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# A MODEL FOR DESIGNING PRODUCT-SERVICE SYSTEMS USING FUNCTIONAL ANALYSIS AND AGENT BASED MODEL

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## ABSTRACT
According to people from management or engineering areas, developing a service is different from developing a product. Indeed, in the emergent service selling and in particular with the Product-Service System paradigm, designers have to consider both physical products and immaterial services to satisfy the customers' needs. So, the key issue for designers is to be able to develop jointly physical products, as it could be done with engineering product design process, but also taking into account services that interact with them. Consequently, engineering designers whom will develop PSS will have to be supported for developing both products and services involved in PSS. Moreover, they have to be assisted to validate the fact that they generate more added value with an integrate design of a PSS to be competitive. In order to develop in integrated way PSS elements, we propose a method based on functional analysis and agent-based value design by considering some value aspects. The Vélo'v example will be used to illustrate our proposition.

*Keywords: PSS development, value, agent, functions, criteria*

## 1 INTRODUCTION
In developed countries, more and more enterprises switch to provide service solutions from selling physical products. It enables enterprises to customize solutions and moreover to stand out from competitors. In addition, by providing service and not anymore selling physical products, it could be possible to decrease waste [1]. This awareness of innovation and sustainability leads to the concept of product-service system (PSS) [2]. PSS are seen as a new selling approach in which both physical products and immaterial services are gathered to fulfill customer's needs [3]. Consequently, the development of PSS can be achieved through service design or product design. But, products and services are involved in a global set, thus it is necessary to develop product and services within an integrated design process in order to optimize cost, quality and time-to-market [4]. As products are not alone but included in a global system, some modifications must be done in order to make the system working efficiently and to be economically attractive [5].
These considerations lead us to analyze the value of the PSS that is the key issue for PSS. Indeed, industries will design solutions (or services) only if the value provided by the service is more important than in traditional business. So during the design, it must be demonstrated that the value of Product-Service Systems is more important than the value of products and additional services.
By using agent-based model and functional analysis representation a methodology that would support the development of Product-Service System will be created [6] while considering value aspects. The agent based model enable designers to highlight and detail value and costs brought by a particular service [7]. On the other hand, functional analysis, which is included in Value Analysis/Engineering [8], is more a functions oriented representation. Tools and representations [9-11] enable engineering designers to highlight and characterize customers' requirements and then to detail technical functions and solutions that will fulfill those requirements. In this article, we will present the current approaches for designing PSS and how is considered the value of PSS. Then, the proposed method to develop PSS will be described and illustrated with the Vélo'v example.

## 2 CURRENT APPROACHES FOR DESIGNING PSS AND VALUE CONSIDERATION

Many researches are developed concerning the design of Product-Service Systems and start from the idea that more benefits are provided for everyone when designing a PSS instead of a product with additional services. But developing a PSS notably differs from developing a product. In this part, the different researches concerning the design of PSS will be presented and the focus on how to consider the value added by a PSS will be detailed.

### 2.1 Current design approaches for PSS

In the literature, two main ways of researches concerning the design of product service systems are identified. The first one concerns the design of PSS from the system point of view whereