). The co-relational matrix uses a 1-3-9 scale to indicate a weak relationship, a medium relationship or a strong relationship respectively. This leads to the assessment of the relative importance of each

PCh and SCh and hence defines the level of product-service integration in the solution.

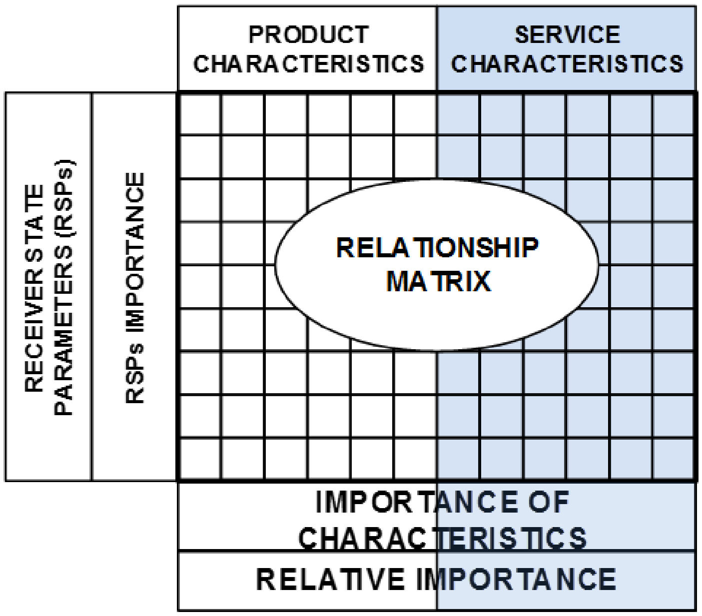


Figure 56 – QFDforPSS phase I

### 4.1.4 Assessment of the PSS idea

Having elaborated the task at hand vis-à-vis customer and manufacturer capabilities, the following phase is running a feasibility study to determine whether the assigned task is profitable and lucrative. Furthermore, feasibility testing helps:

- Proving to the stakeholders the market's existence and the Return On Investment (ROI),
- Recognizing flaws, obstacles, strengths, weaknesses, threats and opportunities.
- Assessing the resources required to launch the solution
- Determining the budget needed to run the business.

A successful and comprehensive feasibility study comprises of six pillars:

1. Economic analysis: to assign the available resources in an optimal manner to maximize profits and make sure that the resources are utilized where they are needed most. A full-scale economic analysis will include governmental and monetary policies, opportunity cost, social cost, importation exportation and inflation rates, tax and currency rates etc.

2. Technical analysis: to assess the type and method of production to be applied, equipment, tools and skills required, facility management etc. The second part of a technical analysis would be to document the elements just stated in order to regularly examine how manufacturing operations are going.
3. Location analysis: vital to determine if a centralized or decentralized approach is to be adopted when setting up facilities. The selection depends mainly on supplier and customer locations, available infrastructure, transportation fleet and costs.
4. Manpower analysis: comprises in weighing the workforce needed and desired competences to strengthen the workers' feeble skills and maintain or improve their stronger ones. Given that a workforce may not always possess the needed aptitudes, a utilization strategy should be mapped out to pinpoint the techniques that require outsourcing. Another important task is to provide the personnel with proper training to ensure a smooth and effective running of operations.
5. Financial analysis: estimating the needed budget in terms of expenses and income. A good utilization of those would be the net present value (NPV) that considers inflows, outflows, and the discount rate to determine whether the investment would be lucrative, costly or neutral (no gains nor costs). The NPV however, relies heavily on assumptions, which may be obstructed by unforeseen expenditures, and unexpected cash flows. Other alternatives include the payback period, the break-even point and internal rate of return, which are easier to use and contain less ambiguity therefore easier and 'clearer' to use.
6. Sensitivity and risk analysis: having run the previous analyses, the last topic to address is the risk-to-reward ratio and sensitivity to competition. A useful method to apply here is the SWOT analysis to uncover macro-factors generally related to the manufacturer's environment and FMEA for a more detailed approach since it generates a risk probability number (RPN) that combined with decision analysis allows discerning a risk-seeking or risk-averse attitude (Martins, 2015).

The outcome of the 'ideation and task analysis' stage is a clear and defined PSS idea that answers the consumer and company's criteria. The idea should be a solution to an existing customer need from one hand, and feasible from the other hand (Table 22).

Table 22 – PSS ideation and task analysis summary

| Sequence | Description |
|---|---|
| Customer's point of view | Classifying the customer, and the market segment he represents. The latter is followed by separating needs from wants, to prioritize the pivotal requirements to meet. The client may have an unanswered request, or may be seeking an upgrade etc.<br>Customer behavior is then analyzed vis-à-vis his situation in order to identify the CTQ attributes sought. |
| Manufacturer's point of view | Assessing the firm's factors, value adding and non-value adding ones, to determine which aspect will provide new value through identifying products and services and the type of solution to offer (PO, UO, RO).<br>The following step consists in identifying gaps and opportunities by benchmarking the company's performance against competitors to prioritize functional areas to cover and the actions needed within their respective context.<br>Finally, evaluating the business process in order to assign the firm's resources given each function's characteristics and thus point out the business process, service process, service cycle, restraints, quality standards etc. |
| Feasibility study | Economic, technical, location, manpower, financial and sensitivity studies have to be carried out to assess the risks involved, and judge the resources deemed necessary to meet production demands. |

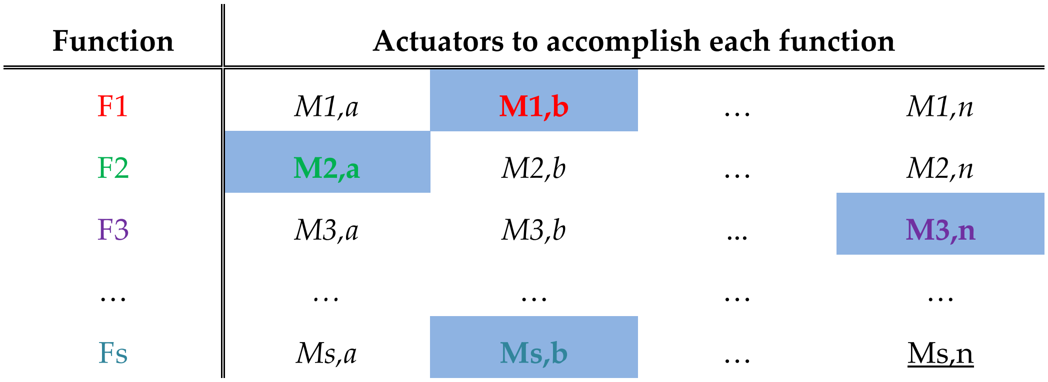
## 4.2 Conceptual design

### 4.2.1 Concept generation

Concept generation essentially includes two phases: idea generation and combining methods to produce concepts. Pahl and Beitz (2007) and George (2012) argue that a distinct division between the two sequences is ambiguous. However, for the purpose of this study, idea generation has been utilized as an initial stage to delineate its outcome as the input of the concept generation process.

Fargnoli et al. (2006), Ritchey (2006), Tiwari et al. (2007) and Olvander et al. (2009) emphasize the adoption of morphological thinking and morphological matrices to decompose problems into sub-problems to explore the design space: each main function is divided into sub-functions vis-à-vis the measures (actuators) to achieve them (Figure 57).

A systematic design ensures quality and efficiency: decomposing the problem into sub-problems and building sub-solutions to the prior (Arai and Shimomura, 2004; Sakao and Shimomura, 2007; Sakao and Lindahl, 2009). Utilizing the morphological matrix (MM) to depict the possible solutions to each elementary function. The concept will be a combination of one element of each row (blue cells in Figure 57): each sub-function will be realized with a specific actuator, and completing all the sub-functions will result in a comprehensively generated concept i.e. M1,b – M2,a – M3,n - …



| Function | Actuators to accomplish each function | | | |
|---|---|---|---|---|
| F1 | *M1,a* | **M1,b** | … | *M1,n* |
| F2 | **M2,a** | *M2,b* | … | *M2,n* |
| F3 | *M3,a* | *M3,b* | … | **M3,n** |
| … | … | … | … | … |
| Fs | *Ms,a* | **Ms,b** | … | Ms,n |

Figure 57– Morphological Matrix illustration

### 4.2.2 Concept generation using the morphological matrix tool

Utilizing the morphological matrix as the core tool to generate PSS concepts in a feasible and plausible manner must answer the requirements listed below:

1. Efficient exploration of the design possibilities within a MM using a realistic number of combinations (number of combinations attempted < number of combinations of all the means in the matrix).
2. Sufficient amount of details to evaluate concept alternatives vis-à-vis the setout requirements.
3. Envision combinations from different stances to promote innovative and harder to imitate concepts.
4. Effective examination of the design environment to fully grasp the design activity
5. Identify the possible potential and limitations.
6. Document the process in terms of decisions made, analysis, success assumptions and generated ideas.

George (2012) decomposes the task into six stages:

1. Grouping the measures in the MM.
2. Filtering and acknowledgement of innovative measures.
3. Identifying combinations for focused ideation.
4. Sub-system concept generation
5. Arranging the sub-concepts to illustrate a comprehensive concept
6. Repeating and producing alternatives.

Stage 1: Grouping the measures in the MM

Similar actuators for a specific function Fs are clustered into a solution stream (Figure 55), i.e. Bluetooth and Infrared can be placed under 'wireless file sharing'. Each function results from a breakdown of the Main Function (MF) the concept seeks to answer. These clusters can be based on analogous working principles, usage of similar mechanisms, complexity, consistency etc. Affinity diagrams are easy to use and useful to successfully group the measures according to particular criteria. This grouping technique helps identify working principles and means that may have been ambiguous earlier, catalyze the concept generation process by shedding light on the possible combinations that can be made to generate sub-concept solutions for a given function.

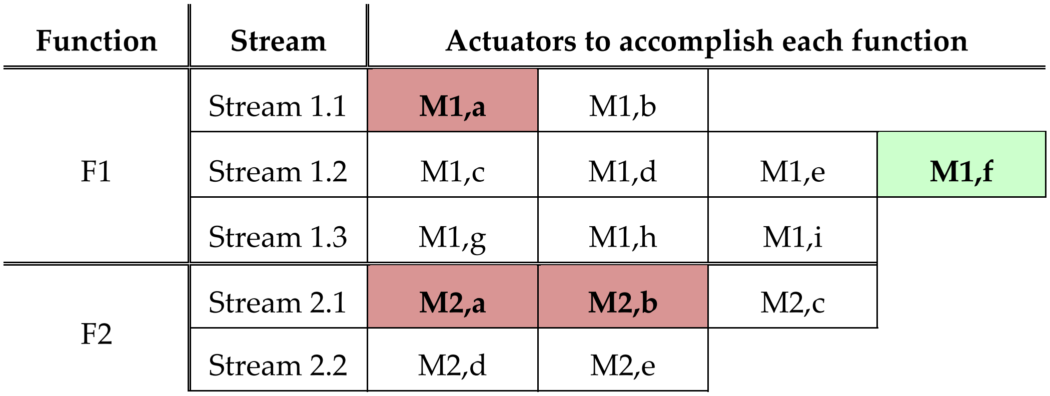
| **Function** | **Stream** | **Actuators to accomplish each function** | | | |
|---|---|---|---|---|---|
| F1 *(sub-function 1)* | Stream 1.1 | M1,a | M1,b | | |
| | Stream 1.2 | M1,c | M1,d | M1,e | M1,f |
| | Stream 1.3 | M1,g | M1,h | M1,i | |

| | | | | |
|---|---|---|---|---|
| F2 *(sub-function 2)* | Stream 2.1 | M2,a | M2,b | M2,c |
| | Stream 2.2 | M2,d | M2,e | |

Figure 58 – Solution stream example

Stage 2: Filtering and acknowledgement of innovative measures

Having identified the streams in the previous phase, each actuator is assessed based on the advantage or downside it carries. A short description of the actuator vis-à-vis its main features, components, pros and cons can be documented in a comparable outline as that of a Kanban card. Formalizing the comparison procedure will ease the actuators' assessment process and highlight the 'candidate actuators' eligible for further inspection. The latter rely on the documented information and the designers' experience. Moreover, the overlooked actuators must also be justified to validate the reason behind their unviability (Figure 59).



| **Function** | **Stream** | **Actuators to accomplish each function** | | | |
|---|---|---|---|---|---|
| F1 | Stream 1.1 | **M1,a** | M1,b | | |
| | Stream 1.2 | M1,c | M1,d | M1,e | **M1,f** |
| | Stream 1.3 | M1,g | M1,h | M1,i | |
| F2 | Stream 2.1 | **M2,a** | **M2,b** | M2,c | |
| | Stream 2.2 | M2,d | M2,e | | |

Figure 59 – Example of filtering measures

In Figure 59, the excluded actuators are shown with a red color while actuators associated with innovation and which should be explored on a deeper level, are marked with a green color. It is worth noting the actuators highlighted in red should in fact be temporarily excluded and not omitted, as a desired outcome may occur when two or more are combined. Nonetheless, the ones worth attacking first are the ones linked with innovation – green color. The outcome of this second stage will be a ranked chart explicating the most optimistic combinations to the least.

Stage 3: Identifying combinations for focused ideation

In order to generate concepts, function (from the MM) combinations are introduced vis-à-vis their respective actuators. Paired functions can contain compatible functions as well as incompatible ones that deliver positive outcomes when unified into one subset. Choosing the functions can be based upon logical relations, strategies… i.e. 'F1: change gear forward' is followed by 'F2: secure gear afterwards'. The choice of combinations is within the design realm and depends of the designers, the design activity and design target. George (2012) states nonetheless *"the first functional combinations set is chosen to begin focused ideation on the possible ways of implementing the functional coupling in the physical domain."* To start off the concept generation sequence and for redundancy reasons, the first iteration should include the single use of each function. Ulterior combinations take place with more complex functional combinations (Figure 60).

| **Functional combinations** | **Acceptance (A) / Rejection (R)** | **Reason for rejection** |
|---|---|---|
| {F1 – F2}, {F3-F4} | **A** | - |
| {F1 – F4}, {F2-F3} | **A** | - |
| {F1 – F4 – F2}, F3 | **R** | Unadvised number of functions in one subset |
| {F1-F2}, {F1-F4}, F3 | **R** | Recurring function F1 |

Figure 60 – Accepting or rejecting a combination given a MM with 4 functions (example)

The first two combinations are acceptable while the third is to be neglected since it implies more effort to map out and explore the combinations. The fourth is to skip as well, given that F1 is redundant and would lead to more than one measure to fulfill one function.

Respecting the initial protocols facilitates the following exploration phase.

Stage 4: Sub-system concept generation

The combinations of stage 3 yield advantages and drawbacks that may arise from certain combinations of measures concerning the functional subset. Thus, a detailed evaluation of the latter is needed.

**Innovation challenges** allow exploring alternate functional combinations to generate sub-systems and indicate the paths for sub-system concept generation by combining actuators from various points of view, to offer new insights on how to combine them in innovative methods. These challenges fall under four pillars:

1. Requirements challenging innovations: identifying inherent assumptions by questioning the requirements' scope and point out misrepresentative or misinforming requirements.
2. Functional redefinition: functional requirements can be conceived in many ways thus a defined way may not only be the correct way and reformulating a certain function can be seen as an innovation. In addition, the MM may not always include all the functions but must involve the main ones involved.
3. Design space innovations: exploring more possibilities leads to new measures to specific functional subsets.
4. Combination innovations: achieving functional combinations is not limited to the outline displayed in Figure 57. Combinations can arise in any form and the preceding stage only defines the starting point of combinational exploration.

An **option matrix** (Figure 61) weighs the actuators of one function against those of another function to enlarge the number of possibly valid combinations and emphasizes an attentive tactic to the functional combination for developing more accurate details.

<table>
<tr><th colspan="2"></th><th colspan="3">Function F2</th></tr>
<tr><th colspan="2"></th><th>F2M1</th><th>F2M2</th><th>F2M3</th></tr>
<tr><th rowspan="3">Function F1</th><th>F1M1</th><td>Not compatible</td><td>A1</td><td>A2</td></tr>
<tr><th>F1M2</th><td colspan="3">Consider exploration at a later stage</td></tr>
<tr><th>F1M3</th><td>A3</td><td colspan="2">Potential for innovation</td></tr>
</table>

Figure 61 – Options matrix example

The possible combinations amongst the means are identified and evaluated for a sub-system concept (A1, A2 and A3) while incompatible combinations are also marked out. F1M2 is compatible with all the measures of F2 and are worth exploring later on to target innovative solutions. F1M3 is compatible with the measures 2 and 3 of F2; hence a detailed investigation may lead to the emergence of novel innovative concepts. An advanced exploitation of the option matrix implies utilizing an option matrix for each specific innovation challenge (Figure 62). Each innovation challenged is listed as column and the measures (actuators) of each function are one-by-one measured against the measures (actuators) of the second function. B1, C1 and C2 denote more than one arrangement to associate the involved measures.

| | | **Innovation challenge 1** | **Innovation challenge 2** |
|---|---|---|---|
| **F1M1** | F2M1 | | |
| | F2M2 | | |
| | F2M3 | B1 | |
| **F1M2** | F2M1 | | C1 |
| | F2M2 | | |
| | F2M3 | | C2 |

Figure 62 – Option matrices to each innovation challenge (George, 2012)

**The sub-system concept generation** therefore consists of matching the combinations of Stage 3 to the option matrices for effective exploration. The measures selected are the most optimistic ones (derived from Stage 2); answering innovation challenges produces the possible structures of the sub-systems; and the ultimate result of Stage 4 is modular realizations of the requirements (having decomposed the problem into sub-functional modules, satisfying each module will be a building block of the holistic system).

Stage 5: Arranging the sub-concepts to illustrate a comprehensive concept

The conceived designs of the preceding stage have to be combined in a homogenous manner to obtain the sought out comprehensive solution. The cornerstone is the MM envisaged in the beginning (stage 1) of which measures are weighed against the potential of fulfilling their respective function. Sub-concepts are then formed via the option matrices which would lead to another, more comprehensive MM (Figure 63).

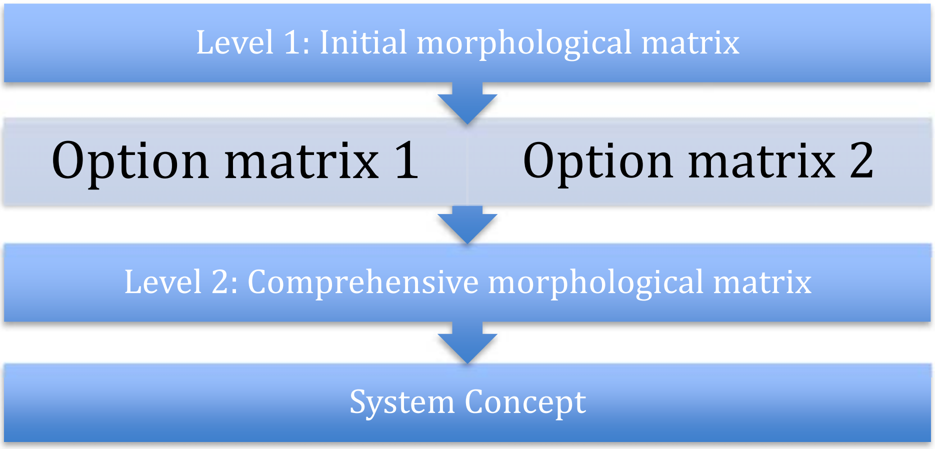


Figure 63 – MM integration procedure

The comprehensive MM (Figure 64) makes use of the functional combinations involved in the options matrices vis-à-vis the Sub-Concepts (SCs) while the remaining, singled out functions are included with their respective actuators as presented in the initial morphological matrix. Having filled out the second MM, stages 1, 2 and 3 are repeated in a similar manner as earlier but now arranging the SC, instead of measures, according to their resemblances (Figure 65).

| **Functional combinations** | **Sub-Concepts** | | |
|---|---|---|---|
| {F1 – F2} | SC12,a | SC12,b | SC12,c |
| {F3 – F4} | SC34,a | SC34,b | SC34,c |
| F5 | M5,a | M5,b | M5,c |

Figure 64 – Comprehensive MM

| | | **Measures for {F3 – F4}** | | |
|---|---|---|---|---|
| | | **SC34,a** | **SC34,b** | **SC34,c** |
| **Measures for {F1 – F2}** | **SC12,a**<br>**SC12,b**<br>**SC12,c** | **SYSTEM CONCEPT** | | |

Figure 65 – Holistic system concept

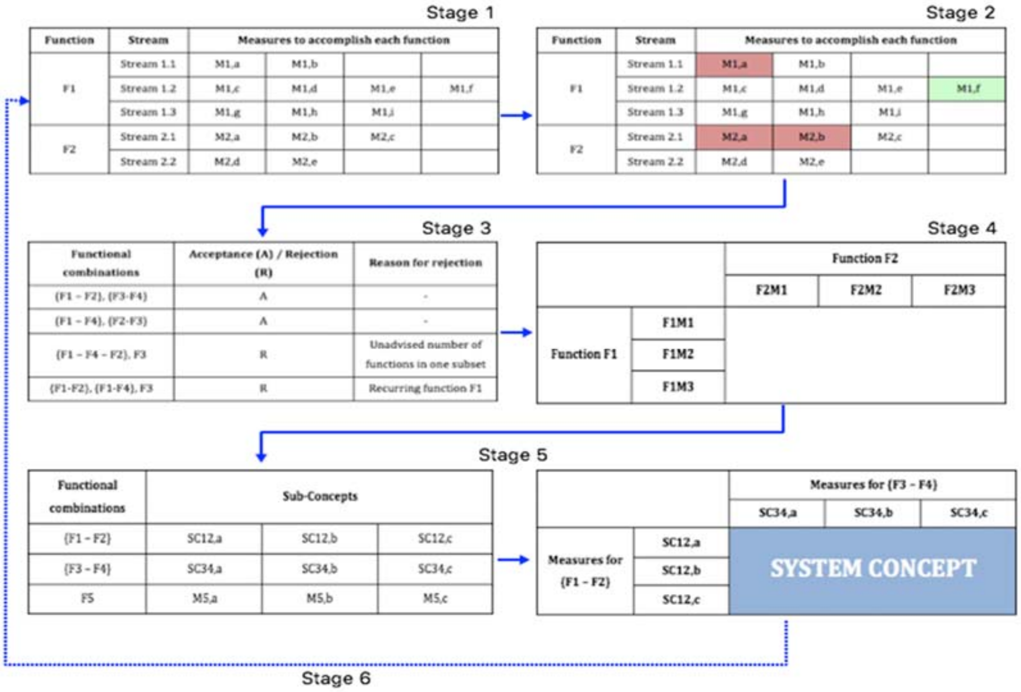
### Stage 6: Repeating and producing alternatives

The final sequence of the concept generation process is to generate alternative ideas in addition to the ones at the end of the last phase (Stage 5). Keeping in mind the amount of specificity and ordering of combinations, functions and measures realized, one can deduce that there are still a rather significant number of concepts to explore by varying the amalgamations of elements to construct new conceptual ideas and ending up with a sufficient quality and quantity of concepts.

### Summary of the method

The first stage consists of filling out the MM with the associated measures/actuators while grouping the prior into solutions streams based on commonalities and similarities. The following procedure is a preliminary filtering of the feasible and promising measures that are likely to be successful when utilized in the succeeding phases. The third step is based on joining functions into pairs to discover how these combinations with their respective actuators will be concretely discerned. In stage 4, sub-concepts are generated which will be re-integrated in another matrix at the fifth stage to pinpoint the specific modules vis-à-vis the sub-concepts. The result will lead to the embodiment of the holistic solution comprising of sorting all the required functions and respective solutions. The penultimate part of the concept generation method requires examining alternative solutions via alternative combinations of the functions and measures to produce substitute holistic solutions.

Proceeding with the steps mentioned above will result in a reduced level of abstraction (fewer implicit assumptions, validated hypotheses, enhanced innovation and bolstered confidence in the spawned concepts) when navigating the design space since additional details arbitrate the measures' feasibility and compatibility thus narrowing down the comprehensive concept generation scope. Additionally, the number of possible combinations will be reduced from a full factorial approach $N^S$ (N: number of measures/actuators, S: number of functions) to a more practical and achievable range of possibilities to explore; and subsequently less computational efforts are necessitated. Figure 66 displays the summary of the approach.



| Function | Stream | Measures to accomplish each function | | | |
|---|---|---|---|---|---|
| F1 | Stream 1.1 | M1,a | M1,b | | |
| | Stream 1.2 | M1,c | M1,d | M1,e | M1,f |
| | Stream 1.3 | M1,g | M1,h | M1,i | |
| F2 | Stream 2.1 | M2,a | M2,b | M2,c | |
| | Stream 2.2 | M2,d | M2,e | | |

| Function | Stream | Measures to accomplish each function | | | |
|---|---|---|---|---|---|
| F1 | Stream 1.1 | M1,a | M1,b | | |
| | Stream 1.2 | M1,c | M1,d | M1,e | M1,f |
| | Stream 1.3 | M1,g | M1,h | M1,i | |
| F2 | Stream 2.1 | M2,a | M2,b | M2,c | |
| | Stream 2.2 | M2,d | M2,e | | |

| Functional combinations | Acceptance (A) / Rejection (R) | Reason for rejection |
|---|---|---|
| (F1 - F2), (F3-F4) | A | - |
| (F1 - F4), (F2-F3) | A | - |
| (F1 - F4 - F2), F3 | R | Unadvised number of functions in one subset |
| (F1-F2), (F1-F4), F3 | R | Recurring function F1 |

| | | Function F2 | | |
|---|---|---|---|---|
| | | F2M1 | F2M2 | F2M3 |
| Function F1 | F1M1 | | | |
| | F1M2 | | | |
| | F1M3 | | | |

| Functional combinations | Sub-Concepts | | |
|---|---|---|---|
| (F1 - F2) | SC12,a | SC12,b | SC12,c |
| (F3 - F4) | SC34,a | SC34,b | SC34,c |
| F5 | M5,a | M5,b | M5,c |

| | | Measures for (F3 - F4) | | |
|---|---|---|---|---|
| | | SC34,a | SC34,b | SC34,c |
| Measures for (F1 - F2) | SC12,a | SYSTEM CONCEPT | | |
| | SC12,b | | | |
| | SC12,c | | | |

Figure 66 – Concept generation summary using the MM:

1. *Grouping the measures/actuators in the MM*
2. *Filtering innovative measures*
3. *Identifying combinations*
4. *Generating sub-system concepts*
5. *Arranging the sub-concepts to generate a holistic solution*
6. *Repeating and producing alternatives*

### 4.2.3 Using the morphological matrix for PSS concept generation

The motives behind adopting a functional decomposition approach when generating a PSS concept lie within the method in which integrated product-service development adopted its predecessor's (product) approach to generating solutions.

Andreasen (1992) argues that a system is represented by a function built of subdivisions which when combined satisfy customer needs. Cowell (1988) and Shekar (2007) underline the need to incorporate the customer and dedicated service staff with the conventional product developers to generate sustainable concepts. This cross-departmental merger would reduce business risks primarily when decomposing the main function into modular tasks easing the overall solution integration process as described by Cavalieri and Pezzotta (2012) and Tukker (2013). The latter, known as modular product service development under Wang et al. (2011) allows mass-customization of PS offerings while overcoming arising life cycle obstacles. Geum and Park (2011) and Marques et al. (2013) emphasize their antecedents by acknowledging the pivotal role of a structured approach in a PSS conceptualization activity: the present levels of functions are to be linked with feasible and compatible characteristics to meet functional as well as non-functional requirements whose integrated aspects' connections will result in a realistic and achievable concept.

PSS conceptualization and design differ from conventional product design by the insertion of services to achieve the required overall function. The latter requires integrating human actors such as providers and receivers who play a pivotal role regarding service quality and interactions.

Once the main function is outlined and well defined, it can be divided into sub-functions. Moreover, the providers and receivers are also fragmented: each sub-function will require its own PSS Provider (SP) and Receiver (SR). To clarify the service actors and their respective activities, Kim et al. (2010) suggest the use of the Service Blueprint (SB) tool exposed earlier with modifications to illustrate the providers and receivers' involvement (Figure 67). The internal interactions are invisible to the PSS receiver (s) and comprise of actions and activities within the manufacturer's environment. On the other hand, external interactions represent the activities visible to the PSS receiver (s). In our context, these activities, both visible and invisible will be treated as functions which comprise of their respective actors and measures to fulfill them (e.g. actuators).

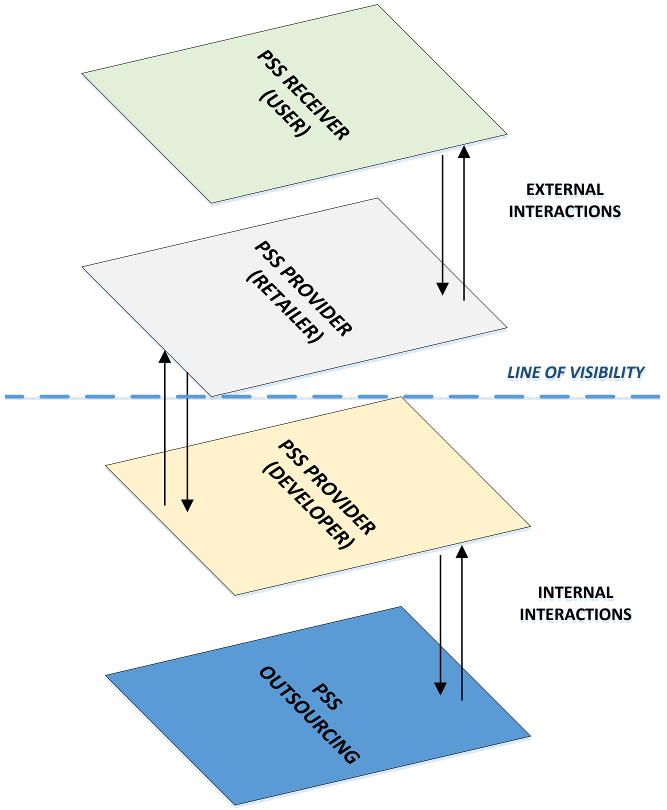


Figure 67 – Adapted PSS blueprint

The literature is redundant in stressing the need to address PSS design as a comprehensive model of functions, products, services and actors given that it is within the PSS culture to develop products and services in parallel and not through independent units.

The functions for a PSS concept skeleton can be derived from functional modeling by assigning the plausible SP and SR to the latter. Ensuing, would be linking the service activities to their SP and SR respectively and relating the respective product and service elements to formulize the PSS concept.

As revealed formerly, functions, providers, receivers, service activities, service elements and product elements should be studied as a whole to produce a PSS concept solution. Hence, the MM has to be modified in order to include the PSS considerations: mapping the functions (Figure 68) will generate the cogitated PSS functions targeted by the concept and the needed service/product elements are linked to the service activities involved in the concept generation process (Figure 69).

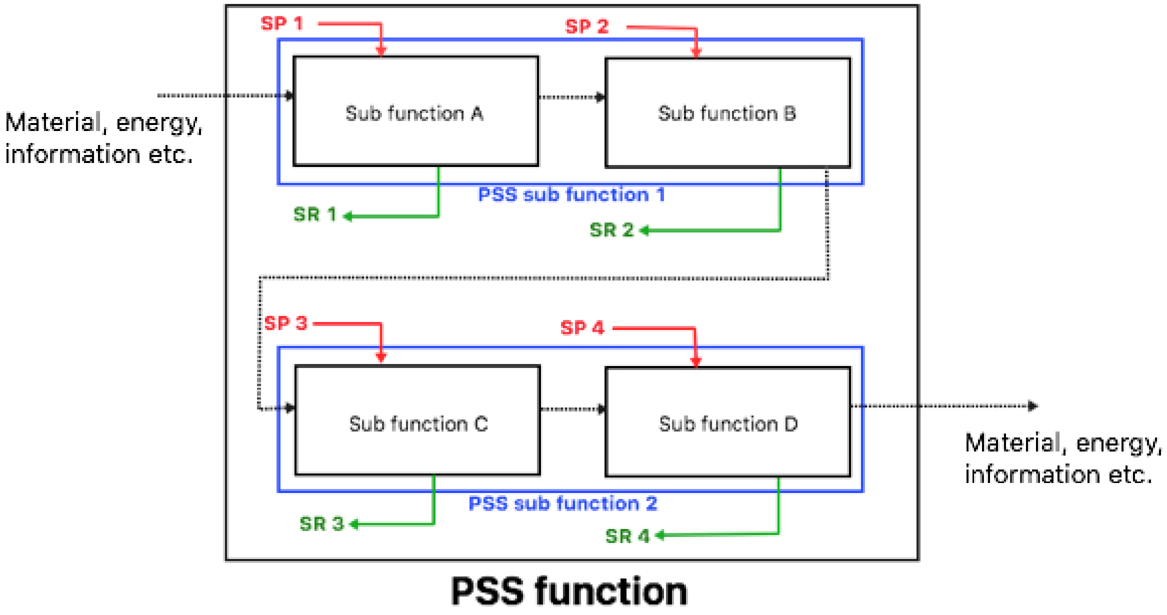


Figure 68 – PSS functional breakdown

| Sub-Functions | Elementary Functions | Product/Service Actuators | | | Actuator Provider | | Actuator Receiver | |
|---|---|---|---|---|---|---|---|---|
| PSS sub function A | A.1 | $P/S_{A1.1}$ | $P/S_{A1.2}$ | $P/S_{A1.3}$ | $SP_{A1.1}$ | $SP_{A1.2}$ | $SR_{A1.1}$ | $SR_{A1.2}$ |
| | A.2 | $P/S_{A2.1}$ | $P/S_{A2.2}$ | $P/S_{A2.3}$ | $SP_{A2.1}$ | $SP_{A2.2}$ | $SR_{A2.1}$ | $SR_{A2.2}$ |
| | A.3 | $P/S_{A3.1}$ | $P/S_{A3.2}$ | $P/S_{A3.3}$ | $SP_{A3.1}$ | $SP_{A3.2}$ | $SR_{A3.1}$ | $SR_{A3.2}$ |
| | A.4 | $P/S_{A4.1}$ | $P/S_{A4.2}$ | $P/S_{A4.3}$ | $SP_{A4.1}$ | $SP_{A4.2}$ | $SR_{A4.1}$ | $SR_{A4.2}$ |
| PSS sub function B | B.1 | $P/S_{B1.1}$ | $P/S_{B1.2}$ | $P/S_{B1.3}$ | $SP_{B1.1}$ | $SP_{B1.2}$ | $SR_{B1.1}$ | $SR_{B1.2}$ |
| | B.2 | $P/S_{B2.1}$ | $P/S_{B2.2}$ | $P/S_{B2.3}$ | $SP_{B2.1}$ | $SP_{B2.2}$ | $SR_{B2.1}$ | $SR_{B2.2}$ |

Figure 69 – PSS concept matrix (adapted from Haber, 2017)

The following step would be the selection of the elements that would be compatible and innovative, thus worth proceeding with (figure 70).

| Sub-Functions | Elementary Functions | Product/Service Actuators | | | Actuator Provider | | Actuator Receiver | |
|---|---|---|---|---|---|---|---|---|
| PSS sub function A | A.1 | $P/S_{A1.1}$ | $P/S_{A1.2}$ | $P/S_{A1.3}$ | $SP_{A1.1}$ | $SP_{A1.2}$ | $SR_{A1.1}$ | $SR_{A1.2}$ |
| | A.2 | $P/S_{A2.1}$ | $P/S_{A2.2}$ | $P/S_{A2.3}$ | $SP_{A2.1}$ | $SP_{A2.2}$ | $SR_{A2.1}$ | $SR_{A2.2}$ |
| | A.3 | $P/S_{A3.1}$ | $P/S_{A3.2}$ | $P/S_{A3.3}$ | $SP_{A3.1}$ | $SP_{A3.2}$ | $SR_{A3.1}$ | $SR_{A3.2}$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A.4 | $P/S_{A4.1}$ | $P/S_{A4.2}$ | $P/S_{A4.3}$ | $SP_{A4.1}$ | $SP_{A4.2}$ | $SR_{A4.1}$ | $SR_{A4.2}$ |
| PSS sub function B | B.1 | $P/S_{B1.1}$ | $P/S_{B1.2}$ | $P/S_{B1.3}$ | $SP_{B1.1}$ | $SP_{B1.2}$ | $SR_{B1.1}$ | $SR_{B1.2}$ |
| | B.2 | $P/S_{B2.1}$ | $P/S_{B2.2}$ | $P/S_{B2.3}$ | $SP_{B2.1}$ | $SP_{B2.2}$ | $SR_{B2.1}$ | $SR_{B2.2}$ |

Figure 70 – PSS concept definition (example)

PSS sub function A consists of 4 elementary functions. To fulfill A.1 two actuators are required (1 and 2) involving the provider (1) and the receiver (2). Similarly, to fulfill A2, the actuator (3) is required and it is provided by the provider (1) and delivered to the receiver (2). The rest of the elementary functions are assessed in the same corresponding manner. Thus, to fulfill (A) and (B), the actuators, providers and receivers needed are the ones shaded in grey in figure 67.

Different combinations are possible as mentioned earlier, hence apart from the compatibility of the actuators (measures) an evaluation of the proposed concept (s) is required. Seen that PSSs are thriving towards an improved environmental performance compared to conventional offerings, an environmental evaluation of the concept (s) is recommended and detailed below. We note that other evaluations are possible (i.e. economic, social, financial) but will not be addressed in this context.

### 4.2.4 PSS and Environmental Evaluation

The potential for PSS implementation to encourage a sustainable usage of the available resources has been thoroughly discussed in the literature. However, improved sustainability (environmental in the context of this research) is not a 'programmed' outcome of a PSS adoption (Costa et al. 2015). Consequently, the shift towards a PSS-based manufacturing strategy requires a thorough evaluation of not only the physical resources used to produce a product, but also the instigated services. A life cycle analysis on the tangible and intangible elements has to be performed. The associated life cycle stages (after design) and considerations in terms of a PSS are illustrated as shown in Table 23.

Table 23 – Product and Service considerations for a PSS LCA (Zhang and Haapala, 2011)

| Life Cycle Phase | Product | Service |
|---|---|---|
| Production | Reduced number of parts, realizing secure components, ease of assembly, eliminate error margins, modular design | Service user guides, contract negotiations and finalization regarding the required aims and results. |
| Delivery | Product, packaging, delivery and/or installation, | Support for service delivery, dedicated staff for product installation |
| Use | Product usage by the customer, product examination and performance analysis | Realization of the solution, Clear instructions and performance evaluation |
| Disposal | Recycling the product or parts of it, remanufacturing, ease of disassembly | Reverse logistics support, product recovery schemes, product's condition monitoring prior to recovery. |

As seen in Table 23, the product and service components represent the respective product and service models that a PSS instance integrates. Acknowledging the intricate relationships involved, understanding how the PSS concept was generated and grasping the rationale behind combining the tangible and intangible components is pivotal to model the PSS's life cycle and to run a credible environmental analysis (Garetti et al. 2012). To realize the latter at a conceptual stage of the design, three successions must be carried out (Fargnoli and Kimura, 2006):

1. An initial eco-assessment to identify the most vulnerable parts for prioritizing interventions with higher gains.
2. Analysis of the realizable interventions.
3. Illustrating the critical modifications as ecological needs.

These sequences, applied to conventional products exemplify Fargnoli and Kimura (2006)'s 'Screening Life Cycle Modeling (SLCM)' approach consisting of outlining a base scenario to distinguish the main indicators, alternative scenarios founded on the base scenario, simulation of the life cycle of each of the prior via LCA, and analyzing the results to select the most optimal solution (Fargnoli et al. 2004; Fargnoli and Kimura, 2006).

#### 4.2.4.1 Life Cycle Assessment

The approach to evaluate the related impacts from an environmental perspective, the most important criteria to interpret PSS performance, is based on the LCA methodology which incorporates all the life cycle stages an offering goes through (Chou et al. 2015). *"Life Cycle Assessment has been described as a cornerstone of current practice in industrial ecology. It is part of the ISO environmental management standards ISO 14040:2006 and ISO 14044:2006, and promoted by the European Union and the United Nations Environment Program. The value of LCA lies especially in its ability to identify a product's environmental impact across its whole life cycle, studying the inputs and outputs of the processes related to its production, use and end-of- life* (Vezzoli et al. 2014)."

The LCA tactic, assessing the potential ecological impacts of a product system, is normalized with the ISO 14040:2006 series standards and estimates its associated effects in terms of green house gas emissions, radiation, ozone layer depletion, carcinogens, climate change etc. (Lanoe et al. 2013). Three axis are adressed in an LCA study: goal and scope definition, life cycle inventory analysis and life cycle impact assessment.

Goal and scope:

The objective of the context in which the solution is being developed has to be outlined. Is the firm seeking to develop a new service, a new product, or to improve an existing solution? A precise and accurate description of the task at hand provides useful information on the processes that may intervene in the design development sequence, i.e. defining the main function to be fulfilled, the funcional unit, what features to consider, tolerance levels and envisioned lifespan among others.

In this study, the identification of the needed functions results from the morphological matrices and QFD tactic established earlier to depict the core functions and its sub-modules thus setting up the requirements to run a LCA.

The second area to tackle is the life cycle stages of the system such as material processes, type of production, EoL considerations. The increased level of detail at this stage results in a more accurate assessment of the concept in question. For each process, the materials used, the type of material, the measurable unit will be defined to constitute a homogenous comparison at the end of the evaluation.

Life cycle inventory analysis:

The second axis consists of specifying the materials used from a product's perspective vis-à-vis their designated processing scheme. For example a plastic component can be made of poly-phenylen, poly-carbonate, poly-propylen… as well as any other related element. For instance, making the plastic material can be a mix of two sub-components (i.e. poly-phenylen and poly-carbonate) which would necessitate a sort of transformation such as extrusion, moulding, foaming etc. Going through the analysis in such a manner would decompose the tangibles into building blocks with distinct characteristics that would adhere when enclosed in a holistic perspective. The relevant database to implement can be on of many, of which the most common are indicated by Lanoe et al. (2013): EcoInvent, Idemat 2001, Industry Data 2.0, Franklin USA 98, ETH-ESU 96 and BUWAL 250.

Life cycle impact assessment:

The opted assessment method is the Eco-Indicator 99 (EI99) which is a damage-oriented technique assessing the impacts of carcinogens, respiratory organics and non-organics, climate change, radiation, ozone layer depletion, ecotoxicity, acidification, land use, minerals and fossil fuels (Figure 71). "*The EI99 reflects the present state of the art in LCA methodology and application. This of course does not mean that all problems are solved. Further developments in environmental science, material technology and LCA methodology will take place and should result in future improvements of the Eco-Indicator. But we are convinced that the revised Eco-Indicator methodology is sufficiently robust to play an important role in eco-design for the next years* (Eco-indicator 99 Manual for designers, 2000)". The assessment activities incorporate the goal, scope and life cycle inventory analysis elaborared above in five key sets:

1. Establishing the objective of the EI calculation by describing the product/product component at stake and defining whether it is a single product analysis or a comparison vis-à-vis the needed level of precision and accuracy.

2. Describing the life cycle stages such as the type of production, processes involved in manufacture, use, waste and disposal related scenarios.
3. Quantifying materials and processes: performance is calculated in terms of functional units (quantity, temperature, duration…) specific for a given process. Any missing information can be meticulously estimated and returned to, once the analysis is finished to reflect on the assumption made.
4. Documenting the materials and processes used with their respective amounts and obtaining the relevant EI values for each. Scores are calculated by multiplying the latter two and summing up the results.
5. To conclude, the scores have to be interpreted and the assumptions verified for validity.

Additional details can be found in Eco-indicator 99: Manual for designers, (2000).

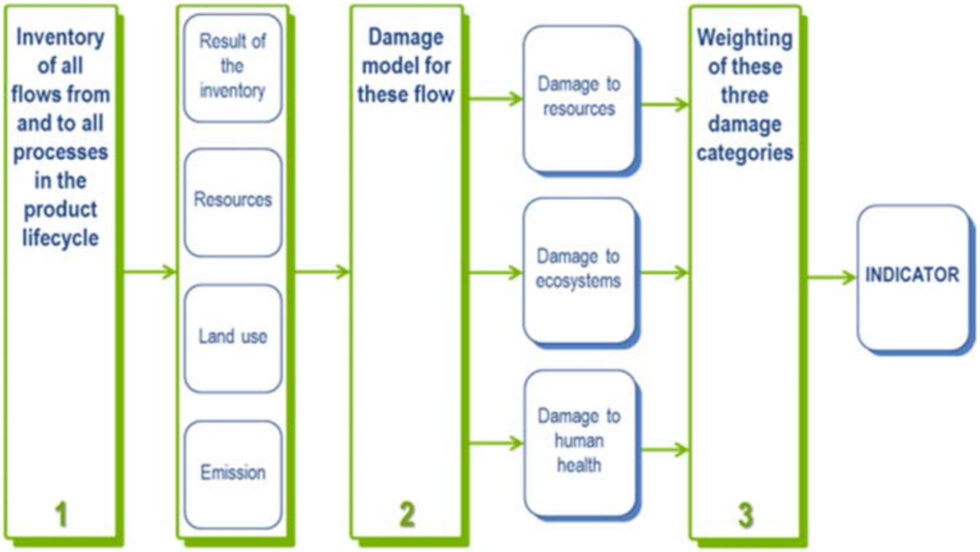


Figure 71 – Eco-Indicator 99 evaluation technique (Goedkoop and Spriensma, 1999; Haapala et al. 2008)

#### 4.2.4.2 PSS concept assessment

Assessing the various sequences involved is the initial point of the environmental assessment which requires consequential considerations when developing a given system in order to optimize the offering's ecological performance (Fargnoli et al. 2014).

In order to simulate the life cycle model of the PSS, the 'Screening Life Cycle Modeling (SLCM)' technique concretized by Fargnoli and Kimura (2006) will be implemented and adjusted for this research. The authors portray the SCLM procedure as follows:

1. *"Base Scenario (BS) definition: in this phase, the base life cycle model is defined, stating main parameters and/ or indicators.*
2. *Alternative Scenarios (ASs) definition: on the basis of the preliminary study concerning the problem which is being studied (i.e. a particular need of the customer, a specific law requirement, etc.) or of precise company needs, several models are developed.*
3. *Simulation: in this step, the life cycle analysis of both the BS and the ASs are carried out.*
4. *Analysis of results: the results of the simulation are critically analyzed in order to deploy a feasibility study and to single out possible modifications and alternatives* (Fargnoli and Kimura, 2006)."

The BS in a PSS context would be to analyze what the stand-alone product's implications are. Notable information to integrate in this phase for a credible establishment of the BS, but not limited to, are: life span, materials used, types of processes involved, product stages, type of delivery/transport, end-of-use schemes, etc.

The ASs imply the shift from the traditional product to a PSS-based theme (PO, UO or RO). The emphasis on the tangible/intangible side of the developed solution depends on the adopted approach to incorporate PSS thinking: the higher is the the focus on the product, the more PO-oriented is the stance while the higher the focus is on the service, the more RO-oriented is the position. For example, a conventional product centered sales can be an air-plane turbine where the latter is manufactured for an intended life span of X years and ownership is transferred to the customer (airplane company) for a certain fee. Replacing this scheme with a UO PSS like Rolls Royce did, shifts the process to providing the motor to the aireplane company while maintaining ownership of the engine, executing its maintenance and handling the EOL process while charging the airplane company for flight hours instead of a one-time fee (Tan, 2010). Simulation, in an ecological scope, relies on the usable information regarding the solutions at hand. Applying LCA using the EI99 method allows obtaining a preliminary assessment of the situation: a benchmark reference. Starting with the BS, having the product at 'hands reach' allows a detailed eco-evaluation of the artifact throughout its life cycle phases (processes, transportation, use, EOL scenarios). Afterwards, the ASs identified are scrutinized as well, thus enabling a benchmarked comparison of the PSS concepts against the existing/old artifact (Figure 72 and Table 24). The review of the concepts compared to the conventional product allows validating or rejecting the PSS proposal. As cited earlier, a positive green outcome is not an automatic result of substituting a product-centered option with a PSS alternative. Moreover, PSS alternatives generate from diversifed product and service combinations which consequently produce different conclusions. The most suitable one can be deduced from the appraisal achieved.

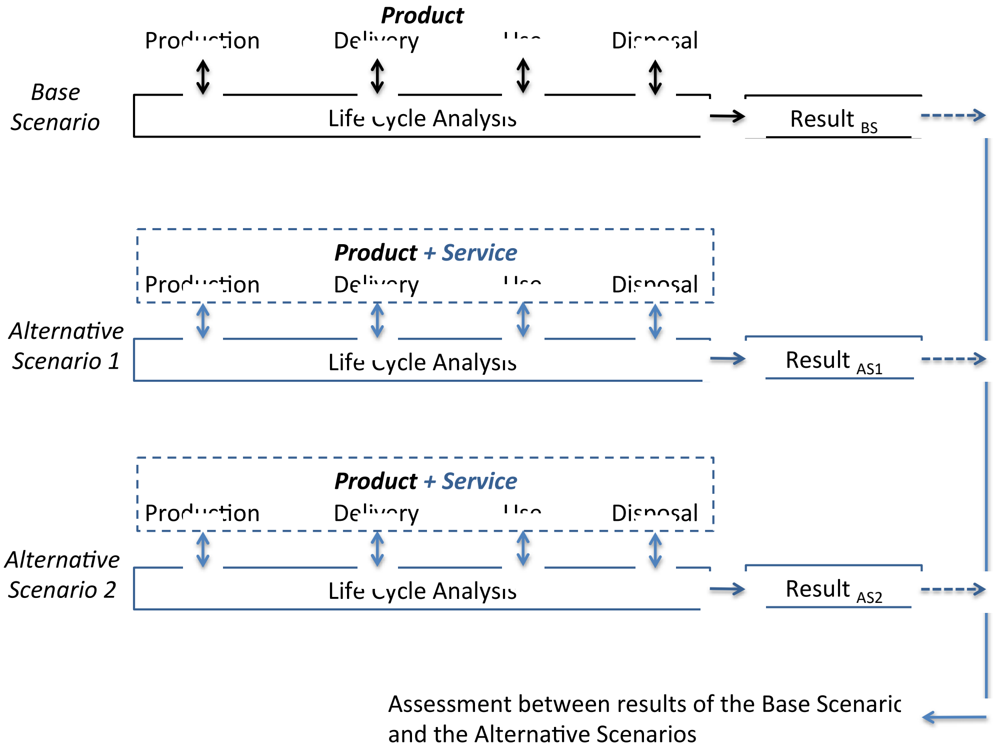


Figure 72 – PSS assessment modeling

Table 24 – PSS assessment modeling inputs

| **Life Cycle Phase** | **Product** | **Service** |
|---|---|---|
| Production | • Energy<br>• Materials<br>• Manufacturing Processes<br>• Techno-sphere inputs<br>• Etc. | • Modularity considerations<br>• Design robustness<br>• Ease of access, of maintenance…<br>• Etc. |
| Delivery | • Packaging material<br>• Type of transportation<br>• Distance of transportation<br>• Etc. | • Support for service delivery<br>• Dedicated staff for product installation<br>• Etc. |
| Use | • Product consumables (energy, infrastructure, wearable parts…)<br>• Etc. | • Realization of the solution<br>• Instructions and responsibilities<br>• Etc. |
| Disposal | • Waste treatment<br>• Waste management<br>• Etc. | • Take-back schemes<br>• Re-manufacturing possibilities<br>• Recycling<br>• Product recovery/re-use<br>• Etc. |

Each of the respective inputs as well as LCA outputs can be visualized on the model shown in figure 73. The extent of breaking down each phase depends on the complexity and needed details to accurately and correctly represent the intended segment of the model. An illustration of the inputs' representation (to be filled with actual numbers) can be seen in Figure 73. Calculation data can be inserted into JMP, Excel or similar software to visualize and compare scenarios.

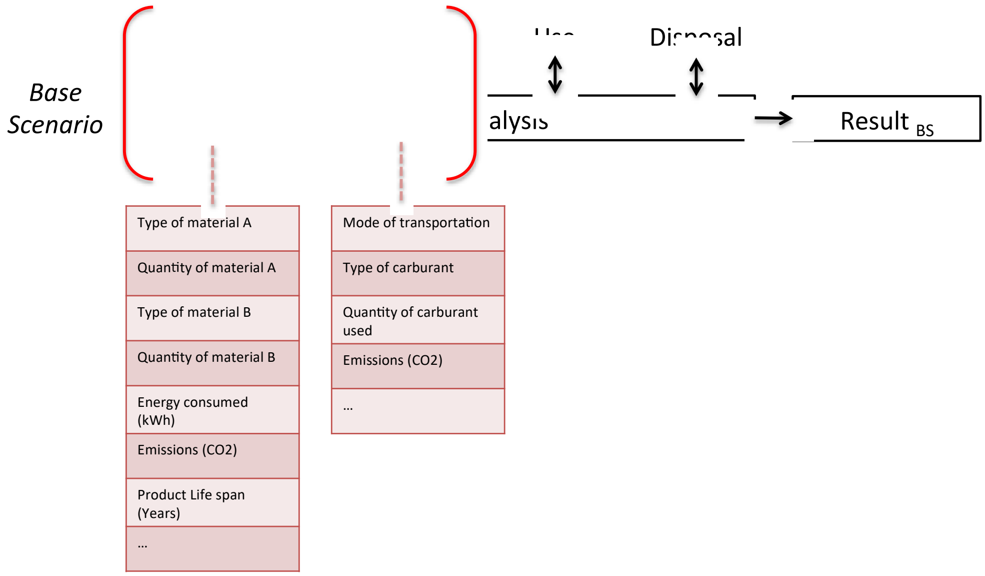


Figure 73 – PSS modeling example applied at the BS level.

### 4.2.5 PSS components and modules

The PSS actuators can be regarded as the components of the PSS at hand. In addition to the environmental evaluation. The assessment (evaluation) of the components can help reduce the conceptualization efforts and hence resources if carried out in a systematic and pragmatic manner. Moreover, carrying out the latter at an early design stage can evade future errors and risks that may arise at an upcoming phase of the PSS development. To do so, and in homogeneity with the QFD based approach exposed earlier (Section 4.1.2), QFDforPSS phase II is applied. This is in line with hints exhibited by Peruzzini et al. (2014) who argue that a QFD-based approach supports companies in producing efficient and sustainable PSS solutions by means of The House of Quality (HoQ) to outline the most dominant PSS components to fulfill, optimize and refine the solution and maximize the performance of the system. In detail, the second phase of QFDforPSS allows defining the most critical components of the PSS solution in relation to the product and service characteristics that the solution requires. The definition of the components can lead to modules which would mitigate the risk of overdesigning (or "over-requirement" to use a software engineering language (Shmueli et al. 2015)) and consequently to both an extra investment of resources (in terms of time, costs, human resources) and the generation of design conflicts (Smith et al. 2012; Cho et al. 2016). As noted by Song and Sakao (2016), solving design conflicts in a PSS context is more difficult than in a conventional product-reliant environment. In fact, once the customers' requirements are defined, a large effort is requested to effectively transform them into design requirements (Hakanen et al. 2016) and to address the PSS provider strategies considering the whole PSS life cycle, i.e. on a long-term perspective (Meier et al. 2010). Moreover, taking into account a PSS life-cycle, if the customers' requirements change, the provider might need to change or modify the existing offering quickly. This can require additional resources and more significant design efforts due to the interdependences among the PSS components (Sakao et al. 2017).

To deal with these problems, PSS providers should adopt a holistic approach that allows them to effectively understand the customers' needs and wants and to manage the whole life cycle of the provided solution, thus making the possibility of changing or updating the PSS components feasible.

In the literature, several studies have addressed these issues as observed by Pigosso and McAloone (2016) and Sun et al. (2017). Aurich et al. (2006) identified process modularization as a promising approach for the integration of product and service design processes, proposing a modular design framework for technical PSSs. Similarly, Li et al. (2017) stressed on the fact that defining a system designed as a series of modules for the physical product and the services, which is aimed at satisfying the customer needs, plays a key role in solving conflicts between offering customization and the PSS providers' bottom line. Regarding this aspect, the economic objectives for manufacturers are strictly related to how efficiently the services are provided rather than the number of sold products (Fargnoli et al. 2012). Qu et al. (2016) revealed that, although numerous studies focus on design methodologies for PSS development, more attention should be directed to improve modularity by means of empirical research works. At a more detailed level Song et al. (2015) discussed the adoption of extended graphical tools (such as service blueprint and fuzzy graphs) to identify service components and partition modules in the context of Product-Extension Services (PES). Their development is still an unexplored subject.

Instead Sakao et al. (2017) focused on the need to generate service modules for customizing PSSs, extending the use of the design structure matrix (DSM) method to the domain of service modularization in order to define and cluster service components.

The generation of modules of PSS components was also addressed by Kimita et al. (2010), who applied the Axiomatic Design (AD) method (Suh, 2001) to achieve such a goal. On one hand, this tool resulted in being very effective for the definition of the PSS features (i.e. service activities and product behaviors, as well as attributes of entities) and modules. On the other hand, they underlined the difficulties in the definition of the information to be used as input, which should be carefully prepared to avoid design conflicts, e.g. uncoupled modules. Hence, a proper methodology to address such an issue is needed. Similarly, Song and Sakao (2017) underlined the lack of a systematic and comprehensive support for PSS customization.

Thus, the identification of service (and PSS) components and modules is beneficial to achieve customer satisfaction. To do so, PSS providers need to visualize the actual and expected integration of products and services, as well as its progression through the PSS life cycle, taking into account both the developer and the customers' perspectives. To achieve such a goal, the service blueprint (Shostack, 1982) is widely used to effectively map the whole PSS life-cycle considering all stakeholders involved (Morelli, 2006; Boughnim and Yannou, 2005; Barquet et al. 2013; Reim et al. 2014). Such a tool fits with the features of both the flow and scenario models (Sakao and Lindahl, 2009), and allows engineers to combine activities and functions to address solutions at different stages of the PSS development (Song et al. 2015; Kim et al. 2016).

As discussed earlier, the definition of service modules satisfying the customer needs plays a key role in PSS development and supports engineers in avoiding possible conflicts among the various PSS components. Although its use in the PSS context is scarcely documented (Kimita et al. 2010; Hosono et al. 2011), we believe that the use of the Axiomatic Design (AD) method can be very beneficial to provide an effective analysis of the PSS functional requirements, providing independent modules of PSS components. The main reasons of this assumption are based on this tool's recognized properties (Cheng and Chen, 2010), allowing engineers to create synthesized solutions in the form of products, processes or systems that satisfy perceived needs through mapping and clustering Functional Requirements (FRs), Design Parameters (DPs) and Process Variables (PVs) (Janthong et al. 2009) as schematized in Figure 74. (More information on AD is shown in Appendix C). Moreover, its integration with the QFD method augment the effectiveness of the latter, providing independent solutions, as remarked among numerous researchers (i.e. Kulak et al. 2010; Du et al. 2013).

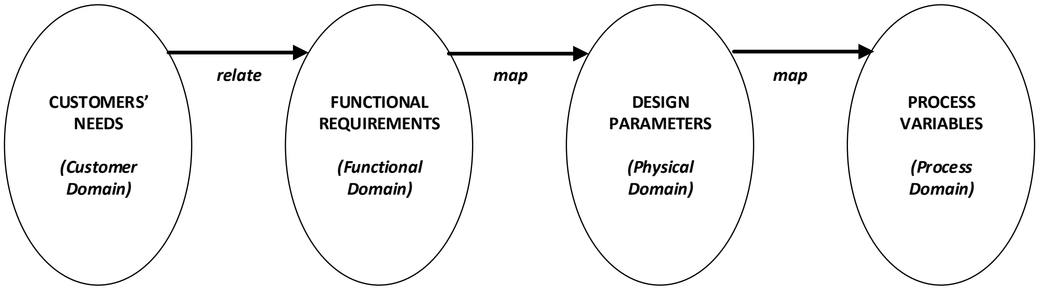


Figure 74 – General scheme of the Axiomatic Design approach.

The proper integration of these tools in a framework that guides engineers in the development of a PSS is needed (Pigosso and McAloone, 2016), to combine and augment their effectiveness, especially when considering operative needs of PSS providers. With this aim in mind, an integrated methodology was developed Figure 75, where the detailed activities and their supporting tools are depicted.

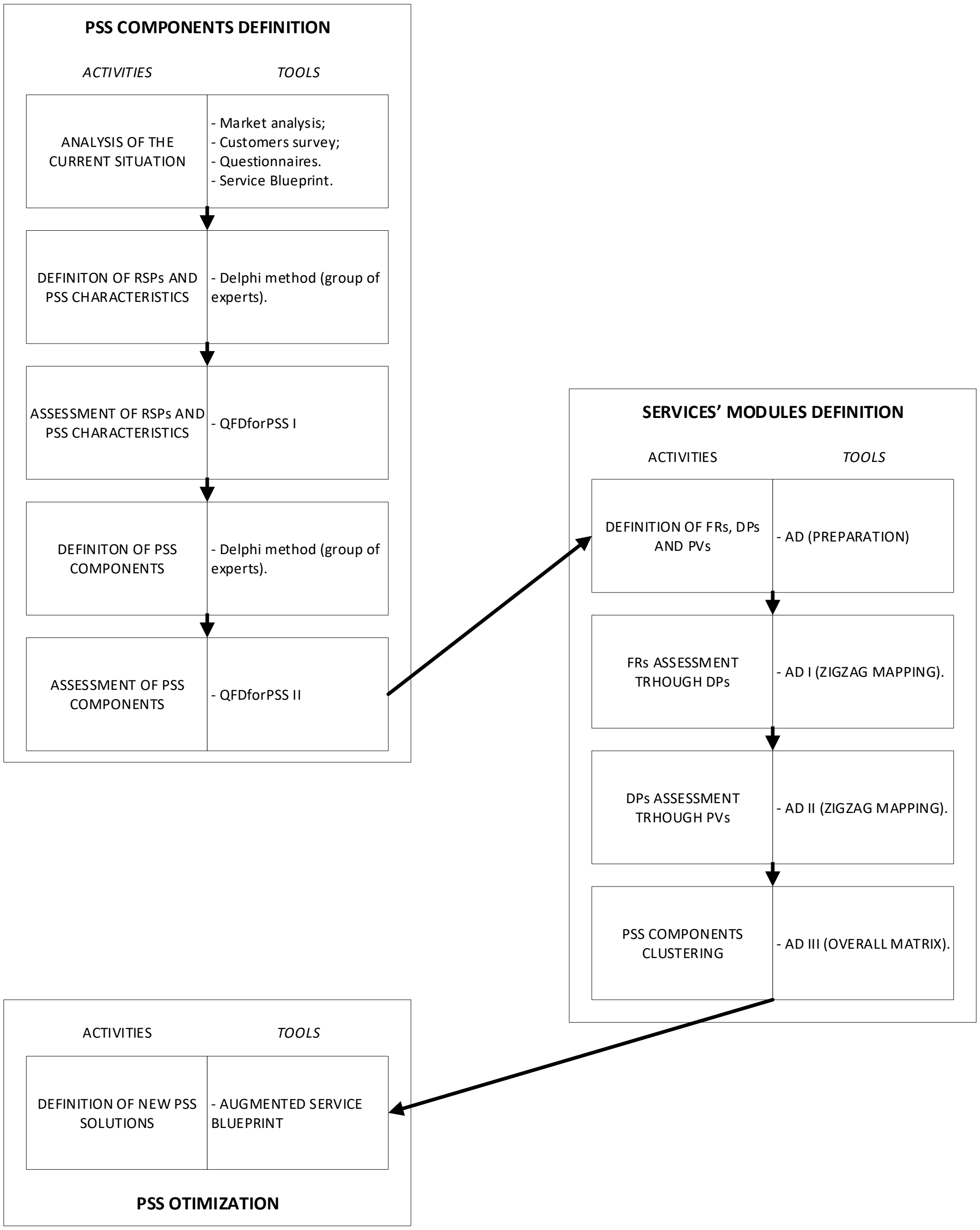


Figure 75 – Scheme of the proposed methodology.

In summary, the PSS concept design phase is illustrated in Table 25.

Table 25 – PSS concept generation summary

| Sequence | Description |
|---|---|
| Functional modelling | The starting stage is defining the overall function and identifying the main inputs and outputs such as energy, information, service provider, service receiver etc. The overall function is then decomposed into sub-functions using a morphologicla approach, and arranged according to logical flows and compatibility. Similarly the service providers and receivers are differentiated into sub-providers and sub-receivers.<br>Having classified the sub-functions and respective components, grouping the prior would generate the sub-concept PSS functions. |
| Service activities and altered (augmented) service blueprint | The feasible and possible service activities are listed and linked to the functions of the previous stage and thus the pivotal function-activities are outlined. Supporting activities are also made visible and form the supporting processes. |
| PSS conceptualization | The concepts ideated rely on the sub-functions whose combination provides a holistic conceptual solution. For each function, the identified receiver and provider are assigned a specific activity with their respective activities or means. Each plotted combination utilizing different activities and elements would lead to diverse PSS concepts. In addition, modularization represents a viable option to avoid overdesigning and optimizing resources at a conceptual design level while focusing on solution’s performance. |
| PSS concept evaluation and modeling | Each generated concept in the preceding stage has to be assessed.<br>From a design perspective, QFD identifies the PSS-Functionalities relationships and highlights strong and weak points in the design.<br>From a life cycle perspective to accept or reject the conceived model. The Eco-Indicator 99 is the utilized approach in most cases given its versatility and robustness. |

## 4.3 Embodiment Design

The following will develop the approach to effectively perform a detailed design in order to build an embodiment sequence of a PSS offering. The latter will be versatile, holistic and robust enough to cover all the essential requirements for a successful implementation.

1. **Usability**

The first criterion is the adaptability of the design framework. A PSS varies from product-centered (PO), product-service distributed (UO) to service-centered solutions (RO). The main difference that segregates these three types is the involvement and level of product-service integration.

In a PO setting, the approach relies heavily on product design while services are viewed as add-ons that supplement the product's value. Value significance lies primarily within the tangible artifact while services' involvement is relatively trivial. In a UO scheme however, physical and non-physical elements are developed simultaneously to answer market needs. The level of integration varies relatively to the product-service association extent. Thirdly, in a RO context, the service is the core of the offering and it is the provider's role to design the product in the most efficient manner to support the service.

The conceptualization phase provides a high-level description of the functions to achieve and the product-service combinations possible to achieve those goals. Nonetheless, traceability is relatively weak given the ambiguity when customers express their needs. Concretizing these needs in an engineering language is the cornerstone of a feasible design.

The first criterion to embrace is therefore the inclusion of both PSS elements from the beginning of the design, and build the prior in an incrementally cognitive fashion.

Initial objectives are described, quality attributes and CTQs are established and the setting/environment is set out. Several possibilities can co-exist and are consequently registered in a database where combinations result from logical reasoning and available resources. Using functional modeling from the concept phase aids in grouping the product and service elements into workable configurations.

### 2. Practicality (process flow and design activities)

Throughout this research and the extensive literature assessment carried out, a notable weakness of the present design approaches is the absence of a structured approach to develop a product-service solution. A process flow/map adorned with design activities and milestones with a sufficient amount of details is required.

The Service CAD and Service Explorer delineate the design process into three stages: initialization, development and completion. The software, using goal quality and environment as inputs, provides an initial PSS model with a limited number of activities linked to supporting elements, which the software interprets in a particular method. However, the interpretation may vary and a different understanding can take place when the user manually modifies the auto-generated model to fulfill unrealized goals and assess the level of quality reached. Completion takes place when all objectives are met and properly evaluated.

In the integrated product and service design processes approach, service blueprinting was adopted and divided the design activities and design flow into two pillars: a system level and a component level. Alonso-Rasgado et al. (2004) also emphasized the use of the blueprint tool to visualize the functions and activities required in each time schedule. Moreover, the SADT representation is introduced to depict the activities, information, inputs and outputs needed to analyze the extent of the product-service integration within the blueprint. The addition of the time frame is valuable to concretize each activity's details and the relationships among the prior, making up the process flow. The RDMo exploits the schedule and extends it throughout a life cycle perspective, allocating the activities to their respective life cycle phases, i.e. production, development. Last but not least, the Spiral Process Model adapts the RDMo phases to a life cycle context utilizing the terms: beginning of life, middle of life and end of life.

The result is a Structure Design Blueprint (SDB) portrayed in Figure 76 and followed by its explanation.

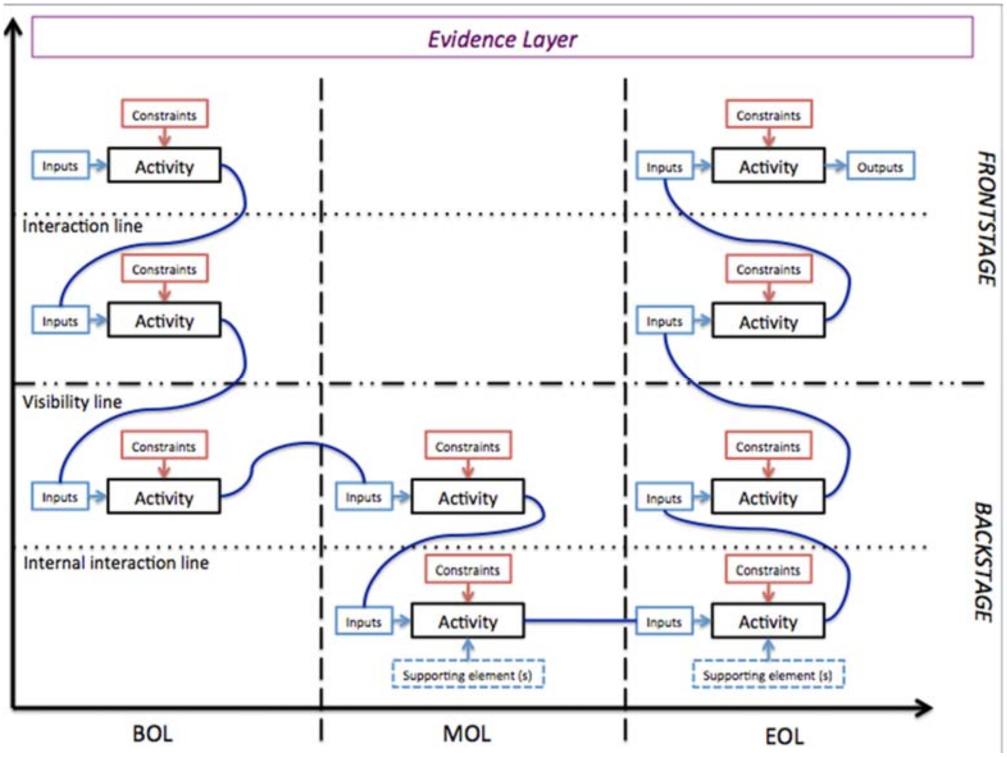


Figure 76 – Structure Design Blueprint (SDB) (Haber and Fargnoli, 2017a)

The SDB utilizes two axes to outline the process and design activities flow. The horizontal axis represents the life cycle stage that is divided in three as seen above. Additional details can be added by decomposing each stage into more accurate junctures. For example, the EOL can be split into: disposal (client disposes of the product), recovery (the manufacturer retrieves the disposed item), recycling (the provider recycles the recyclable material) etc.

On a vertical scale, two main platforms stand out: frontstage and backstage. The first represents the activities visible from a customer's point of view and comprises of customer activities and customer-manufacturer activities. The second represents the 'invisible' activities such as production or packaging activities.

The evidence layer is the tangible evidence that the client interacts concretely with; in other terms, it covers all the tangible features that a consumer is exposed to.

The visibility line separates the activities visible and non-visible (hidden) to the customer.

The interaction line represents the client-provider contact and the internal interaction line illustrates the various contacts between different departments of the PSS developer.

Each activity, represented by a black box encloses 4 modules: inputs, constraints, supporting elements and outputs. The latter derives from the SADT representation elaborated by Trevisan et al. (2015). In the example above (Figure 76), supporting elements are visualized at the bottom layer of the backstage zone, but could well present in any other zone should the conceived solution require it. Additionally, outputs from each activity are considered as inputs for the following one, however each activity may also have its own inputs, which will be combined with the preceding activity's output. For instance, ordering a cup of coffee sees the output from the customer request as 'Coffee order' which would then be merged with coffee beans, sugar etc. when fulfilling the 'Prepare coffee' activity.

Supporting elements can be distributed into product and service elements when assessed at a component level where tangible and intangible parts are developed. It is vital to note that the starting point for product and service development as well as their association-building will derive from the outcomes of the conceptualization phase, where feasible arrangements are already assessed and made ready for extended, comprehensive development.

Constraints are displayed in red to display limitations, inputs in light blue, supporting elements in dashed-lines and the design flow is envisaged as the thick dark blue line making up the flow.

The final step would be delimiting the process flow by asking questions at the end of each major stage to ensure that errors are minimized and all aspects are truly captured before proceeding to the next. A design milestone checklist is an easy-to-use yet efficient tool to use to verify the process and activities flow.

### 3. Co-creativity (stakeholders and their roles)

Having a design plan laid out, alongside the activities required to carry out the task, it is inevitable to identify the various stakeholders involved in the process as well as their roles and capabilities. The basic structure of a product-service system network consists of a provider and a customer. The relationship that ties these two entities dictates the further stakeholders involved in the process. Who is involved, how are they connected, what are their influences and what are their goals are the questions to answer when identifying PSS actors

The first step is to identify the stakeholders: primary, secondary, social, and non-social ones. Primary stakeholders have a direct impact on the success of a PSS, secondary stakeholders are generally influential, social ones can be easily communicated with and non-social ones are those with whom communication is indirect (Van Halen et al. 2005). Figure 77 presents an example of the generic stakeholders that could be involved. The second step would be mapping the stakeholders and the possible connections and relations that bind them (Figures 78, 79). The third and final step would be prioritizing the actors to obtain a meaningful and balanced input into the development process (Van Halen et al. 2005). The suggested method is influence-interest matrix where the vertical axis evaluates the influence over the development process, the contribution to it and the influence over another actors' perception. The interest axis (horizontal) on the other hand depicts the interest in developing the PSS, the level of concern and impact power of the PSS on the shareholder (Figure 80).

A systematic representation of the PSS actors will abide by performing the ensuing tasks:

1. Relative position in the internal and external setting/environment:
    a. Acknowledging internal and external PSS resources
    b. Identifying existing and potential market rivals
    c. Identifying market position
2. Customer segment:
    a. Specifying possible customers
    b. Prioritizing customers and their requirements
    c. Distinguishing functional and non-functional requirements
3. Targeted users:
    a. Classifying users if doable
    b. Identifying benefits and respective relationships

4. Provider-customer relationships:
    a. Highlighting service functions
    b. Establishing a development plan
    c. Establishing provider-customer contact
5. Service value chain
    a. Identifying partners for the manufacturer/provider
    b. Establishing manufacturer-partners contact
    c. Agreeing with the client on the value proposition
6. Value chain constraints
    a. Recognizing constraints due to resources or partners
    b. Planning constraints' minimization
    c. Concretizing each actor's responsibility
7. Maintaining the PSS actor network
    a. Reviewing changes in the setting
    b. Reviewing risks in the relationships
    c. Planning to continuously improve the PSS.

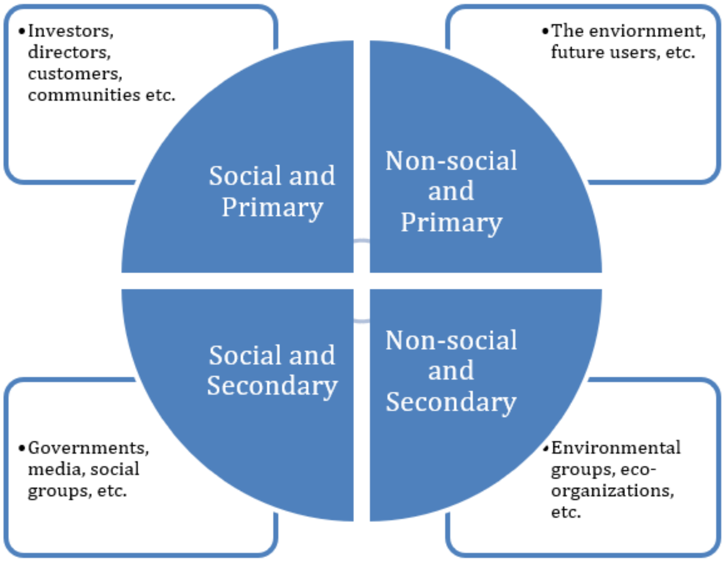


Figure 77 – Possible stakeholder categories and classification (adapted from Van Halen et al. 2005)

The flow model is the most dominant actor's network representation map and it is based on state parameters that represent the PSS influences on each of the designated participants. Expenditure of the flow model includes delineating the functions and activities' performers and receivers to better understand the underlying relationships (figures 78, 79).

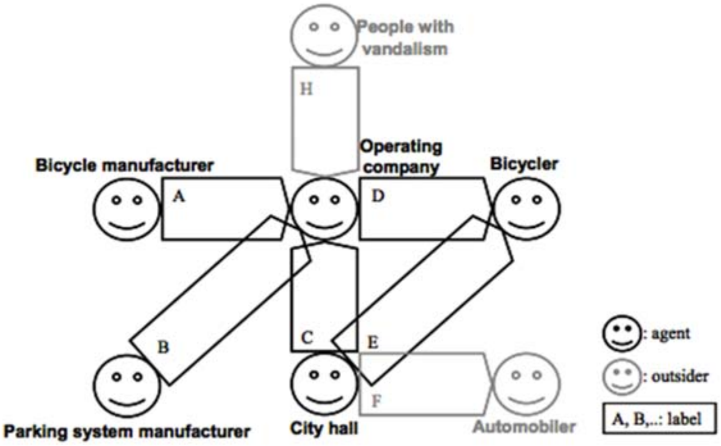


Figure 78 – Stakeholder mapping: Flow model example on Velo'V, a bike sharing scheme (Maussang et al. 2007)

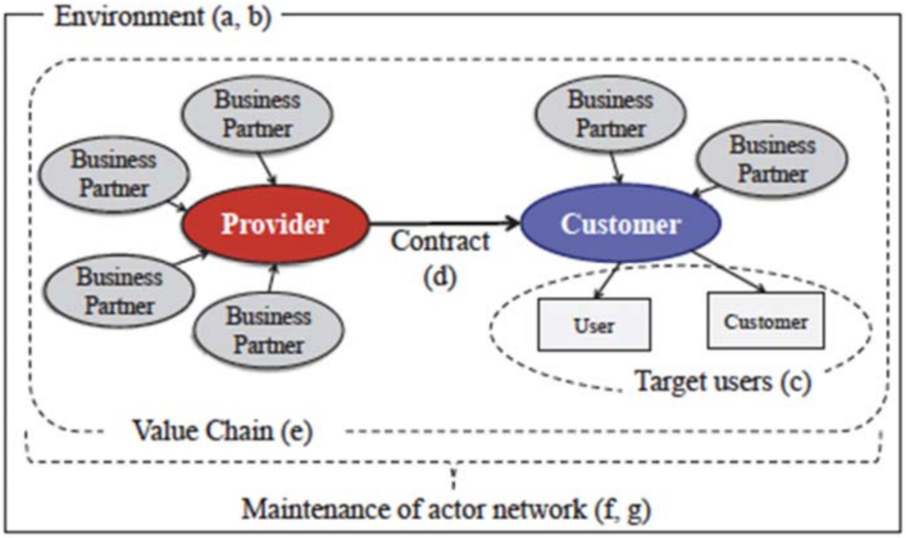


Figure 79 – Actor Network map (Numata et al. 2015)

The highly interested people are the stakeholders that the PSS developer must fully engross and satisfy, while the least interested people require enough work to keep them satisfied in a non-boring manner. On the other hand, high influence targets are a double-edge sword as they have the most to say regarding the PSS offering from one hand and can fluctuate interest from one side to another. A successful trade-off and awareness while prioritizing clients is vital (Figure 80). Answering the below questions will ensure a fruitful and positive prioritization:

- What are the economic interests of the task at hand?
- What motivates the consumers?

- What is the best way of communication?
- How important is their respective opinion?
- Who are the 3rd parties that can be dragged into becoming stakeholders, and how to secure their positive support?
- How viable and credible is the gathered information?

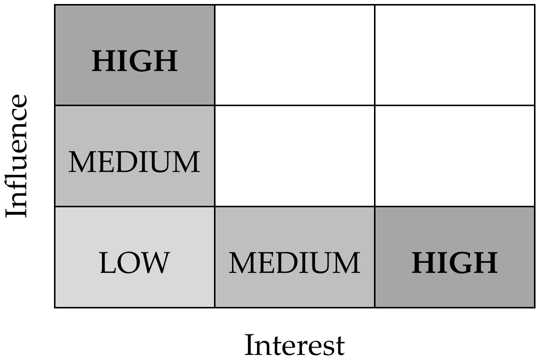


Figure 80 – Priority matrix

### 4. A systemic and systematic approach

Being methodical when developing a PSS, six main areas have to be covered during the design: the business model, the product, the service, the organizational hierarchy, the delivery channel and the actors' participation (Vasantha et al. 2012; Baines et al. 2007).

Analyzing the frameworks established by Barquet et al. (2013), Bonsfills (2012), Reim et al. (2014), Lee et al. (2011), and Alix and Vallespir (2009), an efficient business model for a PSS will have to cover the areas below:

1. Identifying the stakeholders in an organized manner and representing them in a clear and concise fashion.
2. Understanding customer behavior: preferences, usage patterns and customer-company communication/information channels.
3. Value configuration: the resources, assets, activities, partnerships and collaborations, and service delivery channels.
4. Capturing value whether it is an economic or non-economic value.
5. Sustainability, covered from an environmental side only throughout this research.

Having covered the description and details of each of the areas mentioned, the following (Table 26) will depict the tools allowing to successfully represent the latter.

Table 26 – PSS business model tools

| | **Defining the stakeholders** | **Customer behavior** | **Life cycle value** | **Value configuration** | **Seizing the value** | **Sustainability** |
|---|---|---|---|---|---|---|
| **Activity Based Environmental Costing** | | | | | X | X |
| **Business Ecosystem Map** | X | | | | | X |
| **Eliminate-Reduce-Raise-Create matrix** | | | X | | | |
| **Modified Ishikawa diagram** | | | | X | | X |
| **Persona** | | X | | | | |
| **Product Life Gallery** | | | X | X | | X |
| **SWOT analysis** | | | X | X | X | X |
| **Value Network Analysis** | | | X | X | X | |

<u>Activity Based Environmental Costing:</u> proper evaluation of product and waste flows as a means of tracing back the roots of below par performance and prioritizing decision making to reach higher levels of eco-performance. Extensive production knowledge is needed for a proper assessment of the costs and drivers associated to the production process (Figure 81).

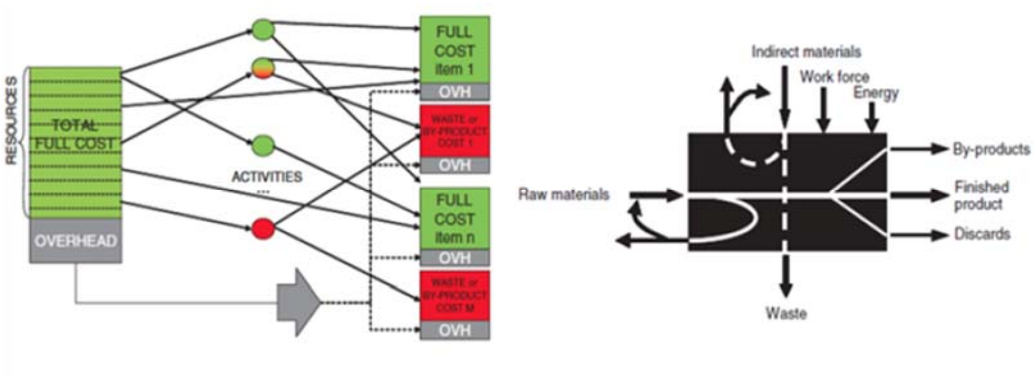


Figure 81 – Activity based environmental costing

<u>Business Ecosystem Map:</u> proper identification of the groups and teams making up the manufacturer's ecosystem (Figure 82)

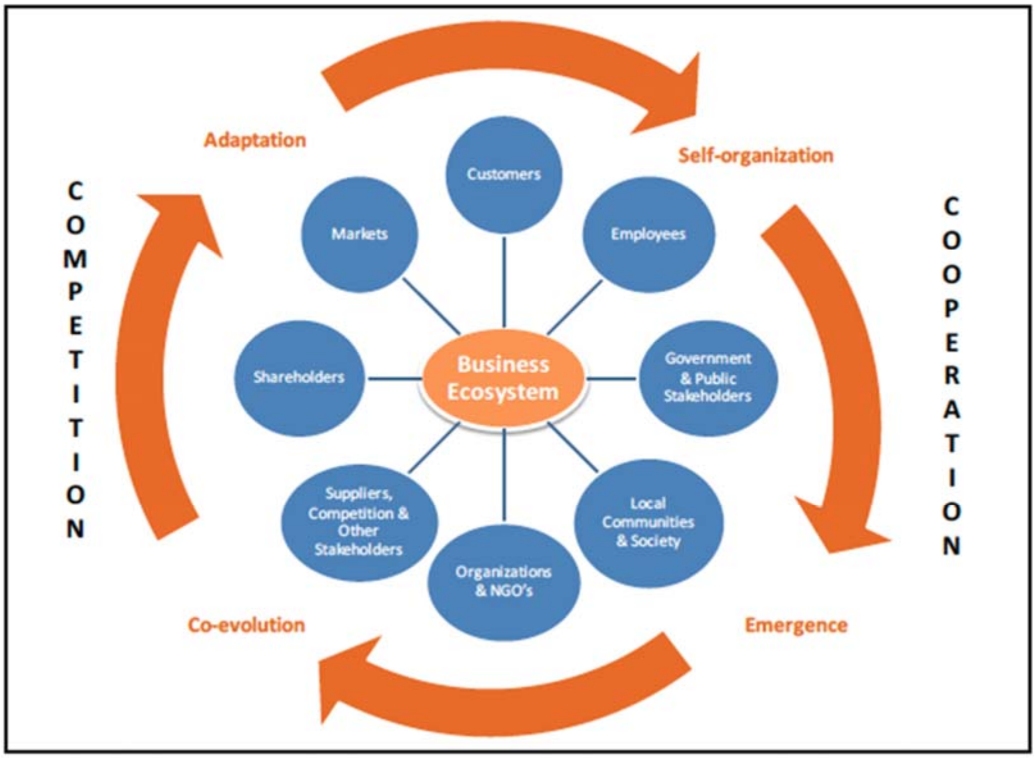


Figure 82 – Business ecosystem map (Bonsfills, 2012)

<u>Eliminate-Reduce-Raise-Create matrix:</u> identifying the factors that should be eliminated, the factors that should be reduced, the ones that have to be increased and the ones a company should create to optimize value via creating a new market space, surpassing competitors and create and answer new market demands (Figure 83).

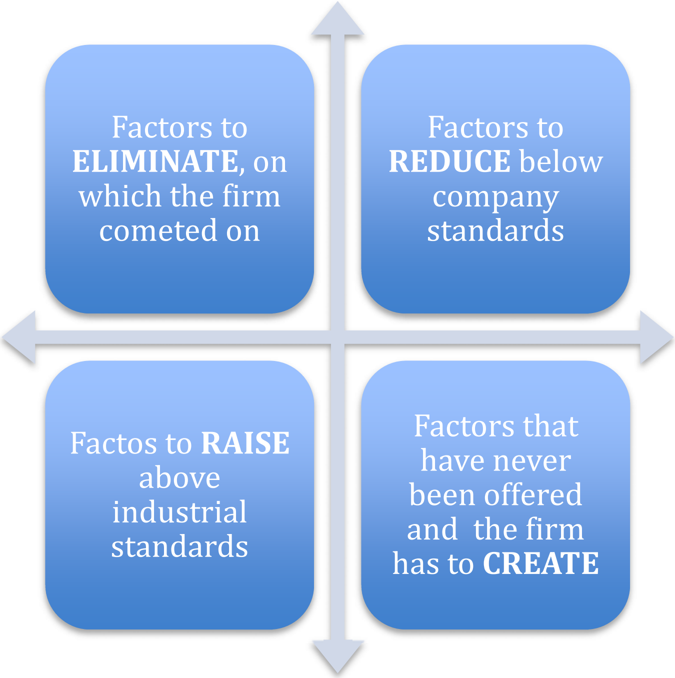


Figure 83 – Eliminate Reduce Raise Create matrix (adapted from Bonsfills, 2012)

<u>Modified Ishikawa diagram:</u> using the same representation of a fishbone diagram, the target will be the Value to generate instead of a problem, and describing how to achieve and attain this value will replace the causes of a problem.

<u>Persona:</u> prototypes of the potential users built through a widespread observation of the latter. A persona is thus a profile of common features (needs, desires, habits, age, societal class…) of a specific customer segment. "*The persona represents patterns of users' behaviors, goals and motives, complied in a fictional description of a single individual. It also contains made-up details in order to make it more tangible and alive for the development team* (Bonsfills, 2012)". Developing a persona is described in Goodwin (2001).

<u>Product Life Gallery:</u> mapping out the product's life cycle to support the product engineering personnel:

1. Product description
2. Environmental analysis
3. Product life phase system
4. Product activities
5. Product value.

SWOT Analysis: From a business perspective, a SWOT analysis allows understanding the in-development offer's position on the market vis-à-vis its strengths, weaknesses opportunities and threats. The credibility of the SWOT evaluation is proportional to the knowledge and information the analysts possess when making their assessments.

Value Network Analysis: mapping out the stakeholders is followed by recognizing the value exchange that occurs between them. In a PSS context, value will include products/services, knowledge and intangible value such as experience. Utilizing the three value transporters as separate entities, a flow representing each of them can be mapped: between which actors is the exchange and what aspect of value is transferred (Figure 84). Allee (2000) provides an example on how value can be perceived, exchanged and assessed by showing an example of a technology vendor providing a web-based discussion group for his clientele:

*"The traditional value chain exchange is the provision of moderated discussions, information, and responses to questions in exchange for a fee.*

*The knowledge flow may involve exchanges of customer usage data and feedback that is valuable for product development. As a result of their participation, users receive in exchange value-added knowledge, which may take the form of personally targeted news or offerings based on their unique personal preferences.*

*By tracing the intangible benefits that accrue in the network, one finds that the underlying logic for creating such a discussion group is not only about gaining revenue from the service (indeed it may barely break-even). The user group may really be about providing a sense of community on the part of the user. In return, of course, one would hope to receive an increase in customer loyalty. The intangible value exchange is the real reason for engaging in the activity."*

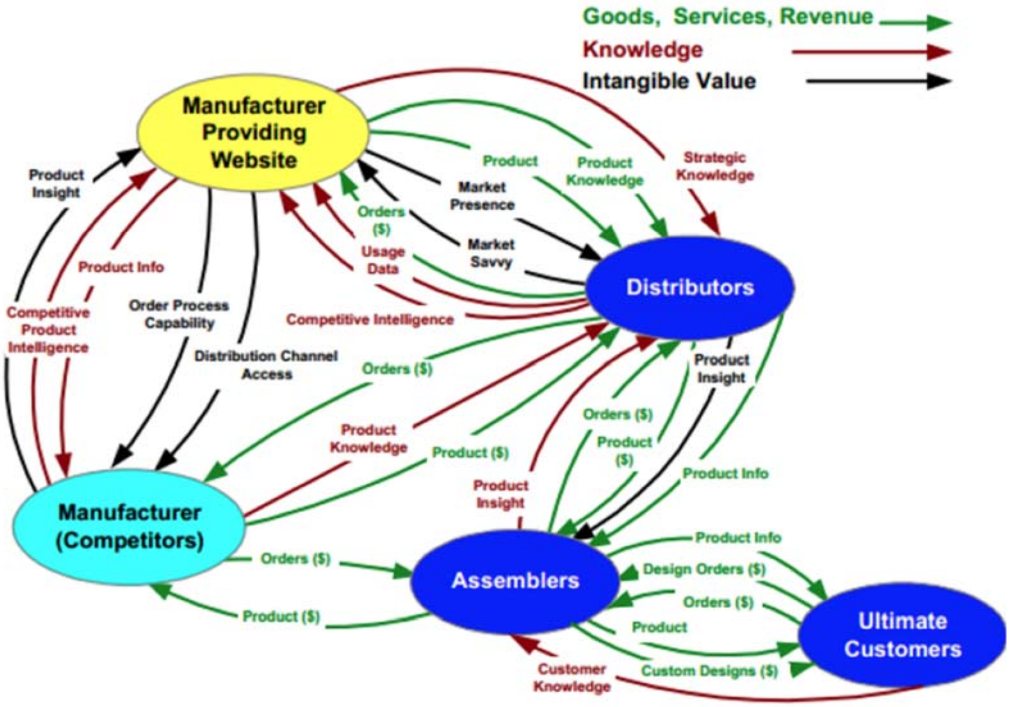


Figure 84 – Value Network Analysis (Allee, 2000)

To correctly represent the flows and value exchanges, the HOW of value exchange has to be established by covering the product and service properties and features of each of the preceding. To do so, the functions identified from the conceptualization phase are optimized to show which entities interact to fulfill every task/activity. A functional representation is needed (Figure 85). Exposed will be:

- The Actors: functional bloc diagram presenting all the stakeholders involved and the functions that connect them.
- External Functional Analysis: showing the constraints and exterior setting/environment in which the PSS will be carried out
- Functional characterization: providing details on the functions being carried out
- Scenario model: predicting and evaluating the values and costs respective to the receiver's state change when put in contact with the PSS (Table 27).

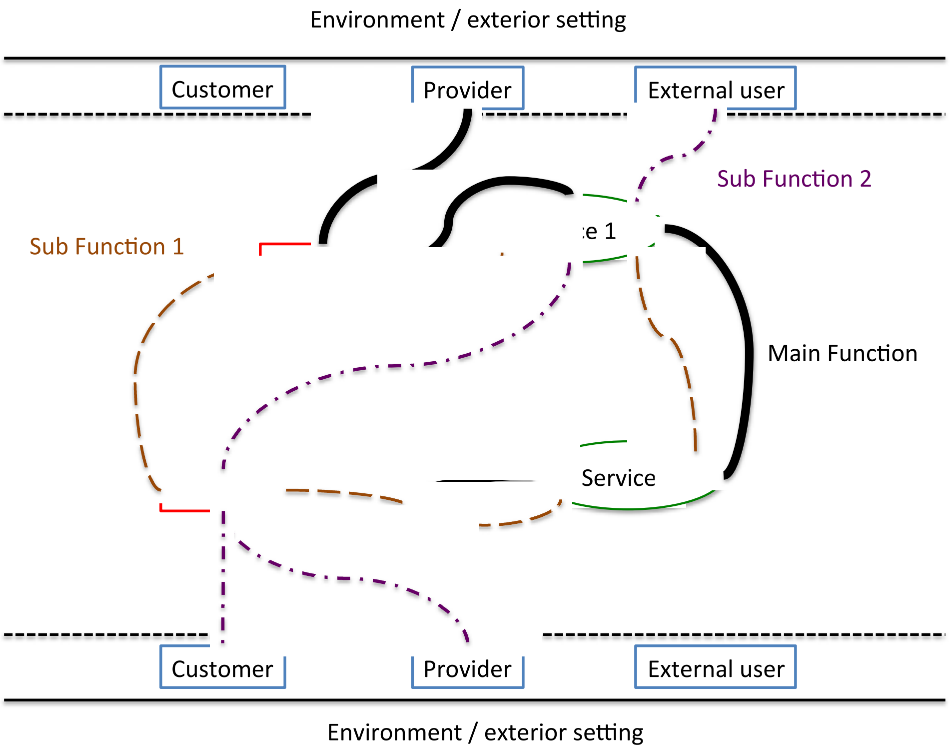


Figure 85 – Functional representation (example)

Table 27– Functional description matrix

| PSS Provider | PSS Receiver | Activity/ Function | Activity/Function type | Activity/Function specs | State Parameters | Value | Cost |
|---|---|---|---|---|---|---|---|
| Provider | Customer | Deliver a solution | Interaction Function or Main Function | Physical specs and service details | Solution Benefits | Revenue from selling the solution | Production and service delivery |
| External User | Provider, Customer | Damage to the solution (i.e. vandalism) | Adaptation Function | Mode and method of damage | Product damage and reduced service performance | N/A | Maintenance, delays, dissatisfaction |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| *The matrix is continuously filled out until all functions (Figure 85) have been described* | | | | | | | |

## 5. Sustainability (environmental) and Life Cycle Management

Designing and managing a PSS by utilizing its life cycle has been stressed by many authors throughout the literature (i.e. Vezzoli and Manzini, 2008; Aurich et al. 2006; Boehm and Thomas, 2013; Pezzotta et al. 2012; Chiu and Chu, 2012) amongst others. Life cycle Management will encompass: requirement analysis, design and integration, retiring/disposal plans, sustainable approach and refinement. Requirements, constraints, design procedures have been covered in the earlier passages, while sustainability, disposal and environmental-refinement will be discussed in the succeeding paragraphs.

The rationale behind implementing integrated product service solutions instead of product-based solutions is achieving sustainable goals to ensure prosperity for future generations. Governments and regulatory bodies have become more aware of the environmental hazards facing society and have imposed strict laws to follow, notably in the manufacturing field.

Accordingly, it is vital to conceive an ecologically sound solution while prioritizing green-objectives. In a PSS field, any activity or component cannot only affect its successor but also its predecessor, which incites identifying all life cycle phases and the environmental profile of each phase. As mentioned earlier, three main stages exist for a PSS: BOL, MOL and EOL, and cover design, production, use and disposal/recycling (Chiu and Chu, 2012). Each activity in every cited stage will undergo life cycle analysis using the Eco-Indicator 99 method (Goedkoop and Spriensma, 1999). The most dominant environmental dimensions to analyze are established by (Vezzoli and Manzini, 2008):

- Life optimization
- Distribution and transport
- Resources
- Biocompatibility
- Non-toxicity/hazardous

In order to perform a proper and informative life cycle assessment, knowledge on the below is needed:

- Details on equipment design
- Energy integration and type of energy used
- Details on service activities
- Retrieval/recovery schemes
- Modes of transport

From a manufacturer's perspective, minimizing resources is the most direct way of ensuring a clean production tactic and smartly developing solutions is another core issue.

Additionally, controlling or directing the customer's use of a solution is another key question. Abuse and mis-use can prove to be costly and create negative, unwanted effects that would be harming the environment, the topic a PSS tries to avoid. Negotiating contracts is an example that helps administer the activities and ways a customer can use the PSS with liabilities against any mistreatment that can occur. To obtain a benchmark, the factors above can be applied on the existing (substituting) product solution currently available. If the PSS to product is new, approximations of what the solution would behave if dissociated from a service plan can serve as an estimate. Based on the results, environmental priorities can be established by:

- Defining design priorities from an eco-perspective for the involved system.
- Defining sustainable ideas regarding the service, product and system as a whole.
- Visualizing the existing system (or estimated) environmental performance.

The LCA run in the concept phase can now be performed again benefiting from the added details resulting from the embodiment sequence of PSS design. Evaluating the requirements and resources, the way products and services are integrated and taking advantage of feedback loops and cradle-to-cradle approaches are part of managing and optimizing the PSS life cycle.

### 6. Embodiment design summary

The embodiment design stage can be summarized as shown in table 28 where each design topic is briefly summarized in its respective recapitulative alongside their required tools.

Table 28 – Embodiment Design Summary

| Design trait | Recapitulative |
|---|---|
| Usability | An effective design methodology that works for a PO solution may not enclose UO and RO offerings. Thus, the procedure must be holistic if it were to be globally adopted. |
| Practicality | Step by step build of the PSS details with a clear process flow illustrating the design activities and their components. Design milestones are also an efficient way of keeping track of the flow. |
| Co-creativity | Considering all involved users in the value creation process and identifying their involvement, exact roles and responsibilities. |
| A systemic and systematic approach | Capturing all the elements of the PSS and entities involved in the process: hierarchy, business model, product, service, etc. |
| Sustainability | Environmental considerations to ensure an eco-friendly solution with no repercussions that could upset the PSS's goal |

## 4.4 Validation and Release

The use of PSS in a broad fashion is hampered by the lack of consistent methodologies (Muller, 2013; Exner et al. 2014). This research throughout its sections aims to provide a robust and reliable approach to strengthen PSS recognition. The final stage, validation, is absent in the PSS literature and is considered as the keystone of the final design phase whether it is a product, a service or a product with integrated services (Yang, 2005; Coughlan et al. 2007; Berglund and Grimheden, 2011). Given the interdependence of product and services in a PSS environment, the validation tactic has to be comprehensive to verify the designed correlation in a practical manner in order to assess the suitability of the objective to which the PSS was designed.

From a product perspective, validation approaches rely heavily on prototyping methods such as physical mock-up (Laroche et al. 2011), computer-aided engineering for properties' assessment, while more recent studies investigated functional mock-ups (Rosenblatt et al. 2011) based on functional analysis and executed in a virtual manner.

From a service point of view, three methodologies are outlined. Flow charts, being the main pillar of service activities, allow optimizing the structure of the service-events and enhance the related process. Secondly, testing methods that rely on questionnaires and collecting the voice of the customer to capture any unexpected situation or missing interaction not covered within the design *(Bruhn, 2006)*. The third is structured on replicating a real-life occurrence for thorough testing. Nevertheless, service testing's associated costs are relatively high compared to products yet valuable since dynamic testing is vital when encountering a service while QFD and FMEA are limited to more 'static' practicing. Consequently, service simulation shifted to mimicking the latter's enactment in a virtual environment (Van Husen and Meiren, 2008).

### 4.4.1 Prototyping

From the framework study and design models' analysis, a lack of attention to the design process's final stages is noted. Testing and prototyping are mentioned, their importance is illustrated but actual practice is absent (Jallat, 2000; Lenfle and Midler, 2009). For a PSS, two main points must be validated:

- The prototype must exemplify the product and service features in a precise and credible manner.

- The prototype must be reliable so that its representation will accurately reflect how the real system will perform.

Prior to mass-launch, a prototype must be exposed to a narrow market segment known as 'first costumers' (Rogers, 1983). The latter will also require the involvement of external stakeholders to convey customer value: communications with the customer to expose the new concept. Even though the client's involvement in the design process is fundamental, it is difficult to control his conditions, forecast his reaction and thus obtain a realistic experience given the uncertainty of the last two factors (Zeithaml et al. 1990). These reasons emphasize the need for a pre-launch phase while developing an integrated solution: the prototyping process (Tran and Park, 2015).

1. Demonstration: the initial model, including the product, service, process, setting and vital components, is shown to a cluster of clients. The consumer is consequently exposed to the PSS's hierarchy and visualizes how the PSS runs and operates.
2. Participation: the same group of users from the previous stage have now gained knowledge concerning the functionalities of the PSS and will now use it while customer-oriented staff gathers information through customer feedback and opinions. Customization according to each client's (or client segment) needs can be made possible by leaving room for design variants within configurable limits.
3. Refinement: customer feedback from the testing that took place allows 'last-minute' adjustments to refine the prototype. The customized and adjusted configurations judged as most promising are introduced into the system to give birth to "user-generated" prototypes (Tran and Park, 2015).
4. Visualization: the morphed prototype is re-introduced to the testing pool to sensitize the customer to the modifications made.
5. Assessment: customers rate the new exemplar and comment on the alterations made and designers evaluate company-oriented aspects. The PSS manufacturer notes the ratings, which allows selecting the best prototype.

### 4.4.2 Marketing

Despite the widespread diffusion of PSS and its proven advantages, many challenges arise, hindering customers' acceptance of the value offering (Vezzoli et al. 2015). These barriers fall under three categories: providers, clients and context.

1. Providers: PSS's complexity compared to traditional product development requires a cultural vision to be established and a holistic participation of all the personnel. *"In other words, changes in corporate mindset and organization are required in order to support a more systemic innovation and sustainable PSS-oriented businesses. PSS receptivity is more likely to happen in organizations where service transactions were already put in place* (Vezzoli et al. 2015)". Personnel need to be trained in delivering the PSS solution, fully grasp the product-service components and develop metrics to measure the delivery process and continuously seek improving it in order to build the long-run relationship with the customer. Accordingly, cooperation between the involved actors is vital to develop and maintain the intrinsic connections of a PSS.
2. Clients: consumer awareness is fairly minimal regarding integrated solutions. The prior leads risks, costs and responsibilities to be in a 'grey area' and expose the PSS's benefits to hampering obstacles. For instance, a lack of understanding may lead to consumers comparing the PSS expense to a product cost without considering the additional charges encountered with the product and that the PSS saves (i.e. disposal, maintenance, repairs…) (Enz et al. 1999). Clients' behavior has to shift towards an ownerless, functional setting to achieve satisfaction. Not all needs can be answered by an ownerless solution and thus customer sensitivity is of high importance (i.e. sleeping in one's own bed vs. car sharing). *"It has to be emphasised that compared to private customers, business customers tend to prefer functional sales to product ownership* (Alexander, 1997; Stahel, 1997). *Moreover, the diffusion of a sustainable PSS (S.PSS) in the consumer market is highly dependent on being sensitive to the culture in which it will be used. For instance S.PSSs have been more readily accepted in communal societies like Scandinavia, the Netherlands than in many other countries* (Wong, 2004)." Moreover, appearances and one's possessions are evolving into becoming life success indicators as Ferraro et al. (2010) emphasize that a person's identity and status are defined by the commodities he owns. Finally, privacy concerns are highlighted in a PSS context and certain information may be delicate, requiring additional attention and handling.
3. Context: governmental incentives are needed to encourage the adoption

of green solutions such as a PSS, given that environmental costs are excluded from market prices and competing with traditional products is relatively hard (Mont and Lindquist, 2003). Additional requirements to carry out a solution such as labor, material, infrastructure and resources have to be taken into account (Vezzoli et al. 2015).

Consumer habits, financial resources and value perception are amongst the dominant obstacles to PSS implementation as the changes required are drastic and severe. Consequently, acceptance has to be staged on a long-term basis with incremental smart steps leading to its full deployment. Despite extensive market research and customer study, success stories lie heavily in the B2B realm (Tukker, 2015) highlighting the difficulties encountered in fully engaging the B2C context. Catulli et al. (2013) and Lettenmeier et al. (2014) argue that penetrating the B2C market requires a socio-psychological approach, which is why prototyping is fundamental to capture and relate to those aspects.

Considering stakeholders in their context allows visualizing customer behavior, customer relationships, value proposition and distribution channels to understand how the client interact with its environment and how service personnel may influence the prior to facilitate the PSS's acceptance.

Governments should encourage these types of proposals by creating advantageous economic conditions to favor the viability of integrated products as well as increasing consumer and company awareness about the benefits that lurk in a functional product and help propagate the profits (and sustainability opportunities) lying for the user as well as the developer.  (Vezzoli et al. 2015). For instance, the European Commission wants to incite re-use as a waste-management alternative to strengthen resource efficiency (EU, 2016), which is homogeneous with use and result oriented ways of proposing integrated offerings. Another example would be utilizing aesthetics: the way a PSS can be made attractive and appealing to increase customer intrigue and lure new clients while highlighting the PSS qualities a conventional product lacks. From a governmental stance, authorities can issue policy measures to tackle the prior and proliferate PSS development approaches:

1. Internalization of environmental and external costs such as pollution charges and polluting emissions taxes.
2. Extended manufacturer responsibility regarding product management throughout various life cycle stages.
3. Informative policy measures similar to collaborative projects support,

promotional campaigns, green-labeling etc. which increase attentiveness regarding functional solutions (Ceschin and Vezzoli, 2010)

**Validation and Release summary**

The fourth and final stage of the FEPSS is summarized as shown in table 29.

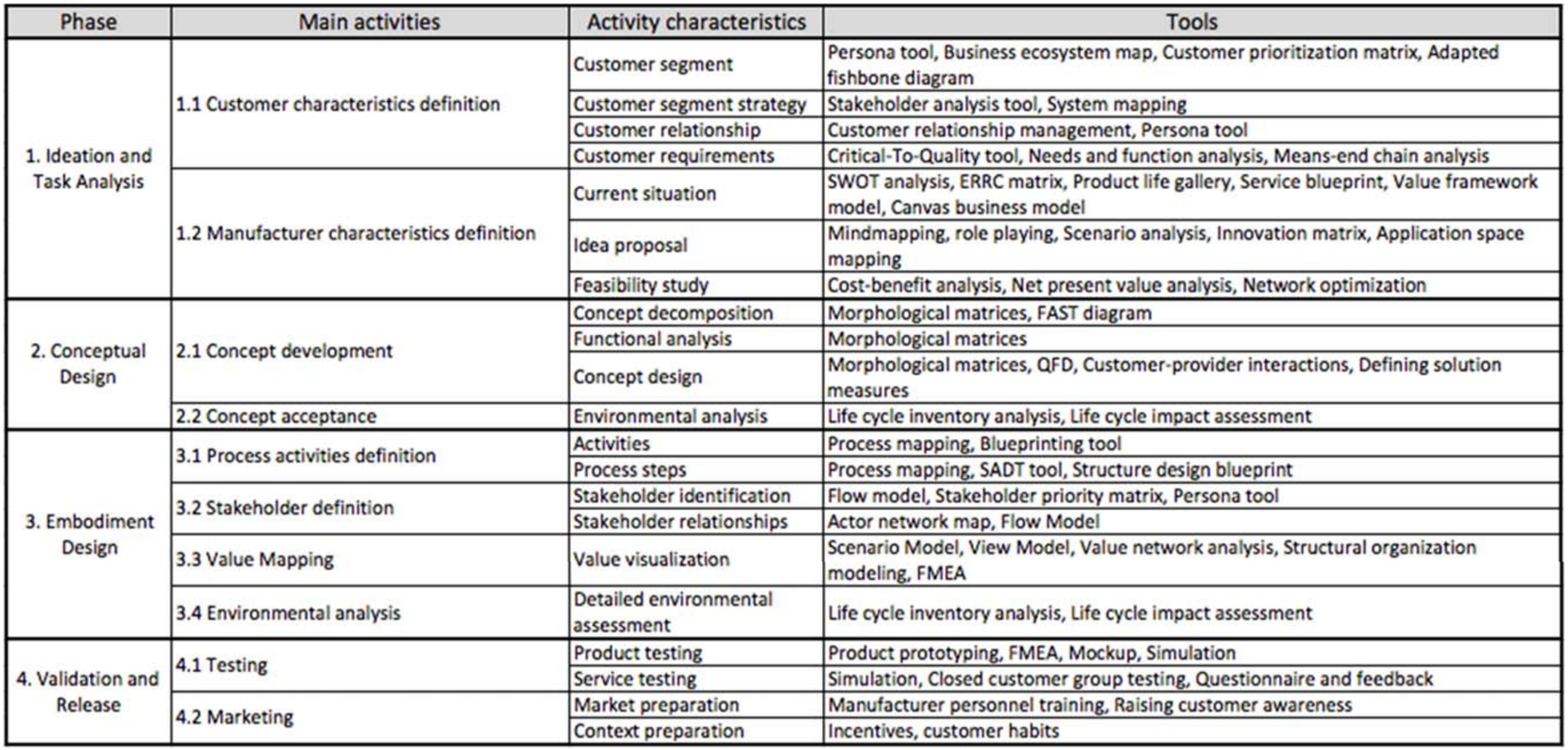
Table 29 – Validation and Release summary

| Sequence | Description |
|---|---|
| Prototyping | The developed solution is subjected to a closed group of users representing a sample of the desired market segment. Interactions between the users and the solution are assessed and documented, knowing that they must reflect real-life happenings in order to obtain credible results from this prior-launch phase. The product's attributes are measurable through quality assurance and management tools while the service's performance is weighed according to the consumer's satisfaction regarding the overall experience |
| Marketing | In order to launch the PSS solutions, the market has to be prepared: the PSS benefits have to be concretely explicated and clarified to gain the potential consumer's interest. Accordingly, the provider must train its marketing staff and prepare its marketing strategy to seize the user's attention. Moreover, governments can incite customers to adopt PSS proposals by offering perks and benefits creating valuable economic conditions. |

## 4.5 The FEPSS model

The four stages depicted above (4.1, 4.2, 4.3, 4.4) built on Hubka and Eder, (1992)'s design science methodology converge towards a generic and robust model that can be applied in various product-service integration environments. Entitled the 'Functional-Engineered Product-Service System' model, its structure is presented in Table 30. The framework is built on the analysis of the literature's best-known approaches, coupled with the most widespread design tactics elaborated by Vasantha et al. (2012) and (2015) and Tran and Park (2014) and (2015). Each stage is described using the required activities to perform, alongside adequate engineering tools, to ensure that all the necessary aspects are covered.

Table 30 – The FEPSS model (Haber and Fargnoli, 2017a) *



| Phase | Main activities | Activity characteristics | Tools |
|---|---|---|---|
| 1. Ideation and Task Analysis | 1.1 Customer characteristics definition | Customer segment | Persona tool, Business ecosystem map, Customer prioritization matrix, Adapted fishbone diagram |
| | | Customer segment strategy | Stakeholder analysis tool, System mapping |
| | | Customer relationship | Customer relationship management, Persona tool |
| | | Customer requirements | Critical-To-Quality tool, Needs and function analysis, Means-end chain analysis |
| | 1.2 Manufacturer characteristics definition | Current situation | SWOT analysis, ERRC matrix, Product life gallery, Service blueprint, Value framework model, Canvas business model |
| | | Idea proposal | Mindmapping, role playing, Scenario analysis, Innovation matrix, Application space mapping |
| | | Feasibility study | Cost-benefit analysis, Net present value analysis, Network optimization |
| 2. Conceptual Design | 2.1 Concept development | Concept decomposition | Morphological matrices, FAST diagram |
| | | Functional analysis | Morphological matrices |
| | | Concept design | Morphological matrices, QFD, Customer-provider interactions, Defining solution measures |
| | 2.2 Concept acceptance | Environmental analysis | Life cycle inventory analysis, Life cycle impact assessment |
| 3. Embodiment Design | 3.1 Process activities definition | Activities | Process mapping, Blueprinting tool |
| | | Process steps | Process mapping, SADT tool, Structure design blueprint |
| | 3.2 Stakeholder definition | Stakeholder identification | Flow model, Stakeholder priority matrix, Persona tool |
| | | Stakeholder relationships | Actor network map, Flow Model |
| | 3.3 Value Mapping | Value visualization | Scenario Model, View Model, Value network analysis, Structural organization modeling, FMEA |
| | 3.4 Environmental analysis | Detailed environmental assessment | Life cycle inventory analysis, Life cycle impact assessment |
| 4. Validation and Release | 4.1 Testing | Product testing | Product prototyping, FMEA, Mockup, Simulation |
| | | Service testing | Simulation, Closed customer group testing, Questionnaire and feedback |
| | 4.2 Marketing | Market preparation | Manufacturer personnel training, Raising customer awareness |
| | | Context preparation | Incentives, customer habits |

*The tools for the fulfillment of the activities shown in Table 30 can be extended. The ones mentioned serve as an example and any tool deemed suitable can be used and adapted for the fulfillment of the activity.

# 5. Case Studies

## 5.1 Overview

To investigate the applicability of the FEPSS, its implementation was carried in case studies in the agricultural machinery and medical devices sectors. Due to limitations regarding available data and while respecting the privacy concerns of the companies, the case studies are limited to the early stages of the design and development process (Ideation and task analysis, and Conceptual design). Nevertheless, such exploratory applications are fruitful and beneficial in verifying the effectiveness and feasibility of the FEPSS since these stages are the core of the solution design and enable the definition of its main characteristics (Fargnoli et al. 2005; Haber and Fargnoli, 2017a). The first case study (Section 5.2) focuses on the first stage of the FEPSS: ideation and task analysis whereas the remaining case studies (Sections 5.3, 5.4 and 5.5) implement the two stages of the FEPSS: ideation and task analysis, and conceptual design. Section 5.3 utilizes the QFDforPSS method, section 5.4 implements the morphological matrix approach and section 5.5 adopts axiomatic design for the development of service modules. Each case study is then discussed highlighting the results achieved and the respective limitations of each application are mentioned. Section 5.6 provides conclusive remarks.

## 5.2 Company "A" – An Echography Equipment Distributor

### 5.2.1 The case study

This first case study focuses on the first phase of the design process: Ideation and Task Analysis. In particular, and as mentioned earlier, defining the customers' requirements in a PSS context is hindered by uncertainties and ambiguities mainly due to the qualitative and intangible nature of services. Hence, to reduce these limitations, both the Fuzzy Logic and the AHP (Saaty 1990) approaches were used. While the latter allows engineers to determine the weights of the CRs more precisely by means of pairwise comparison questionnaires, the Fuzzy logic reduces the vagueness of judgements introducing fuzzy numbers instead of crisp numbers such as triangular fuzzy numbers (TFNs) (Kahraman et al. 2003). These TFNs are represented by the parameters (l, m, u). Where, in accordance with (Zaim et al. 2014), these parameters namely refer to the smallest possible value (l), the most promising value (m), and the largest possible value (u). Bearing this in mind, the general scheme of the proposed approach is represented in Figure 86, where the final output of the HoQ extended with Fuzzy logic and AHP (FAHP) is represented by the definition and ranking of the ECs, in this case the Service Characteristics (SChs). In addition, to better verify the effectiveness of this approach, the results obtained were compared with the ones provided by using the traditional HoQ and the ones derived by the HoQ augmented with the Fuzzy logic approach only. Hence, the following section starts with the application of the traditional HoQ and it is concluded by the FAHP implementation.

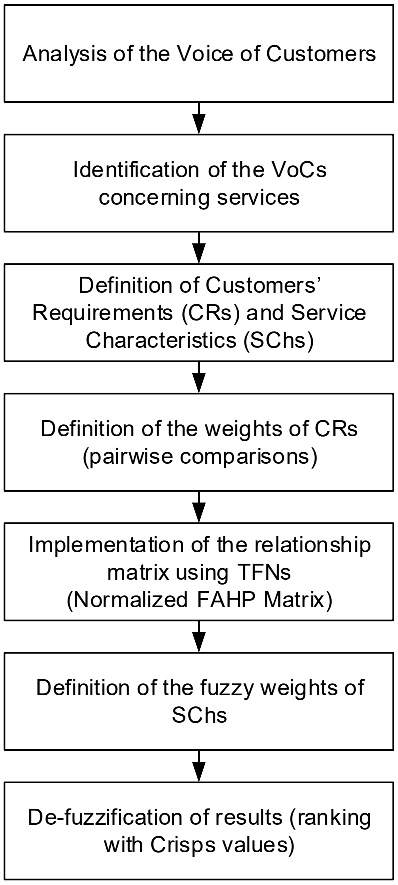


Figure 86 – Scheme of the proposed procedure

The study was carried out at a distributor operating in the medical device sector. The manufacturer (located in South Korea) produces ultrasound machinery and probes used in various medical applications such as cardiology and radiology among others. Company "A" is the representative of the Korean manufacturer in Italy. The company handles the distribution and maintenance of the ultrasound equipment and provides training.

The object of our study is an echography equipment used for diagnostic, therapy and research purposes (Figure 87). The product consists of seven main components: the transducer probe, the pulse controls, the central processing unit, the display, the keyboard, the cursor and the storage disk. As a means of improving its market position, the company was interested in augmenting its product by employing value-creating services. In particular, it was interested in enhancing the life-cycle of the transducer probes, the maintenance activities of the equipment and its disposal.

Figure 87 – The echography equipment

### Definition of the Customer Requirements (CRs)

As an initial step, the company experts completed a market survey to accurately define the customers and their requirements, i.e. the VoC. The customers are mainly medical professionals and laboratory technicians working in private clinics and hospitals. The assessment of their requirements was made through questionnaires (Appendix A) sent to 20 customers from one side, and from the analysis of 14 calls for tenders issued in a 36-months period (2014-2017). In detail, the analysis concerned the service characteristics required by these calls and their assessment criteria. Then, the gathered information was thoroughly assessed to separate the mandatory service characteristics (i.e. 1-year warranty on all parts of the equipment, installation by manufacturer's technicians etc.) from the optional ones that may prove to be beneficial for the company in expanding its market share. Consequently, the service-related requirements were defined and their Raw Importance (RI) was assessed according to a (1-not important; 5- very important) Likert scale (Likert, 1932) (Table 31).

Table 31 – Customer requirements and their respective importance

| CR Code | CR description | RI | Relative RI |
|---|---|---|---|
| CR1 | Easy to use | 3.7 | 12.3% |
| CR2 | Availability of the equipment for the entire contract period | 4.4 | 14.7% |
| CR3 | System upgradability: software updates and modular upgrades when available | 3.0 | 10.0% |
| CR4 | Quality of maintenance service | 4.6 | 15.3% |
| CR5 | Availability of remote technical support | 4.1 | 13.7% |
| CR6 | Supply of consumables and wearables (i.e. probes, connection cables) | 3.9 | 13.0% |
| CR7 | Complete data storage | 3.4 | 11.3% |
| CR8 | Assistance to environmental and safety conformance matters | 2.9 | 9.7% |

Then, in collaboration with the company's engineers, the engineering characteristics regarding the service (Service Characteristics (SChs)) were defined (Table 32).

Table 32 – List of SChs

| SCh Code | SCh description |
|---|---|
| SCh1 | Training for users |
| SCh2 | Management and documentation of environmental and safety issues |
| SCh3 | Cloud data storage service |
| SCh4 | Provision of consumables and related tools for their daily maintenance (i.e. cleaning) |
| SCh5 | Extended warranty for consumables |
| SCh6 | Calendar time of consumables delivery |
| SCh7 | Replacement of malfunctioning devices in 72 hours |
| SCh8 | Repairs within 48 hours from notification |
| SCh9 | Extended remote technical support |
| SCh10 | Training of customer care operators |
| SCh11 | Remote software updates |
| SCh12 | Periodic training and refresher courses when updates are available |
| SCh13 | Time for response |
| SCh14 | Time for intervention inferior to 24 hours |
| SCh15 | Training of service center technicians |

To complete the collection of the information, the company's experts submitted another questionnaire to the same 20 customers to compare the CRs' importance among each other's in a pairwise comparison manner (Liu 2009; Ho et al. 2012). In Figure 88 an excerpt of this questionnaire concerning the pairwise comparison between CR1 and CR2 is shown. The scale used for such assessment as well as their equivalents in terms of Triangular Fuzzy Numbers (TFNs) (Kamvysi et al. 2014) is shown in Table 33. The use of fuzzy logic is suggested to eliminate biasness and imprecisions when developing a solution (Abdolshah and Moradi 2013; Liu and Tsai 2012).

Table 33 – The pairwise comparison scale and its fuzzy equivalent (Saaty, 1990)

| Linguistic variables | Rating Scale (crisp) | Equivalence in Fuzzy numbers | |
|---|---|---|---|
| | | TFNs | Reciprocal TFNs |
| Equally important | 1 | (1, 1, 1) | (1, 1, 1) |
| Intermediate | 2 | (1, 2, 3) | (1/3, 1/2, 1) |
| Moderately more important | 3 | (2, 3, 4) | (1/4, 1/3, 1/2) |
| Intermediate | 4 | (3, 4, 5) | (1/5, 1/4, 1/3) |
| Strongly more important | 5 | (4, 5, 6) | (1/6, 1/5, 1/4) |
| Intermediate | 6 | (5, 6, 7) | (1/7, 1/6, 1/5) |
| Very strongly more important | 7 | (6, 7, 8) | (1/8, 1/7, 1/6) |
| Intermediate | 8 | (7, 8, 9) | (1/9, 1/8, 1/7) |
| Extremely more important | 9 | (8, 9, 10) | (1/10, 1/9, 1/8) |

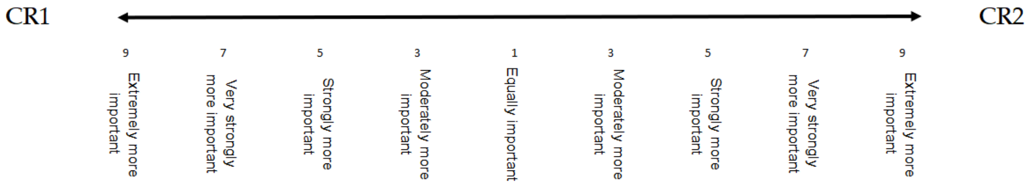


Figure 88 - Example of a pairwise comparison between CR1 and CR2

## Traditional QFD

The traditional QFD method was applied, taking into consideration the information mentioned earlier and the Absolute Importance (AI) of each SCh was obtained using (1).

$$AI_j = \sum_{i=1}^{n=8} RI_i \text{ x } S_{ij} \quad (1)$$

Where 'i' indicates a CR as a row entry, 'j' indicates a SCh as a column entry and $S_{ij}$ indicates the relationship score between $CR_i$ and $SCh_j$ evaluated as 1, 3 or 9 for a weak, medium or strong relationship respectively (Revelle et al. 1998). Accordingly, the traditional QFD was implemented and the AI of the SChs was deduced (Table 34).

Table 34 – Traditional HoQ

|  | RI | Relative RI | *CR ranking* | SCh1 | SCh2 | SCh3 | SCh4 | SCh5 | SCh6 | SCh7 | SCh8 | SCh9 | SCh10 | SCh11 | SCh12 | SCh13 | SCh14 | SCh15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR1 | 3.7 | 12.3% | *5* | 9 |  | 3 | 3 |  |  |  |  | 3 | 3 | 9 | 9 |  |  |  |
| CR2 | 4.4 | 14.7% | *2* |  |  |  |  |  |  | 9 | 3 | 9 |  |  |  | 1 | 9 | 3 |
| CR3 | 3.0 | 10.0% | *7* | 3 |  |  |  |  |  |  |  |  | 3 | 9 | 9 |  |  | 1 |
| CR4 | 4.6 | 15.3% | *1* |  |  |  |  |  |  | 9 | 9 | 3 | 9 |  |  | 9 | 9 | 9 |
| CR5 | 4.1 | 13.7% | *3* |  |  |  |  |  |  | 1 | 1 | 9 | 9 |  |  | 9 |  |  |
| CR6 | 3.9 | 13.0% | *4* |  |  |  | 9 | 9 | 9 |  |  |  |  |  |  |  |  |  |
| CR7 | 3.4 | 11.3% | *6* | 1 |  | 9 |  |  |  |  |  |  |  | 3 |  |  |  |  |
| CR8 | 2.9 | 9.7% | *8* | 1 | 9 | 1 |  | 1 |  |  |  |  | 1 |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SCh Absolute Importance (AI) | 48,6 | 26,1 | 44,6 | 46,2 | 38 | 35,1 | 85,1 | 58,7 | 101,4 | 101,3 | 70,5 | 60,3 | 82,7 | 81 | 57,6 |
| SCh relative AI (%) | 5,2% | 2,8% | 4,8% | 4,9% | 4,1% | 3,7% | 9,1% | 6,3% | 10,8% | 10,8% | 7,5% | 6,4% | 8,8% | 8,6% | 6,1% |
| *SCh ranking* | 10 | 15 | 12 | 11 | 13 | 14 | 3 | 8 | 1 | 2 | 6 | 7 | 4 | 5 | 9 |

### Fuzzy Logic Implementation

In a fuzzy context, linguistic preferences are translated into fuzzy functions as a means of quantifying them in a reliable and realistic manner (Vinodh et al. 2017). Regarding the CRs, the conversion from the crisp importance as per Likert (1932) to fuzzy numbers (i.e. Triangular Fuzzy Numbers (TFNs) (Kamvysi et al. 2014) is indicated in Table 35.

Table 35 – Crisp to fuzzy conversion (adapted from Vinodh et al. 2017)

| Linguistic definition | Likert Scale | Triangular Fuzzy Number equivalent | | |
|---|---|---|---|---|
| Not Important | 1 | 0 | 0 | 0.3 |
| Poorly important | 2 | 0.1 | 0.3 | 0.5 |
| Fairly important | 3 | 0.3 | 0.5 | 0.7 |
| Important | 4 | 0.5 | 0.7 | 0.9 |
| Very important | 5 | 0.7 | 1 | 1 |

The importance ratings of each of the 20 customers regarding the CRs are then transformed into TFNs (Table 36) and the final importance is deduced as the average of these TFNs (Table 37).

Table 36 - Crisp to fuzzy conversion of the importance levels of the CRs (excerpt for 3 CRs).

| | CR1 | | | CR2 | | | CR3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Customer 1 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 |
| Customer 2 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 3 | 0.3 | 0.5 | 0.7 | 0.7 | 1 | 1 | 0.3 | 0.5 | 0.7 |
| Customer 4 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 5 | 0.5 | 0.7 | 0.9 | 0.7 | 1 | 1 | 0.1 | 0.3 | 0.5 |
| Customer 6 | 0.3 | 0.5 | 0.7 | 0.7 | 1 | 1 | 0.5 | 0.7 | 0.9 |
| Customer 7 | 0.5 | 0.7 | 0.9 | 0.7 | 1 | 1 | 0.3 | 0.5 | 0.7 |
| Customer 8 | 0.7 | 1 | 1 | 0.7 | 1 | 1 | 0.5 | 0.7 | 0.9 |
| Customer 9 | 0.3 | 0.5 | 0.7 | 0.7 | 1 | 1 | 0.3 | 0.5 | 0.7 |
| Customer 10 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 11 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 |
| Customer 12 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.1 | 0.3 | 0.5 |
| Customer 13 | 0.5 | 0.7 | 0.9 | 0.7 | 1 | 1 | 0.3 | 0.5 | 0.7 |
| Customer 14 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 |
| Customer 15 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.1 | 0.3 | 0.5 |
| Customer 16 | 0.7 | 1 | 1 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 17 | 0.5 | 0.7 | 0.9 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 18 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 |
| Customer 19 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0 | 0 | 0.3 |
| Customer 20 | 0.5 | 0.7 | 0.9 | 0.7 | 1 | 1 | 0.3 | 0.5 | 0.7 |
| Fuzzy CR importance | 0.44 | 0.66 | 0.82 | 0.58 | 0.82 | 0.94 | 0.30 | 0.50 | 0.70 |

Table 37 – Fuzzy importance levels of the CRs.

| | Fuzzy | | | Fuzzy Importance | Relative Importance level |
|---|---|---|---|---|---|
| | Lower value (L) | Middle value (M) | Upper value (U) | | |
| CR1 | 0.44 | 0.66 | 0.82 | 0.65 | 12.3% |
| CR2 | 0.58 | 0.82 | 0.94 | 0.80 | 15.2% |
| CR3 | 0.30 | 0.50 | 0.70 | 0.50 | 9.5% |
| CR4 | 0.62 | 0.88 | 0.96 | 0.85 | 16.1% |
| CR5 | 0.52 | 0.75 | 0.90 | 0.73 | 13.9% |
| CR6 | 0.48 | 0.70 | 0.87 | 0.69 | 13.0% |
| CR7 | 0.38 | 0.58 | 0.78 | 0.58 | 11.0% |
| CR8 | 0.28 | 0.48 | 0.68 | 0.48 | 9.1% |

Similarly, the relationship scores between the SChs and CRs are transformed into fuzzy numbers using the following transformation (Table 38). This leads to the importance levels of the SChs shown in Table 39.

Table 38 – Crisp to fuzzy conversion of the relationship scores (adapted from Vinodh et al. 2017)

| Linguistic definition | Crisp score | Triangular Fuzzy Number equivalent | | |
|---|---|---|---|---|
| Weak relationship | 1 | 0 | 0 | 0.3 |
| Medium relationship | 3 | 0.3 | 0.5 | 0.7 |
| Strong relationship | 9 | 0.7 | 1 | 1 |

Table 39 – Importance levels of the SChs using the fuzzy approach

| | SCh1 | SCh2 | SCh3 | SCh4 | SCh5 | SCh6 | SCh7 | SCh8 | SCh9 | SCh10 | SCh11 | SCh12 | SCh13 | SCh14 | SCh15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SCh AI | 0,221 | 0,099 | 0,208 | 0,213 | 0,152 | 0,138 | 0,341 | 0,274 | 0,473 | 0,461 | 0,302 | 0,233 | 0,330 | 0,322 | 0,270 |
| SCh relative AI (%) | 5,47 | 2,46 | 5,15 | 5,28 | 3,76 | 3,41 | 8,44 | 6,79 | 11,71 | 11,42 | 7,49 | 5,77 | 8,18 | 7,98 | 6,69 |
| *SCh ranking* | 10 | 15 | 12 | 11 | 13 | 14 | 3 | 7 | 1 | 2 | 6 | 9 | 4 | 5 | 8 |

**FAHP implementation**

The fuzzy logic is implemented based on the criteria shown earlier where the scores of the pairwise comparisons are transformed into TFNs leading to a fuzzy pairwise comparison matrix (Table 40). The importance of a horizontal-entry $CR_i$ is prioritized over a vertical-entry $CR_j$ by using (2).

$$CR_i = \frac{1}{CRj} \tag{2}$$

Table 40 – Example of a fuzzy pairwise comparison matrix (excerpt from a customer)

| | CR1 | | | CR2 | | | CR3 | | | CR4 | | | CR5 | | | CR6 | | | CR7 | | | CR8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR 1 | 1 | 1 | 1 | 1/8 | 1/7 | 1/6 | 1 | 1 | 1 | 1/8 | 1/7 | 1/6 | 1 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 2 | 3 | 4 |
| CR 2 | 6 | 7 | 8 | 1 | 1 | 1 | 6 | 7 | 8 | 2 | 3 | 4 | 3 | 4 | 5 | 4 | 5 | 6 | 4 | 5 | 6 | 6 | 7 | 8 |
| CR 3 | 1/4 | 1/3 | 1/2 | 1/8 | 1/7 | 1/6 | 1 | 1 | 1 | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 |
| CR 4 | 6 | 7 | 8 | 1/4 | 1/3 | 1/2 | 4 | 5 | 6 | 1 | 1 | 1 | 3 | 4 | 5 | 4 | 5 | 6 | 4 | 5 | 6 | 4 | 5 | 6 |
| CR 5 | 1 | 1 | 1 | 1/4 | 1/3 | 1/2 | 2 | 3 | 4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| CR 6 | 1/4 | 1/3 | 1/2 | 1/6 | 1/5 | 1/4 | 1 | 1 | 1 | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CR 7 | 1/6 | 1/5 | 1/4 | 1/6 | 1/5 | 1/4 | 2 | 3 | 4 | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CR 8 | 1/4 | 1/3 | 1/2 | 1/8 | 1/7 | 1/6 | 1 | 3 | 1 | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

To verify the consistency of the fuzzy pairwise comparison matrix values, a consistency check is carried out as per Liu (2019). The Consistency Index (CI) is defined as per (3) and used in (4) to determine the Consistency Ratio (CRa) of the fuzzy pairwise comparison matrix. A matrix is determined consistent if the CRa is inferior to 0.1

$$CI = \frac{\lambda_{max} - m}{m-1} \tag{3}$$

$$CRa = \frac{CI}{RI} \tag{4}$$

where $\lambda$max is the largest eigenvalue of the fuzzy pairwise comparison matrix, 'm' is the number of entries (e.g. customer requirements) and RI is the random index of the latter matrix (Liu, 2009). The CRa was deduced as 0.084 verifying the consistency of the used matrix.

The fuzzy pairwise comparison matrix is then normalized through equation (5) where R represents the set of CRs from 1 to n, $\tilde{a}_{ij}$ is an element of the fuzzy pairwise comparison matrix, 'i' indicates the row and 'j' indicates the column (Liu, 2009). This leads to the normalized FAHP matrix.

$$Normalized\ FAHP\ Matrix = \begin{bmatrix} \frac{\tilde{a}_{11}}{\sum_{i\in R}\tilde{a}_{i1}} & \frac{\tilde{a}_{12}}{\sum_{i\in R}\tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{1n}}{\sum_{i\in R}\tilde{a}_{in}} \\ \frac{\tilde{a}_{21}}{\sum_{i\in R}\tilde{a}_{i1}} & \frac{\tilde{a}_{22}}{\sum_{i\in R}\tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{2n}}{\sum_{i\in R}\tilde{a}_{in}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\tilde{a}_{n1}}{\sum_{i\in R}\tilde{a}_{i1}} & \frac{\tilde{a}_{n2}}{\sum_{i\in R}\tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{nn}}{\sum_{i\in R}\tilde{a}_{in}} \end{bmatrix} \tag{5}$$

Then, the means of the row-entry elements of the normalized FAHP matrix are determined using (6) to obtain the column vector (Table 41) representing each the importance of each CR$_i$.

$$C_{fuzzy} = \begin{bmatrix} c^1_{1k} \\ \vdots \\ c^1_{nk} \end{bmatrix} = \begin{bmatrix} \dfrac{\left(\frac{\tilde{a}_{11}}{\sum_{i\in R}\tilde{a}_{i1}}+\frac{\tilde{a}_{12}}{\sum_{i\in R}\tilde{a}_{i2}}+\cdots+\frac{\tilde{a}_{1n}}{\sum_{i\in R}\tilde{a}_{in}}\right)}{n} \\ \vdots \\ \dfrac{\left(\frac{\tilde{a}_{n1}}{\sum_{i\in R}\tilde{a}_{i1}}+\frac{\tilde{a}_{n2}}{\sum_{i\in R}\tilde{a}_{i2}}+\cdots+\frac{\tilde{a}_{nn}}{\sum_{i\in R}\tilde{a}_{in}}\right)}{n} \end{bmatrix} \tag{6}$$

Then, the relative importance of the CRs (Table 42) is deduced through the Ĉ vector obtained through (7) and implemented in the HoQ (Table 43).

$$\hat{C} = \begin{bmatrix} \bar{c}^1_{1k} \\ \vdots \\ \bar{c}^1_{nk} \end{bmatrix} = \begin{bmatrix} \dfrac{\left(c^1_{1k}\tilde{a}_{11}+c^1_{2k}\tilde{a}_{12}+\cdots+c^1_{nk}\tilde{a}_{1n}\right)}{c^1_{1k}} \\ \vdots \\ \dfrac{\left(c^1_{1k}\tilde{a}_{n1}+c^1_{2k}\tilde{a}_{n2}+\cdots+c^1_{nk}\tilde{a}_{nn}\right)}{c^1_{nk}} \end{bmatrix} \tag{7}$$

Table 41 – The normalized column vector C$_{fuzzy}$

| | C$_{fuzzy}$ | | |
|---|---|---|---|
| CR1 | 0.538 | 0.793 | 1.170 |
| CR2 | 1.936 | 2.823 | 4.146 |
| CR3 | 0.226 | 0.297 | 0.429 |
| CR4 | 1.383 | 2.003 | 2.955 |
| CR5 | 0.559 | 0.895 | 1.455 |
| CR6 | 0.269 | 0.351 | 0.496 |
| CR7 | 0.303 | 0.426 | 0.646 |
| CR8 | 0.255 | 0.411 | 0.458 |

Table 42 – Importance of the CRs through the Ĉ vector

| | RI | Relative RI |
|---|---|---|
| CR1 | 0.813 | 9.9% |
| CR2 | 2.896 | 35.3% |
| CR3 | 0.307 | 3.7% |
| CR4 | 2.058 | 25.1% |
| CR5 | 0.932 | 11.4% |
| CR6 | 0.361 | 4.4% |
| CR7 | 0.442 | 5.4% |
| CR8 | 0.393 | 4.8% |

Table 43 – The FAHP augmented HoQ.

| | RI | Relative RI | *CR ranking* | SCh1 | SCh2 | SCh3 | SCh4 | SCh5 | SCh6 | SCh7 | SCh8 | SCh9 | SCh10 | SCh11 | SCh12 | SCh13 | SCh14 | SCh15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR1 | 0.813 | 9.9% | *4* | 9 | | 3 | 3 | | | | | 3 | 3 | 9 | 9 | | | |
| CR2 | 2.896 | 35.3% | *1* | | | | | | | 9 | 3 | 9 | | | | 1 | 9 | 3 |
| CR3 | 0.307 | 3.7% | *8* | 3 | | | | | | | | | 3 | 9 | 9 | | | 1 |
| CR4 | 2.058 | 25.1% | *2* | | | | | | | 9 | 9 | 3 | 9 | | | 9 | 9 | 9 |
| CR5 | 0.932 | 11.4% | *3* | | | | | | | 1 | 1 | 9 | 9 | | | 9 | | |
| CR6 | 0.361 | 4.4% | *7* | | | | 9 | 9 | 9 | | | | | | | | | |
| CR7 | 0.442 | 5.4% | *5* | 1 | | 9 | | | | | | | | 3 | | | | |
| CR8 | 0.393 | 4.8% | *6* | 1 | 9 | 1 | | 1 | | | | | 1 | | | | | |
| SCh AI | | | | 9,08 | 3,54 | 6,82 | 5,69 | 3,65 | 3,25 | 45,52 | 28,15 | 43,07 | 30,67 | 11,41 | 10,08 | 29,81 | 44,59 | 27,52 |
| SCh relative AI (%) | | | | 3,0% | 1,2% | 2,3% | 1,9% | 1,2% | 1,1% | 15,0% | 9,3% | 14,2% | 10,1% | 3,8% | 3,3% | 9,8% | 14,7% | 9,1% |
| *SCh ranking* | | | | 10 | 14 | 11 | 12 | 13 | 15 | 1 | 6 | 3 | 4 | 8 | 9 | 5 | 2 | 7 |

### 5.2.2 Discussion of results

The case study addressed the early stages of the service development by defining and evaluating the CRs. This information can support engineers in properly augmenting the services' offer related to the supplied equipment. The different approaches (i.e. the traditional HoQ, the fuzzy HoQ and the fuzzy-AHP HoQ) provide different understanding of customer needs and expectations, especially considering the prioritization and the relative weight of CRs. In detail, as shown in Figure 88, the traditional approach provided the most indistinct and unclear results. The variation range of the CRs is 5,67 % making the prioritization of the requirements blurry. Such a trend can be observed also when considering the results obtained with the Fuzzy logic approach (the broken line in Figure 89), since a slightly higher distinction among the CRs was achieved resulting in a variation range of 7,0%.

On the contrary, the FAHP integration resulted in the most distinct and sensible assessment of the CRs through the use of the fuzzy logic in combination with the pairwise comparisons, resulting in a variation range of 31,56 %.

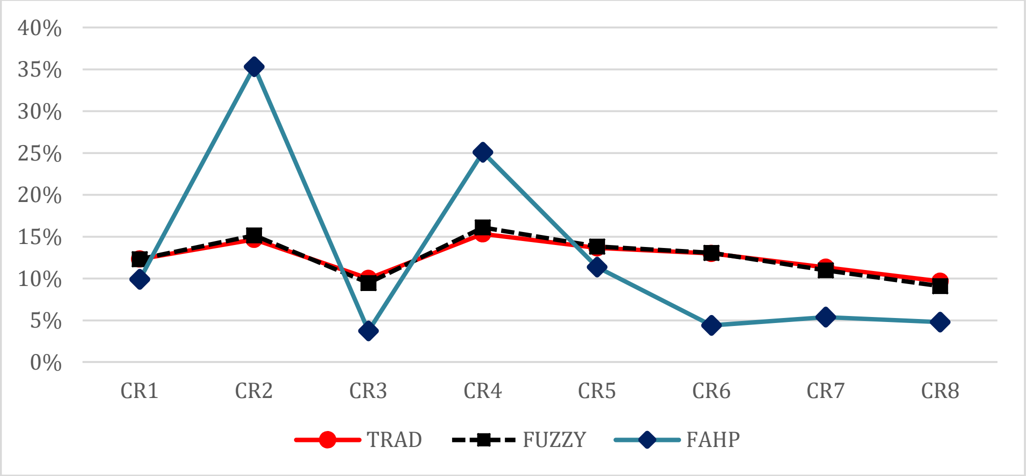


Figure 89 – Comparison of the relative importance of the CRs (normalized values (%)).

As far as the relative importance of the SChs is concerned, the differences in terms of the variation range of values are less consistent. In fact, the variation range using the traditional approach was of 8,03% whereas the Fuzzy logic and the FAHP approach led to higher ranges of 9,25% and 13,96% respectively (Figure 90). Based on this, the main service characteristics are clearer and more easily discernible allowing a better direction of the design process.

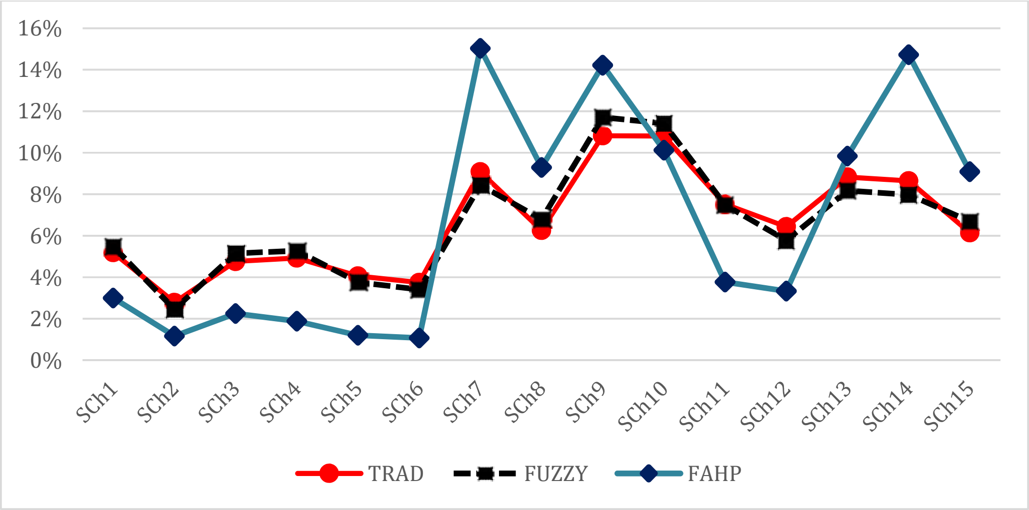


Figure 90 – Comparison of the relative importance of the SChs (%).

Another relevant aspect concerns the ranking of both CRs and SChs, i.e. the prioritization of the customers' needs and the interventions that should be accomplished to satisfy them. On one hand, as shown in Table 44, a similar prioritization is provided by the different approaches when considering the CRS: the most three important CRs (shaded in Table 44) are the same even though with a different ordering. On the other hand, when we look at the service characteristics, only SCh7 (Replacement of malfunctioning devices in 72 hours) and SCh9 (Extended remote technical support) belong to the group of the most three important SChs. While SCh14 (Time for intervention), which resulted in being quite relevant according to the FAHP, has a lower ranking when considering both the fuzzy and the traditional approaches.

Table 44 – Ranking of CRs and SChs in accordance with the three QFD-based approaches.

| | TRAD | FUZZY | FAHP |
|---|---|---|---|
| **CR1** | 5 | 5 | 4 |
| **CR2** | 2 | 2 | 1 |
| **CR3** | 7 | 7 | 8 |
| **CR4** | 1 | 1 | 2 |
| **CR5** | 3 | 3 | 3 |
| **CR6** | 4 | 4 | 7 |
| **CR7** | 6 | 6 | 5 |
| **CR8** | 8 | 8 | 6 |

| | TRAD | FUZZY | FAHP |
|---|---|---|---|
| **SCh1** | 10 | 10 | 10 |
| **SCh2** | 15 | 15 | 14 |
| **SCh3** | 12 | 12 | 11 |
| **SCh4** | 11 | 11 | 12 |
| **SCh5** | 13 | 13 | 13 |
| **SCh6** | 14 | 14 | 15 |
| **SCh7** | 3 | 3 | 1 |
| **SCh8** | 8 | 7 | 6 |
| **SCh9** | 1 | 1 | 3 |

|  |  |  |  |
|---|---|---|---|
| **SCh10** | 2 | 2 | 4 |
| **SCh11** | 6 | 6 | 8 |
| **SCh12** | 7 | 9 | 9 |
| **SCh13** | 4 | 4 | 5 |
| **SCh14** | 5 | 5 | 2 |
| **SCh15** | 9 | 8 | 7 |

Thus, these results can address engineers differently when only a few interventions can be made by the company in order to improve the service characteristics. In other words, when the company has limited resources and cannot afford the improvement of all characteristics, decision making is strictly related not only to the results of the prioritization itself, but also to the differences among the different options. With this aim in mind, certainly the FAHP approach can be considered more effective than the other two approaches, since it indicates how addressing one solution can be beneficial compared to another in terms of customer satisfaction.

The case study highlights the limitations of the traditional QFD in an intangible and more subjective context such as PSSs. In fact, the prioritization of the CRs using the traditional approach was proven limited as shown by its narrow variation range compared to the fuzzy and FAHP approaches. The fuzzy approach revealed to be more effective in translating the qualitative and subjective aspects of a service into quantitative figures. In addition to that, the combination of the fuzzy approach with the AHP approach led to an even more effective assessment of the CRs as the pairwise comparisons enabled a clarification of the service ambiguities leading to a more effective determination of the service characteristics to implement.

From a general point of view, the case study presents an approach to effectively manage customer requirements for the implementation of a PSS solution. Unlike a conventional product, a service embeds much more ambiguity to which pairwise comparisons and fuzzy approaches are beneficial in identifying and prioritizing them as the cornerstone of the design process. This is in line with findings by Kurtulmuşoğlu and Pakdil (2017) who underlined the importance of an accurate evaluation of customers' needs when developing services. In detail, the FAHP integration with QFD allowed the management of the CRs in a more sensible manner leading to a more precise and valuable evaluation of the service characteristics as to identify and classify the most relevant ones. In coherence with Shad et al. (2014), the approach underlined the effectiveness of the AHP in handling customer requirements under uncertainty while extending the latter's research by integrating the AHP with the fuzzy logic. This is due to the adoption of pairwise comparisons which enabled a holistic and coherent assessment of the CRs to capture and understand the interrelationships among them.

Further work could include the use of different types of fuzzy numbers (i.e. trapezoidal) and the use of other QFD augmentation tools such as the Analytic Network Process (ANP) and alpha-cuts.

## 5.3 Company “B” – A Hemodialysis Equipment Manufacturer

### 5.3.1 The case study

The subsequent case study adopts a quantitative approach based on the Kano model, the QFDforPSS method and the FAHP approach (Figure 91). It was carried out in the medical device sector where the need for an appropriate service strategy is emphasized (Lee et al. 2015). In particular, the work concerned the implementation of this approach in a company operating in the renal support devices market at an international level. This company, referred to as company “B”, produces hemodialysis devices, and provides both the equipment and all the services related to its use to the customers. The company was chosen based on previous collaborations with the university, which facilitated the request and collection of data as well as the organization of meetings and interviews under a non-disclosure agreement.

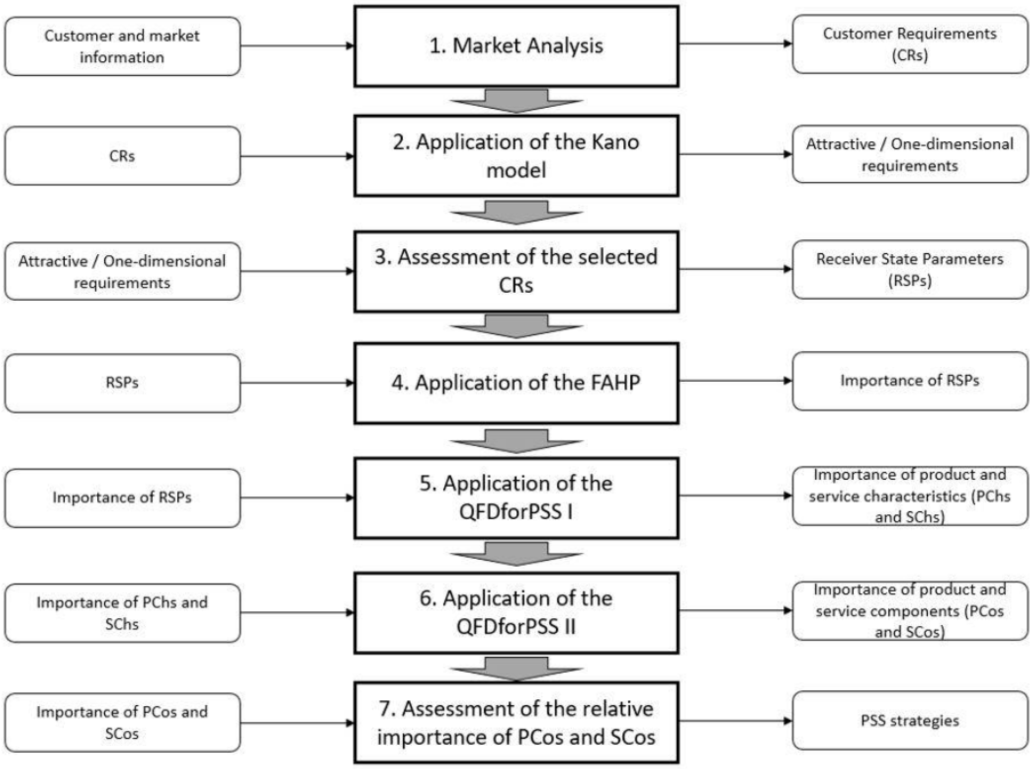


Figure 91 – Scheme of the approach

The proposed procedure is characterized by the following features.

1. Market analysis: market surveys and questionnaires for customers’ involvement constitute the basis for the definition of CRs.

2. Application of the Kano model: the individuation of the attractive and one-dimensional CRs by means of the Kano model, since the attractive CRs create more room for innovative means for profit generation and cost reduction opportunities (Matzler and Hinterhuber, 1998). One-dimensional CRs represent the measurable technical performances of the PSS that the customer expresses explicitly. These CRs are usually 'standard' and specified by the customer prior to using the PSS (Madzik, 2016). In other words, the Kano model helps in filtering CRs by removing the basic ones, which are a must-be in a regulated market. This allows engineers to define the requirements whose fulfilment could contribute to an increased customer value and, as noted by Cheng and Chiu (2007), leads to the quality strategy to follow.
3. Assessment of the selected CRs: a translation process is carried out by means of a group of experts to transform the CRs into RSPs, which allow a more coherent integration of the stakeholders' requirements and hence a more reliable evaluation of their comparability. This is necessary because CRs are sometimes expressed vaguely and in such a way that they are difficult to be compared. Based on this, the group of experts is also able to better define the characteristics of the product (PChs) and the characteristics of the service (SChs).
4. Application of the Fuzzy-AHP: the prioritization of the RSPs is performed by means of the FAHP; in detail, the importance level of each RSP is determined thanks to the pairwise comparisons (Saaty, 1990) and refined through the fuzzy logic approach (Singh and Prasher, 2017).
5. Application of the QFDforPSS I: the first phase of the method allows engineers to assess the relative importance of each PCh and SCh, as well as to define the level of the product-service integration in the solution.
6. Application of the QFDforPSS II: in the second phase, the components of the product (PCos) and of the service (SCos) are defined and their relative importance is calculated.
7. Assessment of the relative importance of PCos and SCos by means of a group of experts, which facilitates finding possible PSS improvement strategies.

### Identification of the Customer Requirements

As a first step, a market survey was conducted in collaboration with a group of the company's experts (i.e. a marketing manager, the product development manager and the director of the scientific affairs unit) Since the majority of the company's customers is represented by public hospitals and clinics, and the public procurement system is based on calls for tender (Bergman and Lundberg, 2013).We screened the invitations to tender issued in a 24-month period (2015-2016) at the national level and selected 25 of them that fit the company's target (for instance, invitations that included the fitting out of haemodialysis room ex novo were not taken into account). This activity included the analysis of both the tangible (technical) and the intangible (service) characteristics required by the invitations, as well as the criteria used to assess the tenders' offerings. These data were further analysed in collaboration with the company's group of experts to eliminate requirements concerning characteristics related to the basic functioning of the device. For example, characteristics such as "presence of a display or a monitor", "alarm system to monitor the presence of air", "wheels to move the machine from one room to another", or "maintenance service during the contract period" were considered as standardized elements of this type of PSS representing the so-called "cutting edge" of the sector. Then, we developed a questionnaire (Appendix B) aimed at gathering the importance of the CRs. It was submitted to 47 customers (i.e. doctors who uses the haemodialysis devices daily, belonging to different public hospitals operating as organisational units for public procurement). The hospitals were selected taking into account their geographical locations and the population of the areas they cover in order to obtain a homogenous distribution in the northern, southern and middle parts of the country. Moreover, to prevent any potential bias, the questionnaires were sent under the university edge, omitting any manufacturer related information. Of the 47 customers, 20 of them provided a complete answer. They were asked to evaluate the importance of each CR using a (1 to 5) scale and their current level of satisfaction per each requirement using a (-3, +3) scale (Tontini, 2007). The classification of the requirements within the Kano categories was performed using the Customer Satisfaction Coefficient (CSC) indices which calculate the percentage of customers satisfied with the functional form of the question and the percentage of dissatisfied customers with the dysfunctional form (Matzler and Hinterhuber, 1998). Then, the requirements belonging to Attractive (A) and One-dimensional (O) Kano categories were selected (Table 45).

Table 45 – Attractive and One-dimensional requirements.

| Attractive Requirements | One-dimensional Requirements |
|---|---|
| CR1 – User-friendly equipment | CR2 – Haemodialysis process monitoring |
| CR6 – Easy maintenance | CR3 – Availability of a self-testing system |
| CR7 – Quick setting before each treatment | CR4 – Quick replacement of malfunctioning devices |
| CR8 – system upgradability | CR5 – Quick intervention when requested |
| CR10 – Provision of consumables with a low environmental impact | CR9 – Remote technical support |

It should be noted that in this sector a full risk service as well as the availability of additional equipment in the stock (the so-called "back-up" equipment) should be considered as standard requirements, thus they were also omitted in the definition of the CRs. The selected requirements are of a general nature, i.e. they can be satisfied by a service (intangible), by a product (tangible), or by a combination of both. Hence, to support engineers in better understanding what can enhance the customers' value and how to pursue it, they need to be translated into functions, i.e. into RSPs, that consist of quantitative, observable and controllable value (Arai and Shimomura, 2005).

**Definition of RSPs, Product and Service Characteristics**

In collaboration with the group of experts, the selected requirements were analysed and translated into the following RSPs:

RSP 1. Easiness to use.
RSP 2. Ergonomics (interface operator-machine).
RSP 3. Full monitoring (real-time information during the process).
RSP 4. Short-time for replacement.
RSP 5. Short-time for intervention.
RSP 6. Availability.
RSP 7. Eco-friendliness and biocompatibility.
RSP 8. Upgradability.
RSP 9. Technical support availability.
RSP 10. Inclusion of consumables.

Similarly, the PChs and SChs were also defined as follows:

PCh 1. Product size: the machine's dimensions should be adequate to allow its easy use and transportation.
PCh 2. Monitor type: the monitor size and resolution should be adequate.

PCh 3. Mean Time Before Failure (MTBF): the equipment must function for prolonged working hours before the occurrence of failures.
PCh 4. Software modularity: a modular design enables easier upgrades and interventions.
PCh 5. Number of setup operations specific to the product: the number of steps to carry out for the installation and removal of the consumables should be minimum.
PCh 6. Alarm warning feature: a malfunctioning alarm should arise by means of a visual or sound signal to inform the user.
PCh 7. Availability of a self-testing system to be used before each treatment.
PCh 8. Treatments' data storage in the system hard disk.
PCh 9. Eco-friendliness of consumables (e.g. filters and solutes).
PCh 10. Quality of product manual: the product should be accompanied by a manual describing its components and guiding the user though its calibration and use, including interactive software.
SCh 1. Information for intervention requests.
SCh 2. Calendar time of training: periodic training for the correct use of the machine, notably when updates are available.
SCh 3. Time for response: short time to reply an inquiry and intervene.
SCh 4. Calendar time of consumables delivery: consumables are delivered according to an agreed-on schedule.
SCh 5. Operational time of customer care: the customer care unit should be available to reply to customer calls.
SCh 6. Quality of customer care: customer care should have the capacity to effectively assist the customer.

**Prioritization of the RSPs**

The obtained RSPs are supposed to be quantified and prioritized according to the CRs to define which RSPs are more important. In other words, such an approach allows designers to better understand which RSP holds the highest impact on the holistic performance and quality of the solution. To do so, in collaboration with the manufacturer's group of experts, the customers who provided full responses to the market survey were interviewed and asked to evaluate the importance of each CR compared to another by adopting a pairwise comparison approach (similar to Section 5.1) as per Saaty's scale

(Saaty, 1990). The importance levels of each RSP are then utilized as the inputs of the comparison matrix in a similar manner as shown in the previous section.

Consequently, the shift from crisp numbers to Triangular Fuzzy Numbers (TFNs) was carried out using the transformation exhibited by (Kamvysi et al. 2014) to apply the FAHP method, which led to the results shown in Table 46.

Table 46 – C Crisp values.

| Receiver State Parameters | Importance | Relative Importance | Rank |
|---|---|---|---|
| RSP 1. Easiness to use | 0.64 | 6.14% | 5 |
| RSP 2. Ergonomics (interface operator-machine) | 0.44 | 4.21% | 9 |
| RSP 3. Full monitoring | 0.43 | 4.14% | 10 |
| RSP 4. Short time for replacement | 1.29 | 12.37% | 4 |
| RSP 5. Short time for intervention | 1.98 | 18.94% | 2 |
| RSP 6. Eco-friendliness and biocompatibility | 1.41 | 13.52% | 3 |
| RSP 7. Availability | 2.66 | 25.47% | 1 |
| RSP 8. Upgradability | 0.60 | 5.72% | 6 |
| RSP 9. Technical support availability | 0.53 | 5.09% | 7 |
| RSP 10. Inclusion of consumables | 0.46 | 4.40% | 8 |

These results were then verified for consistency in accordance with (Ho et al. 2012).

### QFDforPSS phase I

Based on these results and their validation, the first phase of the QFDforPSS method was implemented. The PChs and SChs were combined with the RSPs in the co-relational matrix using a 1-3-9 rating scale where 1 indicates a weak relationship, 3 a medium one and 9 a strong one. When a relationship does not exist, the cell is left blank. The output of this phase consists in obtaining the Absolute Importance (AI) of each PCh and SCh and consequently their Relative Importance RI values (Table 47).

Table 47 – QFDforPSS phase I.

| | RSP Importance | RSP Relative Importance | *RSP Ranking* | PCh1 | PCh2 | PCh3 | PCh4 | PCh5 | PCh6 | PCh7 | PCh8 | PCh9 | PCh10 | SCh1 | SCh2 | SCh3 | SCh4 | SCh5 | SCh6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RSP 1 | 0.64 | 6.14% | *5* | 1 | 3 | | | 3 | | | 3 | 1 | 3 | | 3 | | 1 | | |
| RSP 2 | 0.44 | 4.21% | *9* | 3 | | | 3 | 9 | | | | | 3 | | 3 | | 3 | | |
| RSP 3 | 0.43 | 4.14% | *10* | | 9 | | | | 9 | 1 | | | 1 | | 3 | | | 3 | 3 |
| RSP 4 | 1.29 | 12.37% | *4* | | | | | | | | | | | 3 | | 9 | | | |
| RSP 5 | 1.98 | 18.94% | *2* | | | | | | | | | | | 9 | | 9 | | 3 | 3 |
| RSP 6 | 1.41 | 13.52% | *3* | | | | | 1 | | | | 9 | | | | | | | |
| RSP 7 | 2.66 | 25.47% | *1* | | | 9 | 3 | | 1 | 3 | 1 | | | | 3 | | 3 | | |
| RSP 8 | 0.60 | 5.72% | *6* | | | 3 | | 1 | | | 1 | 9 | | | | | | | |
| RSP 9 | 0.53 | 5.09% | *7* | | | | | | | | | | | 3 | | | | 9 | 9 |
| RSP 10 | 0.46 | 4.40% | *8* | | | | | 1 | | | | 9 | | | | | 9 | | |
| Ch Absolute Importance ($AI_{Ch}$) | | | | 1.96 | 5.79 | 23.94 | 9.30 | 8.35 | 3.09 | 8.41 | 5.18 | 22.87 | 3.67 | 23.28 | 12.51 | 29.43 | 14.08 | 12.00 | 12.00 |
| Ch Relative Importance ($RI_{Ch}$) | | | | 1.00% | 2.96% | 12.22% | 4.75% | 4.26% | 1.58% | 4.29% | 2.64% | 11.68% | 1.87% | 11.89% | 6.39% | 15.03% | 7.19% | 6.13% | 6.13% |

### QFDforPSS phase II

The second phase of QFDforPSS is aimed at the definition of most critical components of both the service and the product (Table 48). The components as well as the co-relational strengths were decided through a meeting carried out with the company's experts.

Table 48 – List of PCos and SCos.

| Product Components (PCos) | | Service Components (SCos) | |
|---|---|---|---|
| PCo1 | Full HD monitor | SCo1 | Provision of a sufficient number of maintenance technicians |
| PCo2 | Touch-screen monitor | SCo2 | Decentralization of the service centres |
| PCo3 | Automated self-test | SCo3 | Extended customer care service; |
| PCo4 | Low environmental impact filters | SCo4 | Operators periodic training; |
| PCo5 | Treatments' data storage system | SCo5 | Customer care periodic training |
| PCo6 | Range of warnings | SCo6 | Qualification of training instructors |
| PCo7 | Remote operational monitoring system | SCo7 | Maintenance technicians' periodic training |
| | | SCo8 | Supply of a wide range and quality of solutes |

Notably, the components of the services were defined as per the required type of resources for their realization (Sakao et al. 2017). Consequently, they were classified into human resources, information, and service tools (Table 49). The definition of the product components followed a similar syntax by focusing on the components insuring the availability and operability of the equipment, as well as its environmental performances (Table 50).

Table 49 – Classification of SCos.

| Human Resources | Information | Service Tools |
|---|---|---|
| SCo1 | SCo4 | SCo8 |
| SCo2 | SCo5 | |
| SCo3 | | |
| SCo6 | | |
| SCo7 | | |

Table 50 – Classification of PCos.

| Operability | Availability | Environment |
|---|---|---|
| PCo1 | PCo3 | PCo4 |
| PCo2 | PCo6 | |
| PCo5 | PCo7 | |

Then, their assessment was performed by means of the same criteria used previously, where the relationships between PCh and SChs from one side, and

PCos and SCos from the other were evaluated with a 1-3-9 rating scale (Table 51).

Table 51 – QFDforPSS phase II

| | Ch Importance | Ch Relative Importance | *Ch Ranking* | PCo1 | PCo2 | PCo3 | PCo4 | PCo5 | PCo6 | PCo7 | SCo1 | SCo2 | SCo3 | SCo4- | SCo5 | SCo6 | SCo7 | SCo8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCh1 | 1.96 | 1.00% | *16* | | 1 | | 1 | 1 | | | | | | | | | | |
| PCh2 | 5.79 | 2.96% | *12* | 9 | 9 | | | | | | | | | | | | | |
| PCh3 | 23.94 | 12.22% | *2* | | | 3 | | | | 9 | 1 | | | 9 | 1 | 3 | 9 | |
| PCh4 | 9.30 | 4.75% | *9* | | | | | | | | | | | | | | | |
| PCh5 | 8.35 | 4.26% | *11* | 1 | 1 | 9 | | | | | | | | | | | | |
| PCh6 | 3.09 | 1.58% | *15* | 1 | | 3 | | | 9 | | | | | | | | | |
| PCh7 | 8.41 | 4.29% | *10* | | | 9 | | | | 3 | | | | | | | | |
| PCh8 | 5.18 | 2.64% | *13* | | | 1 | | 9 | | | | | | | | | | |
| PCh9 | 22.87 | 11.68% | *4* | | | | 9 | | | | | | | | | | | 9 |
| PCh10 | 3.67 | 1.87% | *14* | | 3 | | | | | | | | | 9 | 3 | | | |
| SCh1 | 23.28 | 11.89% | *3* | | | | | | 9 | 1 | | | 1 | 3 | 3 | | 9 | |
| SCh2 | 12.51 | 6.39% | *6* | | | | | | | | | | | 9 | | 3 | | |
| SCh3 | 29.43 | 15.03% | *1* | | | | | 1 | | 3 | 9 | 9 | 3 | | 1 | | 3 | |
| SCh4 | 14.08 | 7.19% | *5* | | | | | | | 3 | | 3 | 1 | | | | | 9 |
| SCh5 | 12.00 | 6.13% | *7* | | | | | | | | | | 9 | | 3 | | | |
| SCh6 | 12.00 | 6.13% | *7* | | | | | | | | 1 | | 3 | | 9 | | | |
| Co Absolute Importance ($AI_{Co}$) | | | | 63.55 | 73.43 | 237.11 | 207.79 | 78.01 | 237.33 | 394.50 | 300.81 | 307.11 | 269.65 | 430.92 | 278.22 | 109.35 | 513.27 | 332.55 |
| Co Relative Importance ($RI_{Co}$) | | | | 1.66% | 1.92% | 6.19% | 5.42% | 2.03% | 6.19% | 10.29% | 7.85% | 8.01% | 7.03% | 11.24% | 7.26% | 2.85% | 13.39% | 8.67% |

### 5.3.2 Discussion of results

The proposed procedure filtered and analysed the high-level “front-end” requirements defined by the customers. These requirements were then transformed by means of the Kano model criteria into RSPs according to which the customer judges his overall satisfaction with the solution. In order to address their ambiguity and intangibility, the FAHP was adopted making use of a systematic series of pairwise comparisons followed by a consistency check. The FAHP integration with QFDforPSS allowed a more sensible evaluation of the RSPs and accordingly a more accurate importance evaluation of the product and service characteristics and components (in line with Jiao and Chen (2006)). This coincides with Singh and Prasher (2017), who underlined the benefits of the FAHP in assessing the customers’ requirements and preferences in a precise manner, notably in the healthcare industry. More in detail, the study allowed us to identify and classify the most relevant product and service characteristics leading to increase the customers’ value. As it can be noted in Table 52, the most important characteristics concern the service, apart from the need for availability (PCh3) and the attention paid to the supply of environmentally friendly consumables (PCh9).

Table 52 – Relevance of Product and Service Characteristics.

| **PSS Characteristics** | **Relevance (FAHP)** | **Ranking** |
|---|---|---|
| SCh3 – Time for response | 15,03% | 1 |
| PCh3 –MTBF | 12,22% | 2 |
| SCh1 – Information for intervention requests | 11,89% | 3 |
| PCh9 – Eco-friendliness of consumables | 11,68% | 4 |
| SCh4 – Calendar time of consumables delivery | 7,19% | 5 |
| SCh2 – Calendar time of training | 6,39% | 6 |
| SCh5 – Operational time of customer care | 6,13% | 7 |
| SCh6 – Quality of customer care | 6,13% | 8 |
| PCh4 – Software modularity | 4,75% | 9 |
| PCh7 – Self-testing system | 4,29% | 10 |
| PCh5 – Number of setup operations | 4,26% | 11 |
| PCh2 – Monitor type | 2,96% | 12 |
| PCh8 – Treatments’ data storage | 2,64% | 13 |
| PCh10 – Quality of product manual | 1,87% | 14 |
| PCh6 – Alarm warnings | 1,58% | 15 |
| PCh1 – Product size | 1,00% | 16 |

Similarly, the second phase of the method exhibited the importance of the service components, highlighting the interventions that the company can carry out to augment its PSS value (Table 53).

Table 53 – Relevance of Product and Service Components.

| PSS Components | Relevance (FAHP) | Ranking |
|---|---|---|
| SCo7- Maintenance technicians periodic training | 13,39% | 1 |
| SCo4- Operators periodic training | 11,24% | 2 |
| PCo7- Remote operational monitoring system | 10,29% | 3 |
| SCo8- Range and quality of different types of solutes | 8,67% | 4 |
| SCo2- Number of service centres | 8,01% | 5 |
| SCo1- Number of maintenance technicians | 7,85% | 6 |
| SCo5- Customer care periodic training | 7,26% | 7 |
| SCo3- Extended customer care service | 7,03% | 8 |
| PCo6- Range of warnings | 6,19% | 9 |
| PCo3- Automated self-test | 6,19% | 10 |
| PCo4- Low environmental impact filters | 5,42% | 11 |
| SCo6- Number of training instructors | 2,85% | 12 |
| PCo5- Treatments' data storage system | 2,03% | 13 |
| PCo2- Touch-screen monitor | 1,92% | 14 |
| PCo1- Full HD monitor | 1,66% | 15 |

To better analyse the results of the case study, the group of experts was asked to assess the RSPs, PChs, SChs, PCos and SCos using the traditional QFD approach. Based on the outputs of the customers' questionnaires concerning the CRs' importance levels (Section 4.1), the experts assessed the importance of each RSP using a 1 (not important) to 5 (extremely important) rating scale. While the same values of the FAHP relationships matrices were used to derive the relevance of the PChs, SChs, PCos and SCos. This allowed us to better examine the effectiveness of the proposed approach. First, concerning the RSPs, a more accurate rating through the FAHP approach was obtained compared with the traditional QFD. As shown in Figure 92, the traditional QFD approach provided limited results as the variation range of the RSPs was of 13.33% while the FAHP-QFD approach denoted a wider variation range of 21.36%. In addition, through the traditional QFD approach, several RSPs were allocated equal importance levels making a proper distinction between them infeasible (e.g. RSPs 1, 3, 4, 9); whereas the FAHP approach provided distinct levels for each of the RSPs, leading to the elimination of "ties" among the customers' expectations (Franceschini and Maisano, 2015).

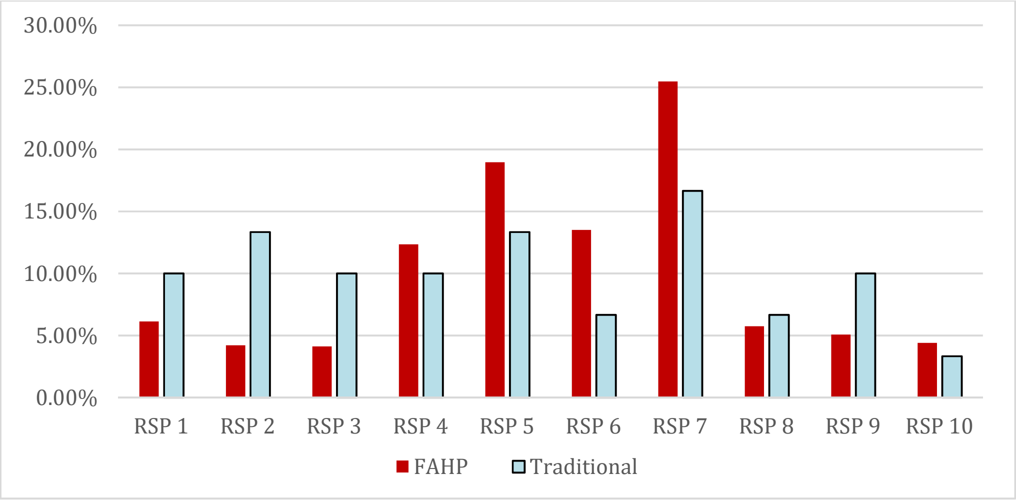


Figure 92 – Comparison of the relevance of the RSPs between the FAHP and traditional QFD approaches.

Secondly, the relevance of the characteristics resulting from the FAHP-QFD method were compared to the ones obtained through a traditional QFD (Figure 93). The results from the FAHP show a higher variation range (14.03%) compared to that of the traditional approach (9.42%) allowing the manufacturer to better prioritize the PSS characteristics.

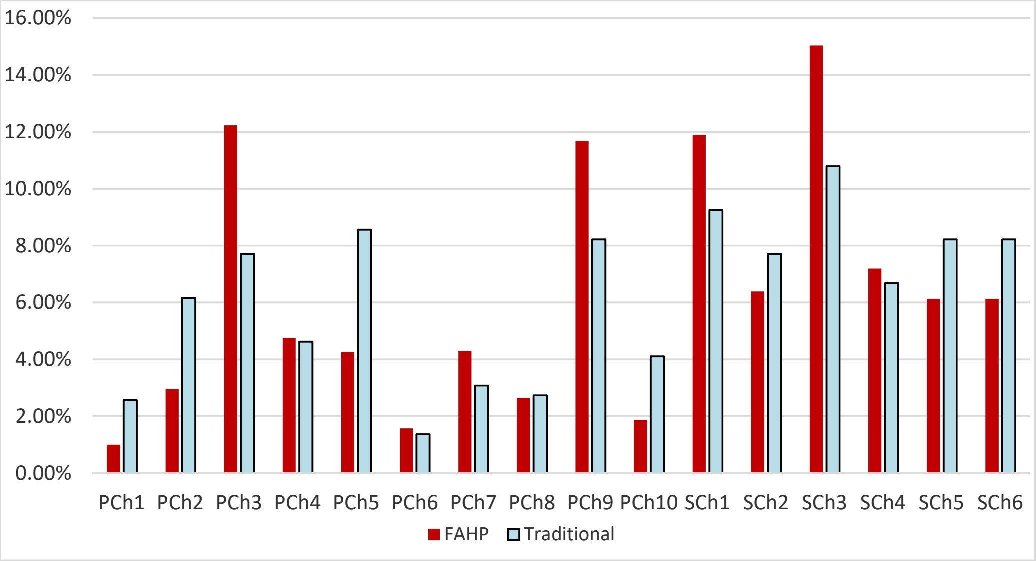


Figure 93 – Comparison of the PSS Characteristics' relevance between the FAHP and traditional QFD approaches.

Similarly, the relevance of the PSS components was compared (Figure 94) enabling a better distinction of the PSS Components as the variation range using the FAHP approach (11.73%) is higher compared to that of the traditional approach (9.55%). It has to be noted that these results might be affected by a potential bias due to the differences existing between the target customers and the responses of the group of experts when applying the traditional QFD. To limit such an effect, the above-mentioned experts were asked to apply the method before knowing the results of the FAHP procedure. Moreover, to obtain a more objective assessment, they were interviewed separately and the scores obtained to fulfil the relationship matrices represent the average values of their responses.

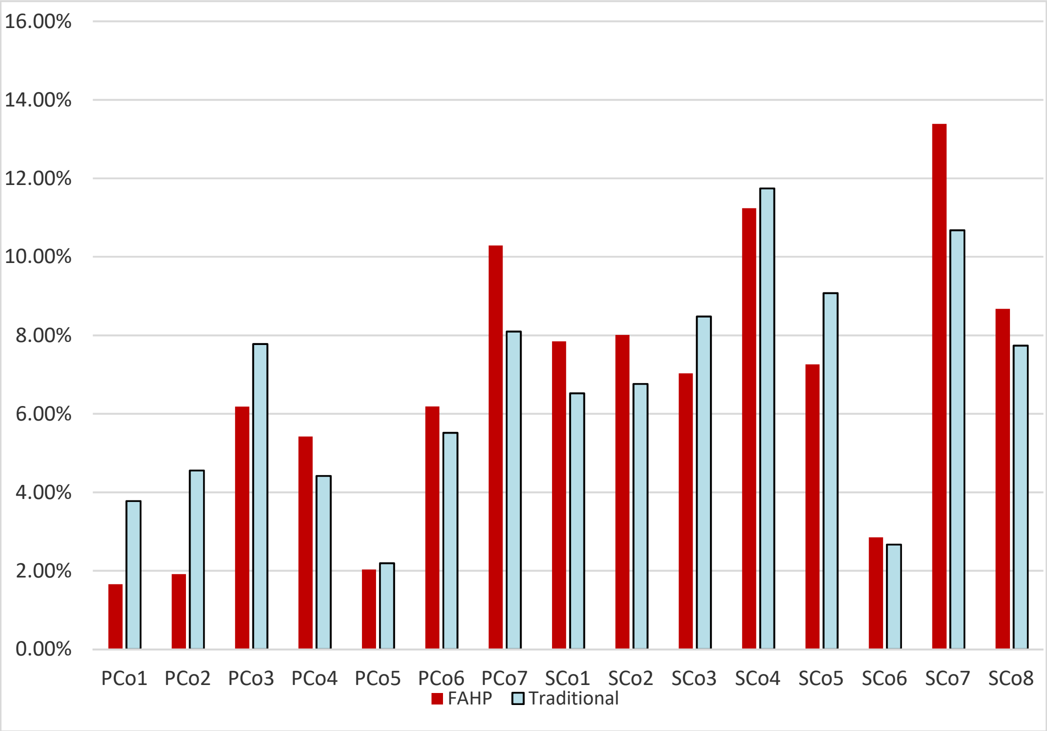


Figure 94 – Comparison of the PSS Components' relevance between the FAHP and traditional QFD approaches.

The comparative assessment denotes the FAHP-QFD's capability to handle PSS characteristics and components in a clearer and more distinct manner, and to quantify the subjectivities and ambiguities embedded in a PSS as hinted by Huang and Hsu (2016). In other terms, the FAHP integration allowed a clearer evaluation and distinction of the expected characteristics and performances of the PSS, supporting the research outcome by Kannan (2008) on the PSS context. Hence, from this case study, the results achieved show that the FAHP integration augmented the effectiveness of the traditional QFD by improving the understanding of PSS customers' requirements through reducing the uncertainties of the relationships between ''hows'' and ''whats".

The study also remarked the importance of filtering the general customers' requirements to separate basic needs from the ones that have the higher potential to increase the value of the offering.This finding is also consistent with the outputs of other studies (e.g. Kumar and Reinartz 2012; Martinez et al. 2010; Raddats, 2011; Song, 2017) and represents a novelty in the sector of medical devices (a specific case of the so-called "Product Lifecycle Services", as per Ulaga and Reinartz (2011)), where usually manufacturers need to ensure the proper functioning of the equipment throughout all its lifecycle stages (as it happens in a regulated market, where basic requirements are contractual requirements). This novel use of the Kano model also contributes to the needed empirical studies on Kano's applications suggested by Materla et al. (2017).

Another contribution of the paper is the presentation of a concrete case of PSS design including the exemplification of the service characteristics and service components, classified according to a proper taxonomy and assessed in a less complex manner by targeting the resources behind each service activity instead of the activity itself (Sakao et al. 2017). This contribution is more relevant to practice in industry, but is useful also to advance scientific knowledge on ontologies in the PSS domain (Ki Moon et al. 2009).

From a service implementation perspective, it has to be pointed out that the results suggest strengthening and innovating the relationships and interactions with the customers. This empirical finding is in line with insights remarked among others by Gebauer and Kowalkowski (2012). This implies that the company has to focus on increasing its capability in running a service network distributed at local level, as well as in improving the knowledge and skills of the service and the customer care operators. The study contributes to the practical needs of manufacturers that deal with the necessity to find a good balance between the improvement of product and service components to provide more convenient offerings. This is also in line with the research results by numerous researchers (e.g. Baines et al. 2009; Fargnoli et al. 2014; Pezzotta et al. 2015)), who suggested a framework to define strategies to deliver competitive integrated product-service offerings. When an offering is related to both a product and a set of connected services, difficulties arise for the company, which mainly consist in the shift from product performance requirements (e.g. the hemodialyzer availability, or the eco-friendliness and the biocompatibility of consumables) to target values in terms of PSS receivers (e.g. maintenance service response within a certain time, the equipment MTBF, etc.). From a more general perspective, the proposed approach facilitates a continuous feedback, which can support engineers to better manage the PSS development activities through verifying inputs and outputs of each step. Our research work also represents an attempt to answer to the need to further investigate the opportunities of improving competitive capabilities and customer satisfaction in a PSS context (Jeong and Oh, 1998; Oliva and Kallenberg, 2003; Ulaga and Reinartz, 2011; Pan and Nguyen, 2015; Long et al. 2016), even though they are often linked to the specific case study and cannot be easily generalized as argued by Bertoni et al. (2017).

Despite these positive contributions, the present study certainly presents some limitations. First of all, we did not consider costs, given that the company's core business is in the public procurement sector, ruled by calls for tenders and thus subject to a price-control system. Nevertheless, we are aware that to properly evaluate and select an improvement strategy a financial analysis is needed. In addition, a larger sample of customers can be addressed to obtain a more accurate understanding of their requirements.

From the company perspective, activities such as "increase the number of service centres", "increase the number of maintenance technicians" or "supply a higher range of different types of solutes" have a different financial impact. Thus, a cost-benefit analysis should be integrated in the model to obtain results that are more complete. Moreover, the proposed approach can be defined as mono-dimensional (i.e. a business-to-customer approach), since the relationships with other companies, such as original equipment manufacturers, maintenance service providers etc., were not considered.

Furthermore, the results were obtained from a single case study and lack external validity. Thus, caution is required in generalizing the findings beyond the sample and industry concerned (Alam and Perry, 2002), although the use of a single case-study as a research tool for exploratory investigation and to generate new understandings is recognized by several authors (e.g. Voss et al. 2002; Yin, 2003; Piercy and Rich, 2009).

# 5.4 Company "C" – A Lawn Mower Manufacturer

## 5.4.1 The case study

The application comprises of the first two phases of the FEPSS model: Ideation and Task Analysis, and Conceptual Design.

It is carried out at a Lawn Mower (LM) manufacturer which produces the latter to be used in gardening and agricultural activities. The manufacturer, due to privacy concerns hereunder named "Company B", is interested in strengthening its position on the market of Lawn Mowers (LMs), since analysts noted a decrease of sales of LMs despite a general growth of this market. In Table 54, the main characteristics of the lawn mower object of the study are summarized.

Table 54 – Main characteristics of the lawn mower.

|  | |
|---|---|
| **Engine** | |
| Producer | Company B |
| Displacement | 190 cm$^3$ |
| Power | 2,4 kW |
| **Advancement system** | |
| Traction system | Self-propelled, Single gear |
| Wheel drive | Rear |
| Speed | 4 km/h |
| **Mower deck** | |
| Material | Aluminium |
| Mowing method | Triple clip |

| | |
|---|---|
| Mowing width | 53 cm |
| Mowing height | Min: 30 mm Max: 87 mm |
| Mowing height options | 6 |
| **Endowment system** | |
| Mowing height calibration | Central |
| Grass collector type | Soft basket |
| Grass collector volume | 60 L |
| Wheel bearings | Double ball bearings |
| **Dimensions** | |
| Height x Width x Length | 0,95m x 0,2m x 0,57m |
| Weight | 43,5 kg |

The product is intended for non-professional users possessing small to medium sized gardens. It is designed for a 10-year lifespan, while the engine's warranty covers 500 operational hours.

Company C is willing to increase its market share by providing a new type of offering to customers. Such a need came out from market surveys carried out by the company's customer-service. Customers' complaints concerning their dissatisfaction with both the reliability of the equipment and the current maintenance service, emerged remarkably. It was also noted that customers are attracted by more environmentally friendly solutions.

### Ideation and Task Analysis

Semi-structured interviews of customers carried out by the manufacturer's customer service team allowed us to identify and prioritize their quality drivers: a critical-to-quality (CTQ) tree representing those drivers is shown in Figure 95.

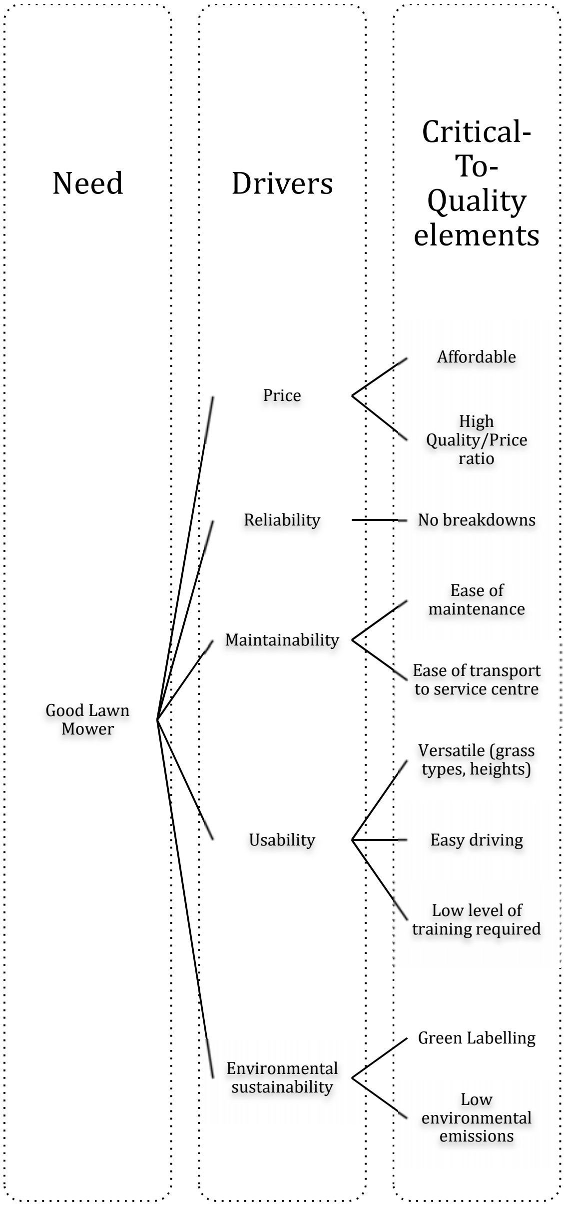


Figure 95 – CTQ tree of a good LM.

To better understand the company's position against its competitors on the market, a macro-analysis using a SWOT matrix was carried out. As shown in Figure 96, strengths and weaknesses highlight the factors internal to the company while opportunities and threats represent the factors external to the company.

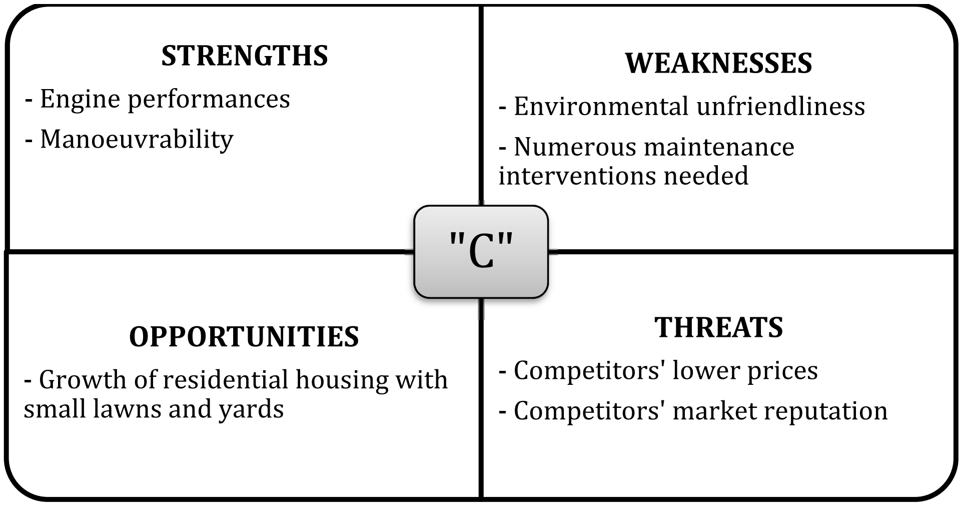


Figure 96 – SWOT analysis of “Company C”.

According to both customers’ surveys and interviews with experts in the gardening machinery sectors, the main problems reside in the “reputation” of the LM: a lower impact of maintenance operations, a higher availability and environmental concerns, greatly influence the non-professional customers when deciding to purchase a new equipment.

An additional technical survey conducted by the manufacturer’s engineers revealed that the product is lasting approximately 7 years instead of its intended 10 years, because of the engine’s limited duration when it is not maintained properly. Actually, in most cases after 7 years the engine needs to be replaced or fully reconditioned. Since the price of a new engine corresponds to 2/3 of the price of a new lawn mower, a large number of customers decide to buy new equipment. In these cases, customers are dissatisfied by the product so they usually opt for a LM produced by a different manufacturer.

On these considerations, the study focused on augmenting Company B business model taking into account a life cycle perspective since a proper product’s life cycle management can improve the product’s reliability and environmental performances, augmenting at the same time the customers’ satisfaction.

In this context, the manufacturer is aiming towards retaining the ownership of the LM to guarantee its correct maintenance and consequently performance, as well as to optimize its end-of-life treatment. To do so, two types of PSSs can be envisioned a RO-PSS or a UO-PSS (as indicated by Tukker, 2004). A RO-PSS would require the manufacturer to produce, use, maintain and dispose of the LM at the end of its lifecycle while charging the customer for a result. On the other hand, a UO-PSS sees the manufacturer responsible for the production, maintenance and disposal of the LM while the use stage is handled by the customer, who pays a fee for the temporary use of the product. Both ideas were assessed using a preliminary feasibility study carried out by the manufacturer. The results led the manufacturer to decide on a UO-PSS.

**Conceptual Design**

The development of possible UO-PSS concepts requires a functional decomposition in order to apply the PSS concept matrix. The grass cutting service idea is defined as the main function the PSS has to realize and it is composed of sub-functions where the fulfilment of each is an incremental step towards a holistic solution (Figure 97).

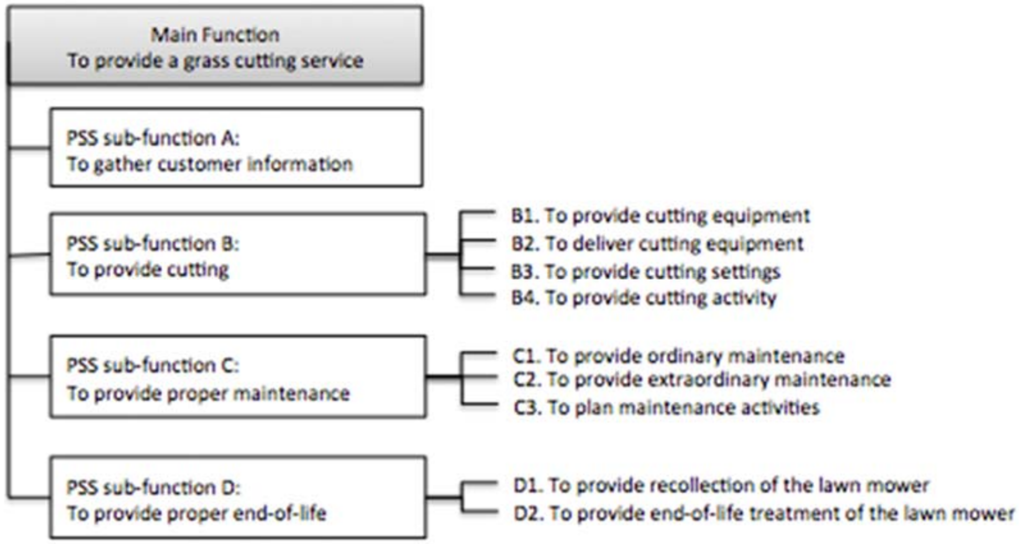


Figure 97 – Function tree deployment.

The PSS concept matrix was applied to identify the product and service actuators of each sub-function and their corresponding providers and receivers (Table 55). It has to be noted that as for the actuators of the PSS sub function D ("To provide proper end-of-life"), in accordance with the manufacturer's technicians the following options were foreseen:

- Recycling and Re-use 1*: after 6 years, the LM is recollected and reconditioned allowing its use for an additional 6 years, 90% of the materials are recycled.

- Recycling and Re-use 2*: after 10 years, the LM is recollected offering scrapping incentives for the purchase of a new LM: 60% of the components of the LM are recycled.
- Landfill: the customer provides the disposal of the LM by himself in a landfill.

From the PSS concept matrix, a Functional Concept (FC) was defined (shadowed parts in Table 55). According to such a scheme, the manufacturer provides a leasing service (UO-PSS) where the customer leases a LM to perform the cutting activities himself and returns the LM to the manufacturer at the end of the lease period. The manufacturer retains the ownership of the product and the customer pays a fee for the temporary use of the LM.

Table 55 – PSS Concept Matrix

| SUB-FUNCTIONS | ELEMENTARY FUNCTIONS | PRODUCT / SERVICE ACTUATORS | | | | ACTUATOR PROVIDER | | | ACTUATOR RECEIVER | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PSS sub function A: **To gather customer information** | N/A | Customer Interaction | Web Platform | | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| PSS sub function B: **To provide cutting** | B1: to provide cutting equipment | Leasing | Rental | Full Service | Purchase | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | B2: to deliver cutting equipment | Customer Pick-up | Home Delivery | — | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | B3: to provide cutting settings | Operator Manual | Training | None | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | B4: to provide cutting activity | Lawn Mower | | | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| PSS sub function C: **To provide proper maintenance** | C1: to provide ordinary maintenance | Preventive Maintenance | Condition-Based Maintenance | Risk-Based Maintenance | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | C2: to provide extraordinary maintenance | Immediate Corrective Maintenance | Deferred Corrective Maintenance | — | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | C3: to plan maintenance activities | Customer Interaction | Web Platform | No plan | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| PSS sub function D: **To provide proper end-of-life** | D1: to provide recollection of the lawn mower | Product Return | Take-back | None | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |
| | D2: to provide end-of-life treatment of the lawn mower | Recycling and Re-use 1* | Recycling and Re-use 2* | Landfill | | Customer | Manufacturer | Third Party | Customer | Manufacturer | Third Party |

To evaluate the feasibility of this solution, the SLCM method was used. As the first step of the method's application consists in the definition of the Base Scenario (BS), i.e. the model representing the current situation, the following assumptions were made:

- LM life span: 10 years.
- Production: constant production of 50 LMs per year.
- Distribution: the LM is delivered to each customer place by means of a mini-truck (average distance 100 km).
- Use and maintenance: Ordinary Maintenance (OM) plan as per the manufacturer's recommendations.
- Extraordinary Maintenance (EM): mainly concerns engine and starter malfunctioning, batteries deterioration and blades deterioration. In accordance with gardening machinery experts, the following schedule is assumed (Table 56).

Table 56 – Replaced components over the life cycle of the LM: Ordinary Maintenance (OM) and Extraordinary Maintenance (EM)

| Code | Type | Frequency | Activity |
|---|---|---|---|
| OM1 | Engine oil | Every 1 year | Replacement |
| | Fuel filter | Every 1 year | Replacement |
| | Air filter cartridge | Every 1 year | Replacement |
| OM2 | Spark plugs | Every 2 years | Replacement |
| OM3 | Distribution belt | Every 3 years | Replacement |
| | Exhaust pipe and silencer | Every 3 years | Replacement |
| | Touch up paint | Every 3 years | Paint |
| OM4 | Wheels | Every 5 years | Replacement |
| | Blades | Every 5 years | Sharpening |
| EM1 | Engine malfunctioning | Every 3 years | Repair/Replacement |
| EM2 | Batteries deterioration | Every 6 years | Replacement |
| EM3 | Blades deterioration | Every 2 years | Sharpening |
| EM4 | Starter malfunctioning | Every 3 years | Cable replacement |

Secondly, the Alternative Scenario (AS) was defined based on the FC that emerged from the use of the PSS Concept Matrix. More in details, it consists in a leasing solution with duration of '6+6' years. The manufacturer leases a LM to the customer for six years and provides him with training on its correct use to prevent breakdowns and decreasing performance. When ordinary maintenance is due, the customer brings the LM to the manufacturer's centre according to the maintenance schedule. Moreover, at the end of the sixth year, the manufacturer recollects the LM, fixes it and gives a reconditioned equipment back to the same customer in a period when gardening activities are not performed (i.e. winter months), if the customer extends the contract. On the contrary, it is put on the market for a new lease contract. By doing so, also maintenance schedule changes as follows (Table 57).

Table 57 – Comparison of maintenance interventions of BS and AS.

| BASE SCENARIO (10-year life cycle) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| EM1 | | | X | | | X | | | X | | | |
| EM2 | | | | | X | | | | | X | | |
| EM3 | | X | | X | | X | | X | | X | | |
| EM4 | | | X | | | X | | | X | | | |
| OM1 | X | X | X | X | X | X | X | X | X | X | | |
| OM2 | | X | | X | | X | | X | | X | | |
| OM3 | | | X | | | X | | | X | | | |
| OM4 | | | | | X | | | | | X | | |
| ALTERNATIVE SCENARIO (12-year life cycle) | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| EM1 | | | X | | | | | X | | | | |
| EM2 | | | | | X | | | | | X | | |
| EM3 | | X | | X | | | X | | X | X | | X |
| EM4 | | | X | | | | | X | | | | |
| OM1 | X | X | X | X | X | | X | X | X | X | X | X |
| OM2 | | X | | X | | | X | | X | | X | |
| OM3 | | | X | | | | | X | | | X | |
| OM4 | | | | | X | | | | | X | | |

The further step consisted in the application of the LCA method by means of the SimaPro software (and the Eco-Indicator 99 evaluation criteria (Goedkoop and Spriensma, 1999)). In Table 58 values used for the assessment of the end of life phase are shown.

Table 58 – Values used for the environmental impact assessment of the EOL phase.

| **Treatment** | **Weight (kg)** | **Treatment** | **Weight (kg)** |
|---|---|---|---|
| **Engine** | | **Frame** | |
| Incineration: carton | 1,32 | Recycling: Aluminium | 10,2 |
| Incineration: PVC | 0,015 | Recycling: Metal | 6,91 |
| Incineration: PE | 0,33 | Recycling: PE | 1,35 |

| **Treatment** | **Weight (kg)** | **Treatment** | **Weight (kg)** |
|---|---|---|---|
| Incineration: Nylon | 0,02 | Recycling: PVC | 0,3 |
| Recycling: Aluminium | 3,78 | Recycling PP | 0,79 |
| Recycling: Metal | 14,047 | **Blade cutting system** | |
| Recycling: PE | 1,03 | Recycling: Metal | 4,5 |
| Recycling: PVC | 0,47 | Recycling PS | 0,35 |
| Recycling PP | 0,03 | **Other: Incineration nylon** | 2,2 |

The results of the LCA of the LM are expressed in damage points (Pt) (Figure 98). The impact of the BS over its 10-year life cycle is 346 Pt with a yearly average of 34,6 Pt while the AS shows an impact of 360 Pt over its 12-year life cycle, and a yearly average 30 Pt.

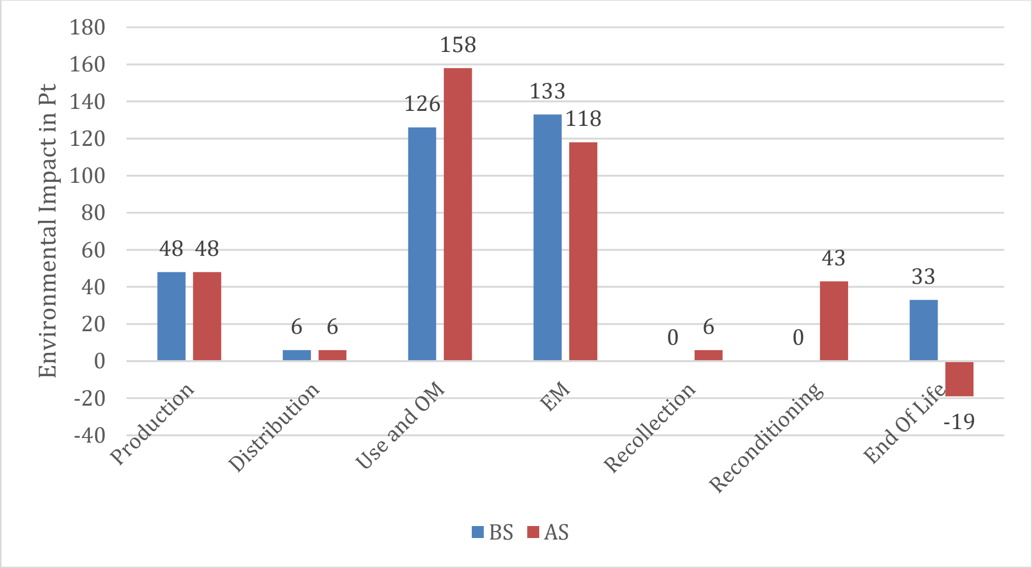


Figure 98 – Comparison of the results of the LCA of the LM (BS and AS).

Then, a simulation was carried out taking into account a 15-year period, during which the number of equipment put on the market is constantly 50 per year, and where each LM runs for 500 hours (the estimated usage of a LM per customer is of about 10 hours a month, apart from two months in winter when it is not used).

The results of the simulation (Table 59) show that the AS leads to a lower environmental impact (168,801 Pt) than the BS (188,614 Pt) due to the recollection and reconditioning scheme and the correct maintenance activities performed by the manufacturer’s technicians.

Based on this, the PSS functional concept (the AS) was proposed to the company for further development.

Table 59 – Results of the simulation (values are expressed in damage points (Pt)).

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BASE SCENARIO (BS) | | | | | | | | | | | | | | | | |
| Production and Distribution | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 |
| Use and OM | | 400 | 1.700 | 1.800 | 2.300 | 3.050 | 4.100 | 6.300 | 5.000 | 5.900 | 6.300 | 6.300 | 6.300 | 6.300 | 6.300 | 6.300 |
| Extraordinary Maintenance | | | 300 | 2.150 | 2.450 | 2.450 | 4.500 | 4.500 | 4.800 | 6.350 | 6.650 | 6.650 | 6.650 | 6.650 | 6.650 | 6.650 |
| Recollection | | | | | | | | | | | | | | | | |
| Reconditioning | | | | | | | | | | | | | | | | |
| End of life | | | | | | | | | | | 1.600 | 1.600 | 1.600 | 1.600 | 1.600 | 1.600 |
| Yearly Impact | 2.704 | 3.104 | 4.704 | 6.654 | 7.454 | 8.204 | 11.304 | 13.504 | 12.504 | 14.954 | 17.254 | 17.254 | 17.254 | 17.254 | 17.254 | 17.254 |
| Cumulative Impact | 2.704 | 5.808 | 10.512 | 17.166 | 24.620 | 32.824 | 44.128 | 57.632 | 70.136 | 85.090 | 102.344 | 119.598 | 136.852 | 154.106 | 171.360 | 188.614 |
| ALTERNATIVE SCENARIO (AS) | | | | | | | | | | | | | | | | |
| Production and Distribution | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 2.704 | 541 | 541 | 541 | 541 | 541 | 541 | 541 | 541 | 541 | 541 |
| Use and OM | | 400 | 900 | 1.800 | 2.300 | 3.250 | 3.250 | 3.750 | 4.650 | 5.150 | 6.100 | 7.500 | 7.900 | 7.900 | 7.900 | 7.900 |
| Extraordinary Maintenance | | | 300 | 2.150 | 2.450 | 2.650 | 2.650 | 2.950 | 4.800 | 5.100 | 5.600 | 5.600 | 5.900 | 5.900 | 5.900 | 5.900 |
| Recollection | | | | | | | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| Reconditioning | | | | | | | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 | 1.947 |
| End of life | | | | | | | | | | | | | -950 | -950 | -950 | -950 |
| Yearly Impact | 2.704 | 3.104 | 3.904 | 6.654 | 7.454 | 8.604 | 8.688 | 9.488 | 12.238 | 13.038 | 14.488 | 15.888 | 15.638 | 15.638 | 15.638 | 15.638 |
| Cumulative Impact | 2.704 | 5.808 | 9.712 | 16.366 | 23.820 | 32.424 | 41.112 | 50.599 | 62.837 | 75.875 | 90.362 | 106.250 | 121.888 | 137.525 | 153.163 | 168.801 |

### 5.4.2 Discussion of results

The results obtained show the positive effects of shifting from product sales to a leasing solution, in other words a UO-PSS. In detail, the product's lifespan is extended from 10 years in the BS to 12 years in the AS. The leasing model (AS) allows the better use of the LM and improved maintenance activities and as well as the recycling of 90% of the LM components. The recycled components reduce the need for new production materials when manufacturing new ones. The improved maintenance and end-of-life activities lead to a 10,5 % environmental impact improvement. The AS also enhances the customer's experience and satisfaction: he is relieved from the maintenance activities as they are performed at the manufacturer's centre ensuring the proper functioning of the LM and a reduced probability of breakdowns. Moreover, based on these initial estimations, the manufacturer's technicians predict that the leasing of LMs would lead to economic benefits due to increased customer satisfaction, and to additional incomes deriving from recycling activities and the use of original spare parts. These results are in line with similar recent studies (i.e. Lindhal et al. 2014; Amaya et al. 2014; Kjaer et al. 2016), and enlighten the importance of the assessment of life-cycle scenarios when developing integrated products.

To summarize, the case study showed an improvement both in terms of environmental performances, and from customer satisfaction point of view.

In line with the research hints provided by Tran and Park (2014), the proposed procedure was developed as a possible solution to augment the ability of manufacturers in implementing a PSS strategy at a practical level.

It also shows how the FEPSS can be used as a step-by-step guideline to identify customer requirements and utilize them to develop a PSS concept through morphological thinking. In fact, it brings out all the benefits that characterize the traditional Morphological Matrix (Ostertag et al. 2012; Payan and Mavris, 2016). Its combination with other methods (e.g. SLCM) can prevent the occurrence of overdesigning, while augmenting the effectiveness of the conceptual design phase.

Moreover, a further implication became prominent concerning the need of applying a functional reasoning approach when developing a PSS. This follows research findings provided, among others by Sakao et al. (2009) Maussang et al. (2009), and Song and Sakao (2016). Differently from these studies, our procedure, based on morphological approach, enables engineers to combine the two "souls" of a PSS, i.e. the product and service characteristics, in a more general and hands-on manner to obtain a comprehensive and unified solution. Nevertheless, beside these positive aspects also some limitations should be underlined.

First, it has to be noted that the product's deterioration and ageing were considered taking into account results of interviews among a limited number of users and experts of the sectors (belonging to both national association of gardening machinery producers and retailers). A quantitative reliability analysis can provide a more objective basis for maintenance operations' planning. At the same time, the production of backup LMs (i.e. an equipment that can replace a malfunctioning one) was not included either, considering that in the worst case repairing activities can be carried out in 24 hours.

Secondly, the economic effects of the solution were not considered in the conceptual design phase. An economic and financial analysis is currently being performed as a further development of the FC by "C" s experts.

## 5.5 Company “D” – A medical imagery equipment distributor

### 5.5.1 The case study

The subsequent case study takes place at medical imagery equipment distributor who is seeking to improve its current business scheme by adopting a modular approach to implementing its services. The main customers and hence users of the devices are public hospitals and centers, by means of public procurement rules (i.e. a regulated market), while 30% of the company’s customers are represented by private clinics. In detail, the company distributes medical imagery equipment used mainly for echography but also for therapy and research purposes.

To better understand the context, interviews with company experts were held in order to define the involved actors and their activities from one hand as well as their requirements on the other. In particular, market surveys gathered by the marketing team concerned the maintenance process as customer data revealed dissatisfaction concerning the actual maintenance service. In addition, since the company operates in a regulated market operated by public bodies, 10 calls for tender in a 24-months period (2015-2016) were selected and analysed to obtain a clearer and more thorough understanding of the customers’ requirements concerning the supply of the equipment and the related services requested. This allowed us to map the processes involved in the PSS supply by means of the Adapted Service Blueprint method (Figure 99).

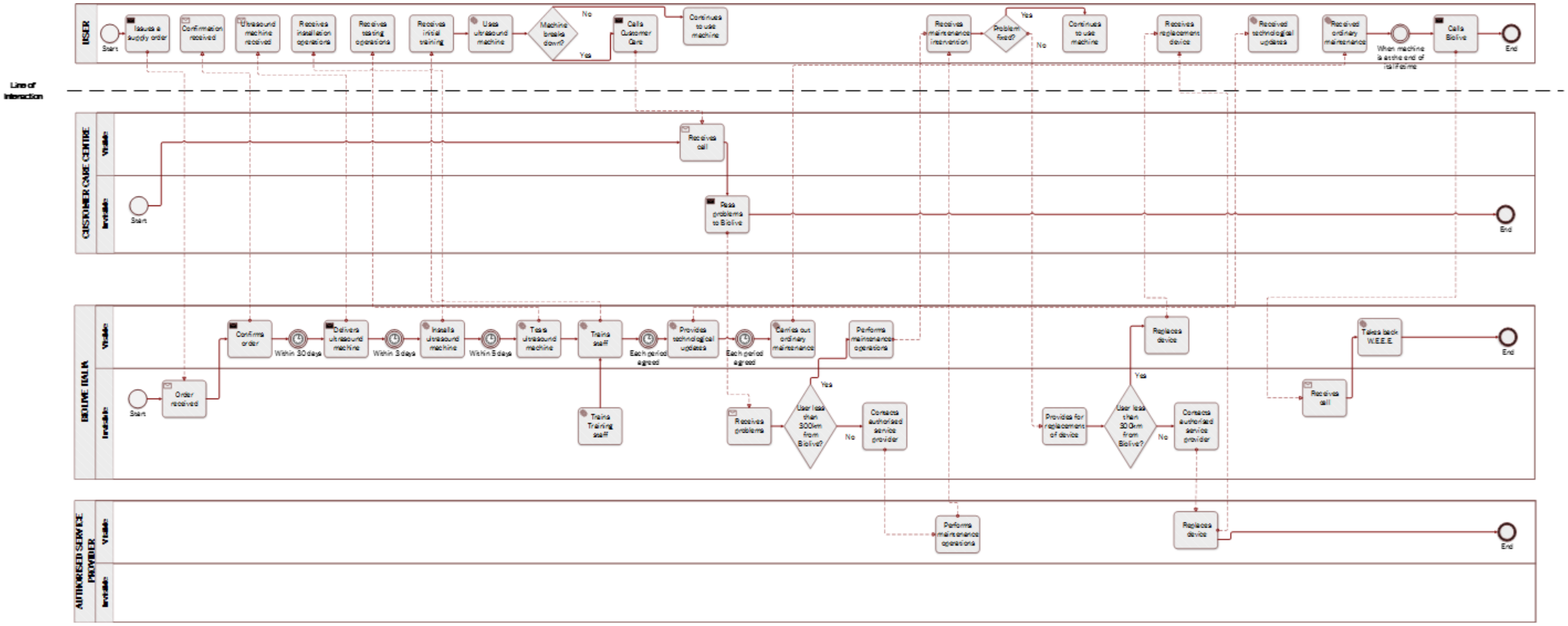


Figure 99 – The Adapted Service Blueprint

**Definition of the PSS Characteristics and Components**

This activity included the analysis of both the tangible (product) and the intangible (service) characteristics required by the calls, as well as the criteria used to assess the offerings. The result of these analyses was the definition of the Customer Requirements (CRs), which were transformed into Receiver State Parameters (RSPs) with the aim of applying the QFD for PSS method (Table 60). Furthermore, 10 selected customers (i.e. medical professionals who operate the equipment on a daily basis) were asked to evaluate the importance of each CR/RSP on a 1-to-5 scale (where 1 designates the lowest level of importance and 5 the highest one) (Likert, 1932).

Table 60 – List of CRs and RSPs

| CUSTOMER REQUIREMENTS | | RECEIVER STATE PARAMETERS | |
|---|---|---|---|
| CR1 | Easy to use | RSP1 | Easiness to use |
| CR2 | Easy to maintain | RSP2 | Availability of the equipment |
| CR3 | Technical capability | RSP3 | Technical performances |
| CR4 | Versatile equipment | RSP4 | Functionality |
| CR5 | Upgradable system | RSP5 | Upgradability |
| CR6 | Safe and reliable functioning conditions | RSP6 | Operability |
| CR7 | Provision of data storage | RSP7 | Data storage availability |
| CR8 | Provision of consumables | RSP8 | Inclusion of consumables |
| CR9 | Provision of technical support | RSP9 | Availability of technical support |
| CR10 | Capability of technical support | RSP10 | Quality of technical support |

Similarly, in collaboration with the company's experts, the Product Characteristics (PChs) and Service Characteristics (SChs) were defined (Table 61). Due to a non-disclosure agreement, here and after some information were simplified to protect the company's confidential and proprietary information and data. Based on this information, the first phase of the QFD for PSS was carried out (Table 62) and the relationships between the RSPs and the PChs and SChs were defined by means of a 1-3-9 scale (where 1 designates a weak relationship, 3 a medium one and 9 a strong one).

Table 61 – List of PChs and SChs.

| PRODUCT CHARACTERISTICS | | SERVICE CHARACTERISTICS | |
|---|---|---|---|
| PCh1 | Quality of product manual | SCh1 | Online support for additional information |
| PCh2 | Ergonomics (user-friendly interface operator-machine) | SCh2 | Online training courses for users |
| PCh3 | Number of setup operations | SCh3 | Time for response |

| | | | |
|---|---|---|---|
| PCh4 | Operational availability (in terms of MTBF (Mean Time Before Failure) and MTTR (Mean Time To Repair)) | SCh4 | Time for recovery |
| PCh5 | Quality of imaging | SCh5 | Time for replacement |
| PCh6 | Fitted internal data storage | SCh6 | Provision of software upgrades in the latest release |
| PCh7 | Efficiency of operations (i.e. central processing unit) | SCh7 | Additional users training in case of available updates |
| PCh8 | Multi-functional devices | SCh8 | Compliance with ordinary maintenance schedule |
| PCh9 | Software modularity | SCh9 | Cloud platform for data storage and transmission |
| | | SCh10 | Provision of sufficient consumables |
| | | SCh11 | Extended customer care service |
| | | SCh12 | Assistance to environmental and safety compliance |
| | | SCh13 | Periodic training of customer care personnel |
| | | SCh14 | Periodic training of maintenance service staff |

Table 62 – QFDforPSS Phase I

| | | **Product Characteristics** | | | | | | | | | **Service Characteristics** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **RSP importance** | PCh 1 | PCh 2 | PCh 3 | PCh 4 | PCh 5 | PCh 6 | PCh 7 | PCh 8 | PCh 9 | SCh 1 | SCh 2 | SCh 3 | SCh 4 | SCh 5 | SCh 6 | SCh 7 | SCh 8 | SCh 9 | SCh 10 | SCh 11 | SCh 12 | SCh 13 | SCh 14 |
| **RSP 1** | 4 | 3 | 3 | 3 | | | 1 | | 1 | 1 | 3 | 3 | | | | 1 | 3 | | 1 | | | 3 | | |
| **RSP 2** | 5 | | | | 9 | | 1 | | | 3 | 1 | 1 | 3 | 3 | 3 | 1 | 3 | 9 | 1 | 3 | | 1 | | 3 |
| **RSP 3** | 4 | | | | | 3 | 3 | 9 | 3 | | | | | | | 3 | | 1 | 3 | | | | | |
| **RSP 4** | 2 | | 3 | 1 | | | | | 9 | 3 | | | | | | | | | 1 | | | | | |
| **RSP 5** | 3 | | | 1 | 3 | | 1 | | | 3 | | | | | | 9 | 3 | | 1 | | | | | |
| **RSP 6** | 4 | | | | 3 | | | | | | 1 | | | | | 1 | | 9 | | 1 | | 3 | | |
| **RSP 7** | 3 | | | | | | 3 | | | | | | | | | | | | 9 | | | | | |
| **RSP 8** | 3 | | | 1 | | | | | 1 | | | | | | | | | | | 9 | | | | |
| **RSP 9** | 5 | | | | | | | | | | 3 | 3 | 9 | | | | 3 | | | | 9 | 9 | | |
| **RSP 10** | 5 | | | | | | | | | | | | 3 | 9 | 9 | | | 3 | | | | | 9 | 9 |
| | **Ch Absolute Impotance** | 12 | 18 | 20 | 66 | 12 | 33 | 36 | 37 | 34 | 36 | 32 | 75 | 60 | 60 | 52 | 51 | 100 | 53 | 46 | 45 | 74 | 45 | 60 |
| | **Ch Relative Importance** | 1% | 2% | 2% | 6% | 1% | 3% | 3% | 4% | 3% | 3% | 3% | 7% | 6% | 6% | 5% | 5% | 9% | 5% | 4% | 4% | 7% | 4% | 6% |

The resulting HoQ was then analysed to identify the PSS components that can suit the obtained characteristics. To do so, in collaboration with the company's experts, the components of the PSS solution (i.e. product and service) were defined (Table 63). Hence, following the same criteria of Phase I, in the second phase of the QFD for PSS the Product Components (PCos) and Service Components (SCos) were assessed and their resulting importance levels are shown in Table 64.

Table 63 – List of the PCos and SCos

| **PRODUCT COMPONENTS** | | **SERVICE COMPONENTS** | |
|---|---|---|---|
| PCo1 | Touch screen monitor | SCo1 | Users periodic training |
| PCo2 | Chariot system with swivel wheels | SCo2 | Decentralized service centres |
| PCo3 | Apple-probe grip: the shape and the grip of the probes should be as comfortable as possible | SCo3 | Maintenance service centers |
| PCo4 | An ergonomic keyboard (i.e. v-shaped) | SCo4 | Supply of a wide range of probes |
| PCo5 | Quick start facilitating safe access and configuration of the system | SCo5 | Wizards to update software |
| PCo6 | Robust transducers | SCo6 | Extra provision of most wearable parts: coupling rubbers, filters, etc. |
| PCo7 | Full HD display | SCo7 | Remote supervision of machine parameters |
| PCo8 | Hard disk with large storage space | SCo8 | Database of patient analysis |
| PCo9 | Efficient CPU | SCo9 | Calendar time of ultrasound gel delivery |
| PCo10 | Number of probes connectable simultaneously to the system | SCo10 | Extended customer care |
| PCo11 | Customizable pre-sets | SCo11 | Environmental and safety compliance assessment |
| PCo12 | Spare battery: in case of blackouts, in order not to lose data | SCo12 | Periodically trained customer care team |
| | | SCo13 | Periodically trained maintenance technicians |
| | | SCo14 | Periodically trained third party technicians |
| | | SCo15 | Qualified training instructors |

Table 64 - QFDforPSS Phase II

| | | | | Product Components | | | | | | | | | | | | Service Components | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ch importance | Ch Relative Importance | PCo 1 | PCo 2 | PCo 3 | PCo 4 | PCo 5 | PCo 6 | PCo 7 | PCo 8 | PCo 9 | PCo 10 | PCo 11 | PCo 12 | SCo 1 | SCo 2 | SCo 3 | SCo 4 | SCo 5 | SCo 6 | SCo 7 | SCo 8 | SCo 9 | SCo 10 | SCo 11 | SCo 12 | SCo 13 | SCo 14 | SCo 15 |
| Product Characteristics | PCh 1 | 12 | 1% | 3 | | | | | | | | | | | | 9 | | | | 1 | | | | | | | 3 | | | |
| | PCh 2 | 18 | 2% | 3 | 3 | 9 | 9 | 3 | | | | | | | | | | | | | | | | | | | | | | |
| | PCh 3 | 20 | 2% | 1 | | | | 9 | | 1 | | | | 3 | | | | | | | | | | | | | | | | |
| | PCh 4 | 66 | 6% | | | | | | | | | | 3 | | 3 | 9 | 3 | 3 | 3 | | 3 | 3 | | 3 | | | 1 | 9 | 9 | 3 |
| | PCh 5 | 12 | 1% | | | | | | 9 | 9 | | 1 | | | | | | | | | | | | | | | | | | |
| | PCh 6 | 33 | 3% | | | | | | | | 9 | | | | | | | | | | | | 3 | | | | | | | |
| | PCh 7 | 36 | 3% | 1 | | | | 1 | | | | 9 | 1 | 1 | | | | | | 1 | 1 | 1 | | | | | | | | |
| | PCh 8 | 37 | 4% | | | | | | 1 | | | | 9 | | | | | | 9 | | | | | | | | | | | |
| | PCh 9 | 34 | 3% | | | | | | 1 | | | | 1 | | | | | | | 9 | | | | | | | | | | |
| Service Characteristics | SCh 1 | 36 | 3% | | | | | | | | | | | | | 1 | | | | | | | | | | | 9 | | | |
| | SCh 2 | 32 | 3% | | | | | | | | | | | | | 9 | | | | | | | | | | | | | | |
| | SCh 3 | 75 | 7% | | | | | | | | 1 | | | | | | 9 | 9 | | | | | | 3 | 3 | | 1 | 3 | 3 | |
| | SCh 4 | 60 | 6% | | | | | | | | | | | | | | | | | | | | | | | | | 9 | 9 | 3 |
| | SCh 5 | 60 | 6% | | | | | | | | | | | | | | 9 | 3 | | | | | | | | | | 1 | 1 | |
| | SCh 6 | 52 | 5% | | | | | | | | | | | | | 3 | | | | 9 | | | | | | | | | | |
| | SCh 7 | 51 | 5% | | | | | | | | | | | | | 1 | | | | 3 | | | | | | | | | | |
| | SCh 8 | 100 | 9% | | | | | | | | | | | | 3 | | 3 | 1 | | | | | | 3 | | | | 1 | 1 | 1 |
| | SCh 9 | 53 | 5% | | | | | | | | 3 | | | | | | | | | | | 9 | 9 | | | | | | | |
| | SCh 10 | 46 | 4% | | | | | | 1 | | | | | | 1 | | | | 9 | | 9 | | | 9 | | | | | | |
| | SCh 11 | 45 | 4% | | | | | | | | | | | | | 1 | | | | | | | | 1 | 9 | | 3 | | | |
| | SCh 12 | 74 | 7% | | | | | | | | | | | | | | | | | | | | | | | 9 | | | | |
| | SCh 13 | 45 | 4% | | | | | | | | | | | | | | | | | | | | | | 1 | | 9 | | | 3 |
| | SCh 14 | 60 | 6% | | | | | | | | | | | | | | | | | | | | | | | | | 9 | 9 | 3 |
| | | Co Absolute Importance | | 146 | 54 | 162 | 162 | 270 | 225 | 128 | 531 | 336 | 601 | 96 | 544 | 1278 | 1713 | 1153 | 945 | 975 | 648 | 711 | 576 | 1182 | 675 | 666 | 1041 | 2059 | 2059 | 793 |
| | | Co Relative Importance | | 1% | 0% | 1% | 1% | 1% | 1% | 1% | 3% | 2% | 3% | 0% | 3% | 6% | 9% | 6% | 5% | 5% | 3% | 4% | 3% | 6% | 3% | 3% | 5% | 10% | 10% | 4% |

### Definition of the PSS modules

The PSS characteristics defined to answer the RSPs, determine the Functional Requirements (FRs) that the solution seeks to fulfill. FRs in an AD context are characterized by independency which facilitates the design process while aiming towards a minimized number of iterations while optimizing the robustness and performance of the solution (Ashtiany and Alipour, 2016). Hence, the further step consisted in the definition of the PSS Modules to properly address engineers in the PSS implementation. With this goal in mind, the AD method was applied in collaboration with the company's experts. Based on the information collected and obtained by means of the QFD for PSS, the FRs, Design Parameters (DPs), and Process Variables (PVs) were defined (Table 65).

Table 65 - Functional Requirements, Design Parameters and Process Variables to be used in the Axiomatic Design method

| FUNCTIONAL REQUIREMENTS (FRs) | | DESIGN PARAMETERS (DPs) | | PROCESS VARIABLES (PVs) | |
|---|---|---|---|---|---|
| FR1 | Plan users training | DP1 | Course planning for users | PV1 | Capability of course planning for users |
| FR2 | Guarantee full territorial coverage of the service centres | DP2 | Distribution of the service centres | PV2 | Optimal service centres distance |
| FR3 | Provide an appropriate number of maintenance service technicians | DP3 | Recruitment of a proper number of maintenance service technicians | PV3 | Capability of selecting a proper number of maintenance service technicians |
| FR4 | Supply a wide range of probes | DP4 | Management of probes functionality | PV4 | Compatibility of probes |
| FR5 | Ensure wizards for upgrading software | DP5 | Development of wizards for upgrading software | PV5 | Usability of wizards for upgrading software |
| FR6 | Provide extra wearable parts | DP6 | Delivery of wearable parts | PV6 | Frequency of wearable parts deliveries |
| FR7 | Allow remote control of machine parameters | DP7 | Real-time machine status control | PV7 | Real-time malfunction warnings |
| FR8 | Allow the use of a patient analysis database | DP8 | Cloud service database | PV8 | Scalability of cloud database |
| FR9 | Schedule ultrasound gel delivery | DP9 | Supply network of ultrasound gel deliveries | PV9 | Optimal ultrasound gel delivery path |
| FR10 | Set operational time of customer care | DP10 | Rotation of customer care staff | PV10 | Optimal working time of customer care |
| FR11 | Guarantee a self-assessment service of environmental and safety compliance | DP11 | Self-assessment check list for environmental and safety compliance | PV11 | Completeness of collected information in the self-assessment service |
| FR12 | Plan customer care training | DP12 | Course planning for customer care | PV12 | Capability of course planning for customer care |
| FR13 | Plan maintenance technicians training | DP13 | Course planning for maintenance technician | PV13 | Capability of course planning for maintenance technicians |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| FR14 | Plan third party technicians training | DP14 | Course planning for third party technicians | PV14 | Capability of course planning for third party technicians |
| FR15 | Ensure qualification of training instructors | DP15 | Evaluation of training instructors | PV15 | Accuracy of evaluation of training instructors |

It has to be noted that in doing so, we only considered as input the SCos because of two main reasons:

- they resulted in being more relevant than the PCos;
- the company can operate modifications on services more easily than on physical components.

Hence, following the approach proposed by Kimita et. al. (2010), the FRs represent the functions related to the RSPs; the DPs represent the service activities; and the PVs are the attributes of entities. The final goal of the application consists in the definition of the design matrix [C], which can be obtained as a product of the matrix [A] per the matrix [B], consisting of the following:

$$[A] = \{FRs\} / \{DPs\} \text{ and } [B] = \{DPs\} / \{PVs\} \qquad (8)$$

where {FRs}, {DPs}, and {PVs} are vectors representing functions, service activities, and attributes respectively.

To achieve a higher level of detail and hence a more feasible design, the above FRs, DPs, and PVs were further decomposed as summarized in Table 66, while the final design matrix that describes the relationships between the functions {FRs} and the attributes {PVs} is represented in Table 67.

Table 66 - Elementary decomposition of the FRs, DPs and PVs.

| FUNCTIONAL REQUIREMENTS | | DESIGN PARAMETERS | | PROCESS VARIABLES | |
|---|---|---|---|---|---|
| FR1 | Plan users training | DP1 | Course planning for users | PV1 | Capability of course planning for users |
| FR1.1 | Schedule resources for users training | DP1.1 | Resource allocation for users’ courses | PV1.1 | Resource efficiency for users’ courses |
| FR2 | Guarantee full territorial coverage of the service centers | DP2 | Distribution of the service centres | PV2 | Optimal service centres distance |
| FR2.1 | Ensure the right number of decentralized service centers | DP2.1 | Allocation of service centres | PV2.1 | Effectiveness of service centres allocation |
| FR2.2 | Ensure the right location of decentralized service centers | DP2.2 | Placement of service centres | PV2.2 | Effectiveness of service centres placement |
| FR3 | Provide an appropriate number of maintenance service technicians | DP3 | Recruitment of a proper number of maintenance service technicians | PV3 | Capability of selecting a proper number of maintenance service technicians |
| FR3.1 | Organize scheduling of maintenance service technicians | DP3.1 | Management of the selected number of maintenance service technicians | PV3.1 | Effectiveness of the selected number of maintenance service technicians |
| FR4 | Supply a wide range of probes | DP4 | Management of probes functionality | PV4 | Compatibility of probes |
| FR4.1 | Supply a range of probes for each type of analysis | DP4.1 | Management of probes for each type of analysis | PV4.1 | Compatibility of probes for each type of analysis |
| FR4.2 | Supply a range of probes for each type of patient | DP4.2 | Management of probes for each type of patient | PV4.2 | Compatibility of probes for each type of patient |
| FR5 | Ensure wizards for upgrading software | DP5 | Development of wizards for upgrading software | PV5 | Usability of wizards for upgrading software |
| FR5.1 | Ensure personnel to develop wizards | DP5.1 | Development interface of wizards | PV5.1 | User-friendliness of wizards’ interface |
| FR6 | Provide extra wearable parts | DP6 | Delivery of wearable parts | PV6 | Frequency of wearable parts deliveries |
| FR6.1 | Guarantee availability in stock of extra wearable parts | DP6.1 | Amount of wearable parts to deliver | PV6.1 | Promptness of wearable parts deliveries |
| FR7 | Allow remote control of machine parameters | DP7 | Real-time machine status control | PV7 | Real-time malfunction warnings |
| FR7.1 | Ensure monitoring of machine status | DP7.1 | Machine data transmission | PV7.1 | Instant alarm warnings feature for machine breakdown |
| FR8 | Allow the use of a patient analysis database | DP8 | Cloud service database | PV8 | Scalability of cloud database |
| FR8.1 | Allow to save analysis on cloud database | DP8.1 | Cloud object storage | PV8.1 | Scalability of cloud object storage |
| FR8.2 | Allow to transmit data via cloud service | DP8.2 | Cloud streaming | PV8.2 | Scalability of cloud streaming |
| FR9 | Schedule ultrasound gel delivery | DP9 | Supply network of ultrasound gel deliveries | PV9 | Optimal ultrasound gel delivery path |
| FR9.1 | Ensure a proper number of ultrasound gel delivery personnel | DP9.1 | Management of ultrasound gel delivery process | PV9.1 | Quickness of ultrasound gel delivery |

| | | | | | |
|---|---|---|---|---|---|
| FR10 | Set operational time of customer care | DP10 | Rotation of customer care staff | PV10 | Optimal working time of customer care |
| FR10.1 | Establish man-hours per day of customer care service | DP10.1 | Management of customer care staff work shifts | PV10.1 | Effectiveness of working time of customer care |
| FR11 | Guarantee a self-assessment service of environmental and safety compliance | DP11 | Self-assessment check list for environmental and safety compliance | PV11 | Completeness of collected information in the self-assessment service |
| FR11.1 | Support users to meet environmental and safety standards | DP11.1 | Degree of compliance with the environmental and safety standards | PV11.1 | Accuracy of check list for environmental and safety compliance |
| FR11.2 | Provide information about audits manner | DP11.2 | Specifications of audits | PV11.2 | Accuracy of information about audits manner |
| FR12 | Plan customer care training | DP12 | Course planning for customer care | PV12 | Capability of course planning for customer care |
| FR12.1 | Schedule resources for customer care training | DP12.1 | Resource allocation for customer care courses | PV12.1 | Resource efficiency for customer care courses |
| FR13 | Plan maintenance technicians training | DP13 | Course planning for maintenance technician | PV13 | Capability of course planning for maintenance technicians |
| FR13.1 | Schedule resources for maintenance technicians training | DP13.1 | Resource allocation for maintenance technicians’ courses | PV13.1 | Resource efficiency for maintenance technicians’ courses |
| FR14 | Plan third party technicians training | DP14 | Course planning for third party technicians | PV14 | Capability of course planning for third party technicians |
| FR14.1 | Schedule resources for third party technicians training | DP14.1 | Resource allocation for third party technicians’ courses | PV14.1 | Resource efficiency for third party technicians’ courses |
| FR15 | Ensure qualification of training instructors | DP15 | Evaluation of training instructors | PV15 | Accuracy of evaluation of training instructors |
| FR15.1 | Perform verifications on training instructors | DP15.1 | Ranking list of training instructors | PV15.1 | Correctness of ranking list of training instructors |
| FR15.2 | Monitor conduct of training instructors | DP15.2 | Follow-up of training instructors | PV15.2 | Accuracy of monitoring of training instructors |

Table 67 - The design matrix between elementary {FRs} and {PVs}.

| | PV 1.1 | PV 2.1 | PV 2.2 | PV 3.1 | PV 4.1 | PV 4.2 | PV 5.1 | PV 6.1 | PV 7.1 | PV 8.1 | PV 8.2 | PV 9.1 | PV 10.1 | PV 11.1 | PV 11.2 | PV 12.1 | PV 13.1 | PV 14.1 | PV 15.1 | PV 15.2 | **Components** | **Modules** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FR 1.1 | X | | | | | | | | | | | | | | | | | | | | 1.1 | 1: Unit for users training |
| FR 2.1 | | X | X | | | | | X | | | | X | | | | | | X | | | 2.1 | 2: Unit for service centers management |
| FR 2.2 | | | X | | | | | X | | | | X | | | | | | | | | 2.2 | |
| FR 3.1 | | | | X | | | | | | | | | | | | | X | | | | 3.1 | 3: Unit maintenance operators' management |
| FR 4.1 | | | | | X | | | X | | | | | | | | | | | | | 4.1 | 4: Unit for spare parts management |
| FR 4.2 | | | | | | X | | X | | | | | | | | | | | | | 4.2 | |
| FR 5.1 | | | | | | | X | | | | | | | | | | | | | | 5.1 | 5: Unit for software engineering |
| FR 6.1 | | | | | | | | X | | | | | | | | | | | | | 6.1 | 6: Unit for wearing parts management |
| FR 7.1 | | | | | | | | | X | | X | | | | | | | | | | 7.1 | 7: Unit for Cloud computing provision |
| FR 8.1 | | | | | | | | | | X | X | | | | | | | | | | 8.1 | |
| FR 8.2 | | | | | | | | | | | X | | | | | | | | | | 8.2 | |
| FR 9.1 | | | | | | | | | | | | X | | | | | | | | | 9.1 | 8: Unit for consumables management |
| FR 10.1 | | | | | | | | | | | | | X | | | X | | | | | 10.1 | 9: Unit for customer care management |
| FR 11.1 | | | | | | | | | | | | | | X | X | | | | | | 11.1 | 10: Unit for environmental and safety assistance |
| FR 11.2 | | | | | | | | | | | | | | | X | | | | | | 11.2 | |
| FR 12.1 | | | | | | | | | | | | | | | | X | | | | | 12.1 | 11: Unit for customer care training |
| FR 13.1 | | | | | | | | | | | | | | | | | X | | X | | 13.1 | 12: Unit for maintenance technicians training |
| FR 14.1 | | | | | | | | | | | | | | | | | | X | X | | 14.1 | |
| FR 15.1 | | | | | | | | | | | | | | | | | | | X | X | 15.1 | |
| FR 15.2 | | | | | | | | | | | | | | | | | | | | X | 15.2 | |

The results obtained allowed us to define the PSS Modules, grouped in 12 independent Components (Table 68), where a PSS Component represents "a minimum subset of modules that are independent from the other", as to use the words of Kimita et al. (2010). Accordingly, the map of the processes related with the PSS was modified taking into account all the actors involved (Figure 100): the provider, the receiver, the customer care center, the external maintenance operators (i.e. third parties), and the cloud computing provider for data exchange and storage. Where the last one is a new actor introduced to fulfil the customers' requirements, that is to have the opportunity to remotely control and to check the machinery parameters in the medium-to-long term, and to have more storage space for the diagnosis data, in addition to the fitted hard-disk. For these reasons, a new service has been implemented (PSS Module 7), designing the product-service based on the effective customers' expectations: the cloud service enables remote monitoring of the machine status and allows the remote storage of the patients' data (i.e. cloud). Another relevant modification concerns the implementation of an additional service consisting in providing technical support in managing environmental, and health and safety issues (PSS Module 10), which are quite relevant in hospitals and clinics due to compulsory requirements as well as the frequent need to adopt quality management systems.

It has to be pointed out that this aspect will also help the device provider in complying with the provisions of the new Regulation (EU) 745/2017, when implementing a post-market surveillance system (EU, 2017). Furthermore, to satisfy the customers' needs concerning the upgradability of the software, the development of specific "wizards" is foreseen (PSS Module 5): this makes the software installed on the machine easier to update directly by the customer, i.e. without the need of the technicians' intervention.

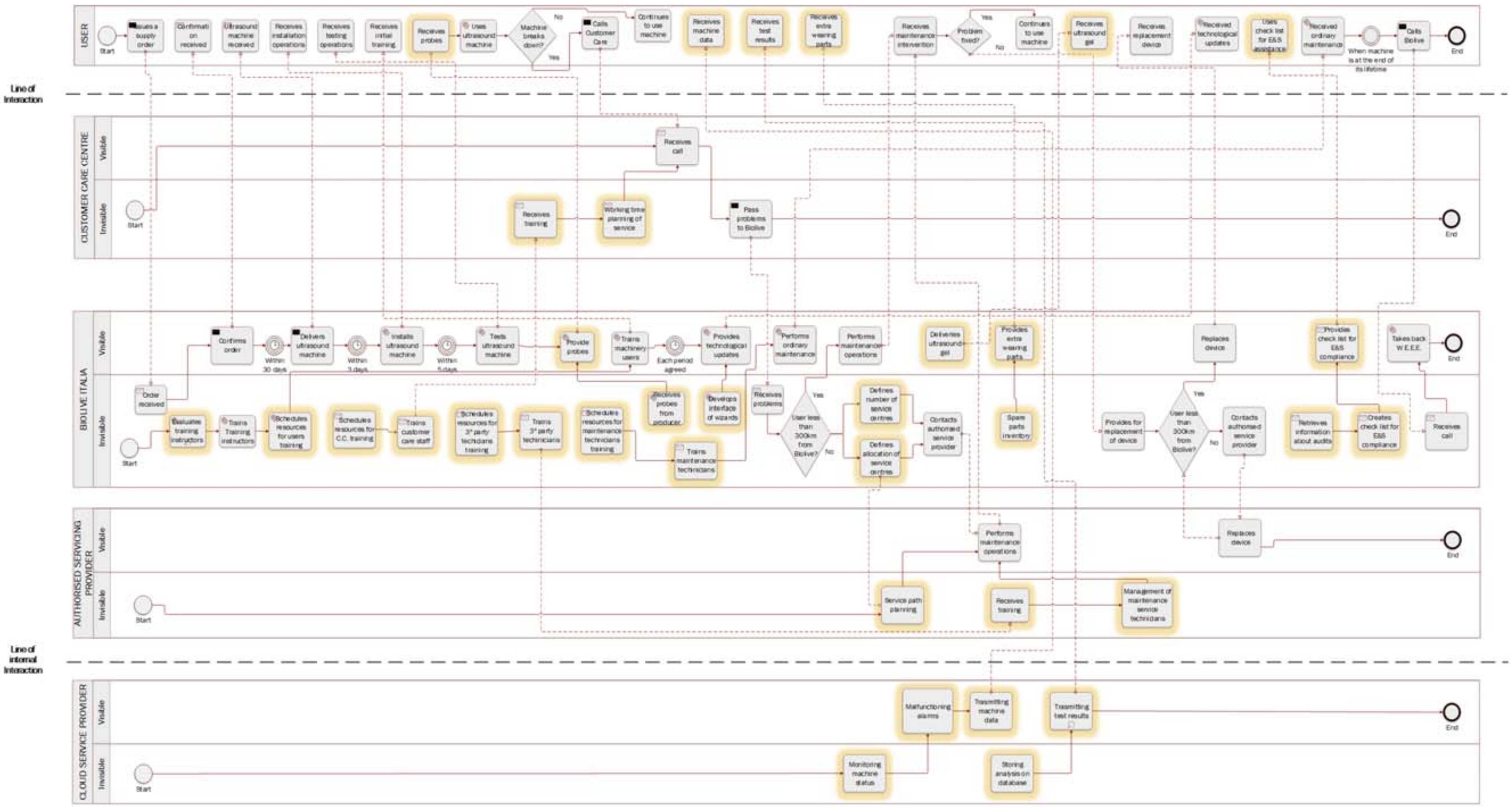


Figure 100 – The new/modified ASB

### 5.5.2 Discussion of results

From a methodical and practical point of views, the results achieved are in line with research findings provided by Pigosso and McAloone (2016), who recognized the importance of close links with customers and stakeholders for value creation by means of a systematic approach, yet underlining the need to augment the attention on the customer support services and customer satisfaction monitoring when developing a PSS, as they play a crucial role in ensuring the business success.

More in detail, the results showed that linking the functional decomposition with the service mapping, engineers can evaluate the influence of the service processes on the customers through the functions directly. This output represents one the major findings of the proposed approach. In fact, the use of the QFD for PSS in combination with the Axiomatic Design and the Service Blueprint methods, augments their effectiveness in focusing on customer value, improving the research roadmap provided by Kimita et al. (2010) by providing a methodology aimed at enabling customization in PSS design. Moreover, the use of QFD for PSS renders a ranking of the PSS characteristics and components, supplying in this way engineers with useful information on customers' priorities. Such an understanding enables a clearer comprehension of the value perception by the customers and hence an improvement of the quality of the offered services (Materla et al. 2017).

At the same time, we have to point out that the proposed approach enables the PSS provider to customize the offerings depending on the type of receiver. For example, based on the results of the present study, the company's experts decided to verify the opportunity to provide a system were the hard disk is replaced by a cloud service for data exchange and storage for private customers (the presence of a physical hard disk of a certain size is a requirement of the call for tenders in the case of public customers, hence it is mandatory). This demonstrates the benefits of the functional decomposition in PSS design, as well as the possibility of achieving more sustainable solutions when applying a PSS approach (Song and Sakao, 2017). Similarly, it demonstrates in practice that a holistic approach can increase the differentiation levels of the offerings depending on customers' needs and without increased costs, in line with the findings of Sundin et al. (2009), who analyzed the role of PSS in Mass Customization. Thus, this study can contribute in reducing the lack in literature of research works aimed at providing a systematic and comprehensive support for a sustainable PSS customization, which has been underlined by Song and Sakao (2017).

As for the benefits from the environmental point of view, the solution of providing specific wizards for assisting the customers was considered a promising output of the study by the company's experts: they have estimated that it can reduce the number of interventions of the service operators by 50% in case of software updates. As demonstrated by several researchers (i.e. Ben-Daya et al. 2000; Jasiulewivs-Kaczmarek and Drozyner, 2013, Haber and Fargnoli, 2017a), in a long-term perspective the reduction of maintenance interventions can be very beneficial for the environment.

Similarly, also the use of a cloud instead of a traditional hard disk can bring benefits from the environmental point of view (e.g. reduction of material used and processed, reduction of maintenance operations and material disposed).

Moreover, thanks to the definition of independent modules, the efforts needed by the provider in making a proposition that augments the fulfilment of customer's needs and wants, ensuring the possible and feasible configuration of services, are reduced in line with research clues by Sakao et al. (2017). In addition to the latter's research, the proposed service modules derive from the RSPs through the PSS characteristics. While the modularization described by Sakao et al. (2017) uses the resources needed for the fulfillment of the services, the proposed approach derives from the customers themselves. Accordingly, the service modules can be seen as customer-driven as opposed to resource-driven.

As far as the case study context is concerned, we have to note that on one hand it is often recognized as one of the sectors where the combination of tangible products and intangible services appears to offer greater possibilities for innovation and value creation due to its peculiarities of (Mont, 2002; Oliva and Kallenberg, 2003). On the other hand, practical case studies in the servitization of the biomedical sector are lacking in the PSS literature (Mittermeyer et al. 2011; Schröter and Lay, 2014). Hence, the present study contributes to analyze the PSS implementation in this specific market, providing a methodology that allows the providers of medical equipment to design services related to the proper functioning of their goods fulfilling customers' needs and expectations.

Thus, based on the above considerations, we believe that the contributions of this study in the PSS design research can be summarized as follows:

- The proposed procedure allows the definition of a business model based on the market demand that succeeded in augmenting the customer satisfaction providing flexible solutions tailored on customers’ needs, while avoiding design conflicts.

- The integrated use of QFDforPSS with Axiomatic Design and Service Blueprint tools contributes in augmenting the knowledge in the PSS design and Mass Customization contexts, thanks to the direct link created between the customers’ needs and the modules of PSS components.
- The results achieved provide additional evidence of the PSS beneficial effects on environmental sustainability, in line with prevalent studies in this field.
- The sector of medical devices is one of the most promising to benefit from the application of the PSS approach and tools to enhance sustainability and customer value.

Beside these positive aspects, we have to underline that the present study also presents some limitations. Firstly, the effectiveness of the proposed approach should be augmented by a financial analysis. Costs were not considered in the case study since the company mainly operates in a regulated market (public procurement mechanism by means of calls for tender). Nevertheless, to extend the validity of the proposed research approach a cost-benefit analysis is needed. Furthermore, the modularization approach proposed, does not consider the company resources assuming the modules to be feasible. Thus, in addition to a cost-benefit analysis, a comprehensive feasibility study (i.e. technical, economic, financial, location, manpower analysis) is valuable to validate or modify the proposed service modules in a manner that is beneficial for the manufacturer as well (Alix et al. 2009).

Finally, the flexibility of the proposed procedure needs to be verified by means of its application in different contexts to further validate the results achieved.

# 6. Conclusive remarks

## 6.1 General Remarks

The dissertation analysed the prevailing PSS design and development models, to bring to light main activities and design tools for a successful implementation of a PSS. Then, by comparing these models to the Design Science approach a comprehensive design framework was outlined as an answer for RQ1: the FEPSS model. Compared to the frameworks present in the literature and exposed in Section 3.1, the FEPSS is proposed as a comprehensive framework and hence solution for manufacturers seeking to implement a PSS. In line with the research hints provided by Tran and Park (2014), the proposed procedure was developed as a possible solution to augment the ability of manufacturers in implementing a PSS strategy at a practical level. Differently from other similar studies, the FEPSS consists in a more detailed step-by-step guideline for PSS developers, that covers all main stages of the design process. The case studies carried out in section 5 show interesting and optimistic results concerning the FEPSS model. First, the use of quantitative and qualitative tools illustrates the flexibility of the FEPSS in a practical context. In other words, depending on the type and quantity of information and data provided on one hand, as well as the type of provider on the other. In fact, cases “A” and “B” utilize the fuzzy logic, AHP, QFD and questionnaires to effectively take into account the customers’ needs and expectations (RQ2), whereas case “C” adopts a functional decomposition, a CTQ tree, SLCM and a SWOT analysis, and case “D” uses QFD, PSS mapping and the axiomatic design.

Hence, in light of this depicted versatility, the FEPSS model can be adapted to suit its intended use allowing a comprehensive and coordinated design process. Table 68 summarizes the activities and tools used in each case study, while illustrating flexibility of the FEPSS model.

Table 68 – Use of the FEPSS model in each case study.

|  | Case Study | A | B | C | D |
|---|---|---|---|---|---|
| Phase | Main Activities | Tools |  |  |  |
| 1. Ideation and Task Analysis | 1.1 Customer characteristics definition | Market Surveys, Questionnaires, FAHP QFD | Questionnaires, Kano model, RSPs, FAHP QFDforPSS | Semi-structured interviews, CTQ | Market Surveys, Interviews, QFDforPSS, PSS mapping |
|  | 1.2 Manufacturer characteristics definition | FAHP QFD | QFDforPSS | SWOT | QFDforPSS |
| 2. Conceptual Design | 2.1 Concept development | N/A | QFDforPSS | PSS concept matrix | QFDforPSS, Axiomatic Design, PSS mapping |
|  | 2.2 Concept acceptance |  | Qualitative assessment | SLCM | Qualitative assessment |

Secondly, cases A (section 5.2) and B (section 5.3) underlined the improvements that the adoption of pairwise comparisons (AHP) and fuzzy logic bring to the prioritization of customer requirements in an intangible and qualitative context such as PSSs.

In a competitive market, the definition of value-adding requirements (i.e. RSPs) that have a potential in increasing the value of a PSS is vital to the manufacturer's profitability. The study shown in section 5.3 showed how the Kano model can help assess and distinguish between potential value-increasing requirements (i.e. attractive requirements) and expected requirements (i.e. one-dimensional requirements). The studies carried out in 5.2 and 5.3 highlight the effectiveness of the FAHP augmented QFD in prioritizing RSPs and customer requirements in general when subjectivities and uncertainties are involved. They portray how the adoption of the fuzzy logic and AHP can eliminate possible "ties" between requirements and hence obtain a clearer and better definition of the characteristics that a PSS should possess to satisfy them (RQ2). Then in section 5.5, the application showed how the better definition of this characteristics can be deployed into PSS components and hence obtain a better design of the solution in a modularization scope through the use of QFD and the axiomatic design.

Thirdly, the case studies underline the benefits of adopting a PSS approach instead of a product-based approach. A PSS can be considered as more comprehensive when capturing the voice of the customer and hence delivering a more customized solution than a conventional product. Therefore, customer value is increased and customer satisfaction as well. Moreover, a PSS can lead to a better environmental performance if implemented effectively as shown in section 5.4 (RQ3).

Despite the positive outcomes of these cases, some limitations should be noted. First, the need for a holistic feasibility study is essential to weigh the PSS idea and concept against the manufacturer's resources. A PSS should bear benefits to both the provider and the receiver (Andrew and Lyford, 2000). Accordingly, to negate negative outcomes and unwanted rebound effects on an environmental nor financial scale, a holistic feasibility study is required (Tukker and Tischner, 2006).

In addition, the results are obtained from four case studies and hence lack external validity (as per Le Dain et al. 2013). Thus, despite the implementation of the FEPSS in two different industries and the positive outcomes achieved, caution is needed in generalizing the findings. Moreover, the use of the ANP can be beneficial as it captures a higher level of interactions and dependencies that the AHP cannot (Gorener, 2012). Other tools can be used as well to further test the applicability of the FEPSS model and aid in its refinement (i.e. SADT blocs, RACI diagram, value mapping etc.)

## 6.2 Conclusions

Despite the recent development and increasing popularity of PSSs, their extension has been hindered by the absence of a unified approach that enables engineers and manufacturers to effectively design an integrated product-service offering. To do so, the presented research addressed the most prevalent PSS design approaches and processes (Sections 2, 3), to propose a framework that serves as a guide for the implementation of PSSs on a bigger scale: the FEPSS model. Built on a design science approach, the FEPSS presents four stages: ideation and task analysis, conceptual design, embodiment design, and validation and release. The activities to be carried out in each stage, as well as the tools to fulfil them are depicted as well (Section 4.5). The FEPSS was employed in 4 case studies (Section 5) each making use of different activities and tools and addressing different stages of the FEPSS model. The results underlined the effectiveness of the FEPSS in handling quantitative and qualitative information as a foundation of the PSS design process. More in detail, the case studies are in two different sectors: the agricultural one and the biomedical field and utilized questionnaires, fuzzy logic, the analytic hierarchy process, quality function deployment, morphological thinking, screening life cycle modelling and axiomatic design to develop PSS ideas and concepts.

It has to be pointed out that results achieved can augment the scientific knowledge on PSS implementation in both the agriculture and biomedical sectors, given the lack of studies concerning the PSS approach which emerged from the literature analysis. In particular, when considering the biomedical sector, it should be stressed that on one hand it is often recognized as one of the sectors where the combination of tangible products and intangible services appears to offer greater possibilities for innovation and value creation due to its peculiarities of (Mont, 2002; Oliva and Kallenberg, 2003). On the other hand, practical case studies in the servitization of the biomedical sector are lacking in the PSS literature (Mittermeyer et al., 2011; Schröter and Lay, 2014). Hence, the present research work can contribute to analyse the PSS implementation in this specific market, providing a methodology that allows the providers of medical equipment to design services related to the proper functioning of their goods fulfilling customers' needs and expectations.

## 6.3 Limitations and Future work

While the achieved results are promising, further work is required to further validate and refine the FEPSS model. In particular, applications in different fields would be beneficial in checking its versatility and applicability to different sectors as well as to different types of PSSs such as product-oriented and result-oriented solutions. In addition, a higher amount of customer participation would be beneficial in obtaining more precise customer requirements. The use of the Analytic Network Process (ANP) would help achieve a better prioritization of the customer requirements, RSPs and PSS characteristics through a more comprehensive approach than the Analytic Hierarchy Process (AHP).

Furthermore, the research was limited to the first two stages of the FEPSS model, a more thorough verification of the model would consist in case studies addressing the third and fourth stages hence allowing a holistic application. Although, the environmental aspects of a PSS solution have been exposed quantitatively (i.e. Case C), addressing the financial and economic matters of a PSS in a quantitative manner would also be beneficial as they would allow a more comprehensive evaluation of the solution prior to its launch on the market.

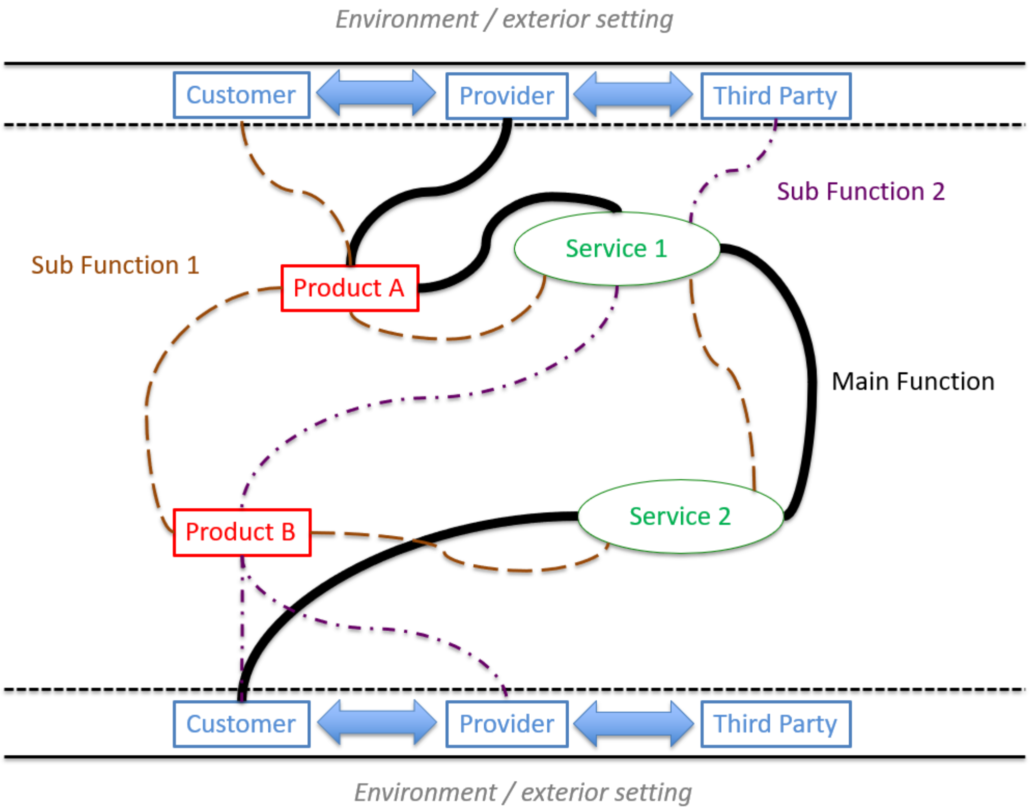


Figure 101 – Graphical abstract of the thesis

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# 8. Appendices

## 8.1 Appendix A: Medical imaging equipment

**Part ONE:** please indicate the level of importance you assign to each category (from a product's point of view).

| REQUISITE | VERY IMPORTANT | IMPORTANT | MODERATE | LOW | VERY LOW |
|---|---|---|---|---|---|
| Size and Dimensions | | | | | |
| Compact size | ☐ | ☐ | ☐ | ☐ | ☐ |
| Easily movable | ☐ | ☐ | ☐ | ☐ | ☐ |
| Reasonable weight | ☐ | ☐ | ☐ | ☐ | ☐ |
| Chariot system for transport | ☐ | ☐ | ☐ | ☐ | ☐ |
| Image Quality and Versatility | | | | | |
| High image quality, even in obese people | ☐ | ☐ | ☐ | ☐ | ☐ |
| Broadband | ☐ | ☐ | ☐ | ☐ | ☐ |
| High frequency linear transducers | ☐ | ☐ | ☐ | ☐ | ☐ |
| Easy transducer switching on the same client | ☐ | ☐ | ☐ | ☐ | ☐ |
| Bright display viewable from different angles | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ease of Use | | | | | |
| Fast boot-up | ☐ | ☐ | ☐ | ☐ | ☐ |
| Clear display | ☐ | ☐ | ☐ | ☐ | ☐ |
| Distinct important buttons | ☐ | ☐ | ☐ | ☐ | ☐ |
| Image saving in different formats | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printing | ☐ | ☐ | ☐ | ☐ | ☐ |
| Use in video mode | ☐ | ☐ | ☐ | ☐ | ☐ |
| Saving on external devices (USB, CD etc.) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Communication with other medical equipment (LAN, WIFI etc.) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Durability | | | | | |
| Long-lasting and durable transducers and probes | ☐ | ☐ | ☐ | ☐ | ☐ |
| Strong and stable support | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | |
|---|---|---|---|---|---|
| Easy replacement of damaged parts | ☐ | ☐ | ☐ | ☐ | ☐ |

**Part TWO**: please indicate the level of importance you assign to each category (from a service's point of view).

| REQUIREMENT | VERY IMPORTANT | IMPORTANT | MODERATE | LOW | VERY LOW |
|---|---|---|---|---|---|
| Initial training of the staff | ☐ | ☐ | ☐ | ☐ | ☐ |
| Periodic update courses | ☐ | ☐ | ☐ | ☐ | ☐ |
| Software updates | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ordinary maintenance | ☐ | ☐ | ☐ | ☐ | ☐ |
| Full Risk assistance (electrical safety checks, breakdown maintenance, unlimited repairs etc.) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Customer care | ☐ | ☐ | ☐ | ☐ | ☐ |
| Intervention within 24h from call request | ☐ | ☐ | ☐ | ☐ | ☐ |
| Intervention time shorter than 48/72 hours | ☐ | ☐ | ☐ | ☐ | ☐ |
| Temporary replacement of machines that require more than 72 hours of repairs | ☐ | ☐ | ☐ | ☐ | ☐ |
| Definitive replacement of repeatedly damageable machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| Substitution of non-repairable machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| Punctual delivery of indicated machines and parts | ☐ | ☐ | ☐ | ☐ | ☐ |
| Delivery time within 1/3 of maximum scheduled delivery time. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manufacturer responsibility for any damages caused to the staff or to the rooms and machinery of the medical center. | ☐ | ☐ | ☐ | ☐ | ☐ |

**Part THREE**: Please answer according to the service contract of your current supplier.
N.B: If no information is available, please leave a blank answer. If additional information is required, please provide a description.

Training of the Medical Staff

1) Are there training sessions for the staff, before the latter uses the equipment?

☐ YES ☐ NO

If yes, how many hours of training are held?

☐ AROUND 4 HOURS
☐ AROUND 8 HOURS
☐ AROUND 12 HOURS
☐ AROUND 16 HOURS
☐ AROUND 20 HOURS
☐ AROUND 24 HOURS
☐ MORE THAN 24 HOURS

Does the training include ordinary maintenance of the product, other than the regular use of the product? (if so, indicate)

2) During the delivery time, are there update/refresher courses in case a new staff is hired and/or the machine is upgraded (software-hardware)?

☐ YES ☐ NO

If yes, how many hours do these update/refresher courses comprise of?

☐ AROUND 4 HOURS
☐ AROUND 8 HOURS
☐ AROUND 12 HOURS
☐ AROUND 16 HOURS
☐ AROUND 20 HOURS
☐ AROUND 24 HOURS
☐ MORE THAN 24 HOURS

3) In the medical center, what is the percentage of the staff that is trained?

☐ NONE
☐ AROUND 25%
☐ AROUND 50%
☐ AROUND 75%
☐ AROUND 100%

4) If beneficial, please state any other information regarding the training of the medical staff and indicate how the overall training may be improved.

CUSTOMER CARE

1) Does the contracting company have a customer care service put in place?

☐ YES ☐ NO

If yes, for how many hours a day is it active?

- ☐ LESS THAN 8 HOURS A DAY
- ☐ 8 HOURS A DAY
- ☐ 12 HOURS A DAY
- ☐ BETWEEN 12 AND 24 HOURS A DAY
- ☐ 24 HOURS A DAY

2) The service consists of

☐ PHONE CALL SUPPORT FROM THE CONTRACTING COMPANY'S MAIN OFFICE.

☐ DIRECT CONTACT WITH TECHNICIANS IN THE CORRESPONDING AREA, PHONE CALL SUPPORT AND DAMAGE REPAIRS (TO REDUCE DOWNTIME OF THE MACHINE AND AVOID UNNECESSARY INTERVENTIONS)

3) If beneficial, please state any other information regarding the customer care service and indicate how it may be improved.

USE OF THE PRODUCT

1) For how many hours, on average, is the product used on a daily basis?

2) How many days per month, is the product used?

MAINTENANCE (ORDINARY AND BREAKDOWN)

1) What types of maintenance (ordinary and breakdown) take place?

2) For each intervention type, can you indicate the frequency (days, months)?

3) What is the average duration of a maintenance intervention?

- ☐ LESS THAN 12 HOURS
- ☐ AROUND 12 HOURS
- ☐ AROUND 24 HOURS
- ☐ AROUND 48 HOURS
- ☐ MORE THAN 48 HOURS

4) In 1 year, how many interventions take place on the same product on average?

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ MORE THAN 3 (SPECIFY)

5) Who is the internal personnel involved in the maintenance activities?

6) Who is the external personnel involved in the maintenance activities?

7) In general, over the years and as the machine is more frequently used, is the reliability of the machine compromised and hence more breakdowns take place?

☐ NEVER
☐ AFTER THE 1st YEAR
☐ AFTER THE 2nd YEAR
☐ AFTER THE 3rd YEAR
☐ AFTER THE 4th YEAR

8) On average, within how much time does the maintenance intervention take place?

☐ AROUND 24 HOURS
☐ AROUND 48 HOURS
☐ AROUND 72 HOURS
☐ MORE THAN 72 HOURS

9) In case, additional information regarding ordinary and breakdown maintenance can be noted, please indicate it, as well as how the maintenance activities can be improved.

TEMPORARY AND PERMANENT REPLACEMENT OF THE PRODUCT

1) Is there a temporary replacement of the equipment in case of a breakdown?

☐ NEVER
☐ FOR REPAIR TIMES EXCEEDING 48 HOURS
☐ FOR REPAIR TIMES EXCEEDING 1 WEEK
☐ FOR REPAIRS THAT CANNOT BE MADE IN THE MEDICAL FACILITY
☐ ALWAYS

If yes, how many temporary replacements of the same product take place within 5 years

☐ NONE
☐ AROUND 1
☐ AROUND 2
☐ AROUND 3
☐ AROUND 4
☐ MORE THAN 4 (INDICATE)

2) If a temporary replacement is required, how many spare machines are present in the medical facility (number of replacement machines per functioning machines)?

☐ NONE
☐ AROUND 1 PER 5 MACHINES
☐ AROUND 1 PER 4 MACHINES
☐ AROUND 1 PER 3 MACHINES
☐ MORE THAN 1 PER 3 MACHINES

If the spare (replacement) machines is available in the medical facility, can it be installed by a member of the medical staff (trained)?

☐ YES ☐ NO

3) A definitive replacement of the equipment is foreseen when (more than 1 answer can be available)

☐ THE FAILURE CANNOT BE REPAIRED
☐ THE MACHINE BREAKS DOWN FREQUENTLY
☐ THE MANUFACTURER PRODUCES A NEWER MACHINE WITH THE SAME FUNCTIONS

On average, how many definitive replacements, for the same machine, take place within a span of 5 years?

☐ NONE
☐ LESS THAN 1
☐ AROUND 1
☐ AROUND 2
☐ MORE THAN 2

4) In case, additional information regarding temporary and permanent replacements can be noted, please indicate it, as well as how they can be improved.

5) Who is the internal staff involved in replacing and/or retiring the equipment?

6) Who is the external staff involved in replacing and/or retiring the equipment?

## 8.2 Appendix B: Hemodialysis equipment

### Questionnaire A

Kindly indicate the level of importance for each requirement related to the use of an ***HEMODIALYSIS EQUIPMENT***. Kindly mark the case corresponding to your evaluation with an “X”.

| | | Not important | Little important | Important | Very important | Extremely important |
|---|---|---|---|---|---|---|
| 1. | Intervention within 24 hours (Extraordinary maintenance) | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 2. | Replacement machine for interventions > 48 hours | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 3. | Periodic trainings in case of updates | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 4. | Extended customer care (intensive therapy) | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 5. | Extended customer care (normal use) | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 6. | Ergonomics of the machine | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 7. | Reliability | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |
| 8. | Machine updates | 1 ☐ | 2 ☐ | 3 ☐ | 4 ☐ | 5 ☐ |

# Questionnaire B

*For each of the following situations related to the* ***HEMODIALYSIS EQUIPMENT****, indicate with an X, the case corresponding to your opinion.*

---

1. a. If the intervention takes place within 24 hours, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

b. If the intervention doesn't take place within 24 hours, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

---

2. a. If the equipment is replaced when an intervention requires more than 48 hours, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

b. If the equipment is not replaced when an intervention requires more than 48 hours, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

---

3. a. If there are periodic trainings when there are updates, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

b. If there are no periodic trainings when there are updates, what is your opinion?

☐ I like this ☐ It has to be like this ☐ I am indifferent ☐ I don't want this, but i can accept it ☐ I don't like this

*For each of the following situations related to the* **HEMODIALYSIS EQUIPMENT***, indicate with an X, the case corresponding to your opinion.*

---

4. a. If customer care is extended – intensive therapy, what is your opinion?

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

b. If customer care is not extended (limited) – intensive therapy, what is your opinion?

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

---

5. a. If customer care is extended – normal use, what is your opinion?

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

b. If customer care is not extended – normal use, what is your opinion?

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

---

6. a. If the ergonomics of the equipment are satisfactory, what is your opinion?

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

b. If the ergonomics of the equipment are not satisfactory, what is your opinion?

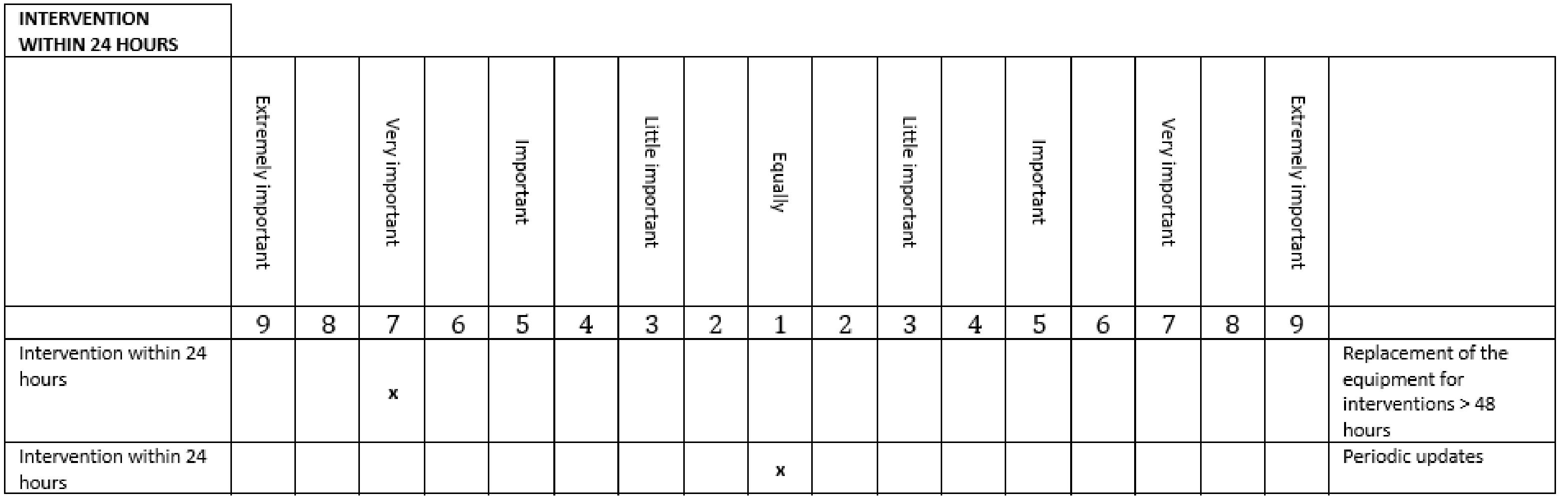
| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| I like this | It has to be like this | I am indifferent | I don't want this, but i can accept it | I don't like this |

*For each of the following situations related to the* ***HEMODIALYSIS EQUIPMENT****, indicate with an X, the case corresponding to your opinion.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7. | a. | If the machine is reliable, what is your opinion? | ☐<br>I like this | ☐<br>It has to be like this | ☐<br>I am indifferent | ☐<br>I don’t want this, but i can accept it | ☐<br>I don’t like this |
| | b. | If the machine is not reliable, what is your opinion? | ☐<br>I like this | ☐<br>It has to be like this | ☐<br>I am indifferent | ☐<br>I don’t want this, but i can accept it | ☐<br>I don’t like this |
| 8. | a. | If the equipment is updated, what is your opinion? | ☐<br>I like this | ☐<br>It has to be like this | ☐<br>I am indifferent | ☐<br>I don’t want this, but i can accept it | ☐<br>I don’t like this |
| | b. | If the equipment is not updated, what is your opinion? | ☐<br>I like this | ☐<br>It has to be like this | ☐<br>I am indifferent | ☐<br>I don’t want this, but i can accept it | ☐<br>I don’t like this |

## Questionnaire C

Confronting the requirements for a ***HEMODIALYSIS EQUIPMENT***, indicate with an **X**, the case corresponding to the importance of a requirement vs. another; as portrayed in the example below.



| **INTERVENTION WITHIN 24 HOURS** | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Intervention within 24 hours | | | x | | | | | | | | | | | | | | | Replacement of the equipment for interventions > 48 hours |
| Intervention within 24 hours | | | | | | | | | x | | | | | | | | | Periodic updates |

Example:

1. Between the intervention within 24 hours and the replacement of the equipment for interventions > 48 hours, which requirement is more important? According to me, the intervention within 24 hours is **more important** than the replacement of the equipment for interventions > 48 hours. How much is it more important? **Very Important (7)**
2. Between the intervention within 24 hours and periodic updates, which requirement is more important? According to me, both requirements are **Equally Important (1)**

| **INTERVENTION WITHIN 24 HOURS** | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Replacement of the equipment for interventions > 48 hours |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Periodic updates |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Extended Customer Care (intensive therapy) |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Extended Customer Care (normal use) |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Ergonomics of the equipment |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Reliability |
| Intervention within 24 hours | | | | | | | | | | | | | | | | | | Equipment Update |

| **REPLACEMENT OF THE EQUIPMENT FOR INTERVENTIONS > 48 HOURS** | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Periodic updates |
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Extended Customer Care (intensive therapy) |
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Extended Customer Care (normal use) |
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Ergonomics of the equipment |
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Reliability |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replacement of the equipment for interventions > 48 hours | | | | | | | | | | | | | | | | | | Equipment Update |
| **PERIODIC UPDATES** | | | | | | | | | | | | | | | | | | |
| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Periodic updates | | | | | | | | | | | | | | | | | | Extended Customer Care (intensive therapy) |
| Periodic updates | | | | | | | | | | | | | | | | | | Extended Customer Care (normal use) |
| Periodic updates | | | | | | | | | | | | | | | | | | Ergonomics of the equipment |
| Periodic updates | | | | | | | | | | | | | | | | | | Reliability |
| Periodic updates | | | | | | | | | | | | | | | | | | Equipment Update |

**EXTENDED CUSTOMER CARE (INTENSIVE THERAPY)**

| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Extended Customer Care (intensive therapy) | | | | | | | | | | | | | | | | | | Extended Customer Care (normal use) |
| Extended Customer Care (intensive therapy) | | | | | | | | | | | | | | | | | | Ergonomics of the equipment |
| Extended Customer Care (intensive therapy) | | | | | | | | | | | | | | | | | | Reliability |
| Extended Customer Care (intensive therapy) | | | | | | | | | | | | | | | | | | Equipment Update |

**EXTENDED CUSTOMER CARE (NORMAL USE)**

| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Extended Customer Care (normal use) | | | | | | | | | | | | | | | | | | Ergonomics of the equipment |
| Extended Customer Care (normal use) | | | | | | | | | | | | | | | | | | Reliability |
| Extended Customer Care (normal use) | | | | | | | | | | | | | | | | | | Equipment Update |

**ERGONOMICS OF THE EQUIPMENT**

| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Ergonomics of the equipment | | | | | | | | | | | | | | | | | | Reliability |
| Ergonomics of the equipment | | | | | | | | | | | | | | | | | | Equipment Update |

**RELIABILITY**

| | Extremely important | | Very important | | Important | | Little important | | Equally | | Little important | | Important | | Very important | | Extremely important | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| Reliability | | | | | | | | | | | | | | | | | | Equipment Update |

## 8.3 Appendix C: Axiomatic Design (AD)

Axiomatic Design (AD) is a design theory that was created and popularized by Suh (1990). It is a general design framework, rather than a design theory (Park, 2007). Design is the interaction between "what we want to achieve" and "how we achieve it." The engineering sequence can be classified into four domains (Figure 102). As shown in Figure 102, the design process consists of three mapping among four domains:

1. The customer domain: is characterized by the Customer Attributes (CAs) that the customer is looking for in a product, process, service, system or materials.
2. The functional domain: in the functional domain, customer needs are specified in terms of Functional Requirements (FRs). FRs are a minimum set of independent requirements that completely characterizes the functional needs and the intended behavior of the product (or software, organizations, systems, etc.) in the functional domain. By definition, the FRs are independent from one another.
3. The physical domain: in order to satisfy the specified FRs, Design Parameters (DPs) are conceived in the physical domain. Design parameters are the key physical (or other equivalent terms in the case of software design, etc.) variables in the physical domain that characterize the design that satisfies the specified FRs.
4. The process domain: finally, a process is characterized by Process Variables (PVs). Process variables are the key variables (or other equivalent term in the case of software design, etc.) that characterize the process that can generate the specified DPs.

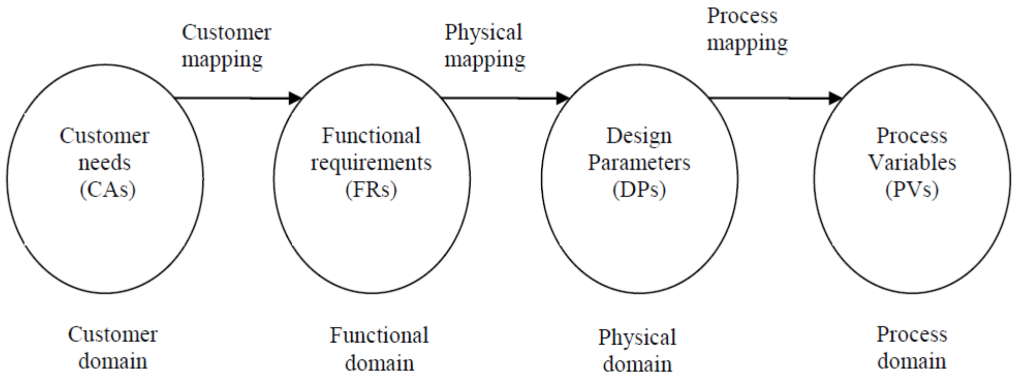


Figure 102 – The AD domains

The aspects for the next domain are determined from the relationship between the two domains. This process is called mapping. A good design process means an efficient mapping process.

According to A), a design needs to satisfy the following two axioms along with several corollaries. One is the Independence Axiom and the other is the Information Axiom. It should be noted that a good design should satisfy the two axioms, while a bad design does not.

### The Independence Axiom

Motivated by the absence of scientific design principles, Suh (1998) proposed the use of axiom as the scientific foundation of design.

The independence axiom states that the independence of FRs must always be maintained. The axiom is formally stated as:

Axiom 1: Maintain the independence of the FRs.

Alternative Statement 1: An optimal design always maintains the independence of the FRs.

Alternative Statement 2: In an acceptable design, DPs and FRs are related in such a way that a specific DP can be adjusted to satisfy its corresponding FR without affecting other functional requirements.

The Independence Axiom indicates that the aspects in the proceeding domain should be independently satisfied by the choices carried out in the next domain. The relationship of FR – DP is defined as independent. When several FRs are defined, each DP should satisfy each corresponding FR. The relationship can be expressed by a design matrix. Using vector notations for FRs and DPs, the relationship is expressed as the following design equation:

$\{FR\}=[A]\{DP\}$ (where matrix A is called a Design Matrix).

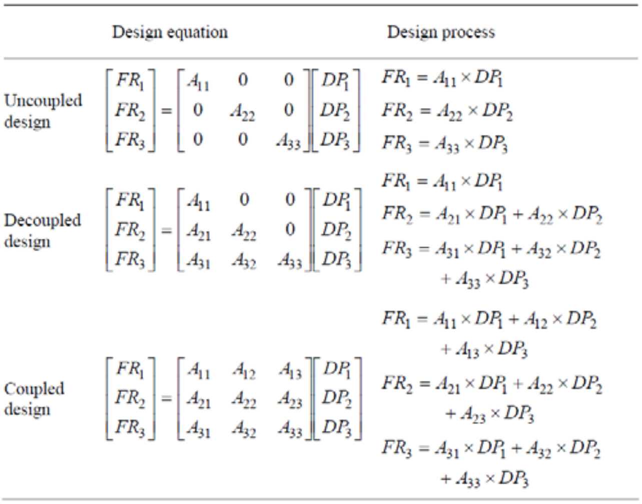
The characteristics of matrix A determine if the independence axiom is satisfied. Supposing we have three FRs and DPs, the FR – DP relationships are exhibited according to matrix A shown in Figure 103.

If the design matrix is a diagonal matrix, it is an uncoupled design. Since each DP can satisfy a corresponding FR, the uncoupled design completely satisfies the independence axiom.

When the design matrix is triangular, as shown in the second case of Figure 103, the design is a decoupled design. A decoupled design satisfies the independence axiom if the design sequence is correct. In the second row of Figure 102, DP1 is first determined for FR1 and fixed. FR2 is satisfied by the choice of DP2 and the fixed DP1. DP3 is determined in the same manner with the fixed DP1 and DP2 (Park, 2007).

When a design matrix is neither diagonal nor triangular, the design is defined as a coupled design. In a coupled design, no sequences of DPs can satisfy the FRs independently. Therefore, an uncoupled or a decoupled design satisfies the independence axiom and a coupled design does not. If a design is coupled, an uncoupled or decoupled design must be found using a new choice of DPs.

It should be pointed out that, with design matrices, multiplication and addition are allowed. However, other manipulations such as coordinate transformation are not allowed.



| | Design equation | Design process |
|---|---|---|
| Uncoupled design | $\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$ | $FR_1 = A_{11} \times DP_1$<br>$FR_2 = A_{22} \times DP_2$<br>$FR_3 = A_{33} \times DP_3$ |
| Decoupled design | $\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$ | $FR_1 = A_{11} \times DP_1$<br>$FR_2 = A_{21} \times DP_1 + A_{22} \times DP_2$<br>$FR_3 = A_{31} \times DP_1 + A_{32} \times DP_2 + A_{33} \times DP_3$ |
| Coupled design | $\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix}$ | $FR_1 = A_{11} \times DP_1 + A_{12} \times DP_2 + A_{13} \times DP_3$<br>$FR_2 = A_{21} \times DP_1 + A_{22} \times DP_2 + A_{23} \times DP_3$<br>$FR_3 = A_{31} \times DP_1 + A_{32} \times DP_2 + A_{33} \times DP_3$ |

Figure 103 – The FR-DP relationship according to the design matrix

### The Information Axiom

Axiomatic design requires the satisfaction of the independence axiom. Different designs that satisfy the independence axiom can be obtained. In this case, the best design should be selected. The best design is the one with minimum information. The information axiom is formally stated as:

Axiom 2: Minimize the information content of the design.

The information axiom provides a quantitative measure of the merits of a given design and it is useful in choosing the best among those designs that are acceptable. Thus, if there is more than one design alternative that meets Axiom 1 and has an equivalent performance, then the design with the lesser amount of information should be selected. In addition, the information axiom provides the theoretical basis for design optimization and robust design.

Among the designs that are equally acceptable from the functional point of view, one may be superior to others in terms of the probability of achieving the design goals as expressed by the FRs (Park, 2007). The information axiom affirms that the design with the highest probability of success is the best design. Information content Ii for a given FRi is defined in terms of the probability Pi of satisfying FRi:

$$I_i = log_2 \frac{I}{P_i} = -log_2 P_i \qquad (9)$$

Many users of axiomatic design focus on value of the independence axiom. The function focus of Axiom 1 is more important for mechanical designers and the relationships between functional requirements and physical design parameters is also clear. Axiom 2 has been enacted more slowly and is still subject of interpretation. The analysis here will focus on Axiom 1. Further information can be found in Suh (1990; 1998; 2001).

### The Zigzagging Process

The design process is considered complete when the mapping from the functional domain to the physical domain is done. However, in many design assignments of higher complexity, a process of cascading the high-level conceptual requirements is needed. The goal of this process is to decompose the FRs, the DPs and the PVs for further detailing before implementation. The process should be detailed in a way that it enables the mapping from FRs to DPs at a certain decomposition level and from the DPs to the FRs of at an additional detailed level. The zigzagging process of axiomatic design does exactly that (Park, 2007) (Figure 104).

This process requires the decomposition in a solution neutral environment, where the DPs are chosen after the FRs are defined, and not vice versa (Yang and El-Haik, 2003). When the FRs are defined, we have to “zig” to the physical domain, and after proper DP selection then we have to “zag” to the functional domain for further decomposition. This process is in direct conflict with traditional cascading processes, which use only one domain, processing the design as the sum of functions or the sum of parts. The process of zigzagging must be carried to an elementary level (no further possible decomposition). The result of this process is the creation of the hierarchical tree, a physical structure, for the FRs and the DPs. This is the main output from the technical side. Naturally, the process should be conducted in the process domain via mapping the DPs to the PVs. The output is the process structure.

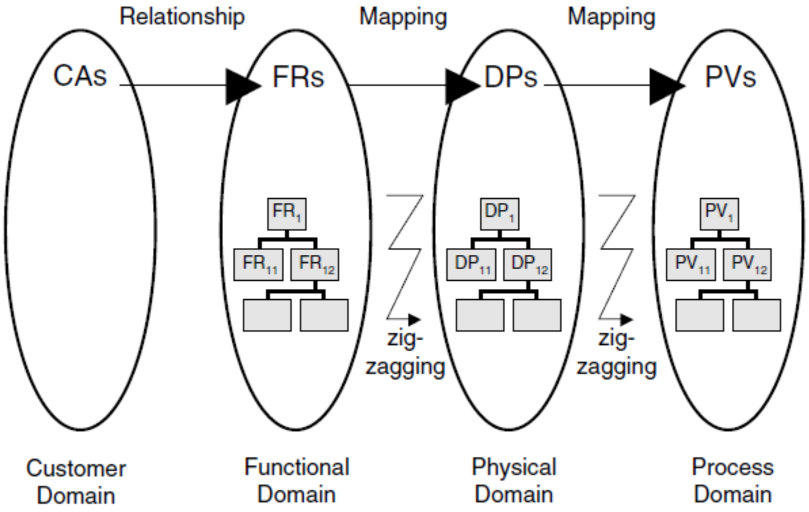


Figure 104 – The zigzagging process

The equation y = f(x) is used to consider the relationship between the domain (array y) and the codomain (array x) in the concerned mapping, where the array $\{y\}_{m \times 1}$ is the vector of requirements with m components, $\{x\}_{p \times 1}$ is the vector of design parameters with p components. In addition, A is the sensitivity matrix representing the physical mapping with $A_{ji} = {}^{\partial y_j}\!/_{\partial x_i}$. In the process mapping, matrix B represents the process mapping between the DPs and the PVs (Yang and El-Haik, 2003). The overall mapping is matrix C, such as: C=A × B, the product of both matrices. The overall mapping (matrix C) is what the customer will experience (Figure 105).

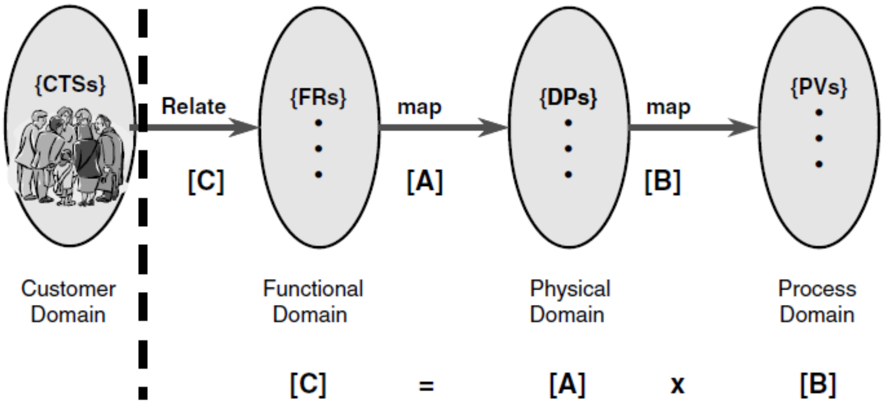


Figure 105 – The overall design mappings

**The need for Axiomatic Design (in the context of this research)**

When examining QFD and AD, many similarities exist that will allow for a relatively simple combination of the two methods. By examining common aspects, the differences can be identified and studied to determine their contributions to an integrated model. Once these similarities have been discussed, an algorithm of the new model will be outlined.

The purpose of the House of Quality (HoQ) is to provide a model for QFD for PSS that allows a visual display of the relationships and interactions between the customer and the PSS. The goal is to develop the most marketable design of a PSS based on customer inputs.

The purpose of AD is to develop a defined set of principles which provide a mapping technique between a PSS's functional requirements and its design parameters to produce a suitable or ideal design. These principles consist of the information and independence axioms earlier discussed. Using these axioms aids the mapping process in providing an ideal solution that will satisfy the functional requirements of the design.

One common similarity between the two methods is providing a sequential design process structured on formulated requirements and their resolution (depending on design parameters). The HoQ uses its relationship matrix to map these requirements to product-service characteristics to create a design solution. AD also uses a design matrix to map functional requirements to design parameters and to display the interactions between FRs and DPs in the model.

The differences in the purpose QFD and AD are in the methods used to develop the structure model. HoQ is a physical model with structural rooms, or matrices, that assist the comparison of alternatives. AD does not rely on mathematical relationships between structural rooms, but only on two principles. Another difference between the two methods is the end means of goal achievement. In the HoQ, the goal has been achieved when the PSS's final design involves the customer's input to provide a more "marketable" solution. However, in AD the goal has been achieved when a "final" PSS is designed using minimal effort and information.

Finally, when comparing the two methods, it is evident that the HoQ model requires more time and effort to construct. The major difference between AD and HoQ is that its use of the design axioms enables a conflict resolution between functional relationships. As a matter of fact, the AD's use of the independence axiom, attempts to eliminate relationship conflicts at the very start of the model, therefore producing an acceptable design in a more efficient manner. On the other hand, QFD can map customer requirements (more effectively) based on their level of satisfaction.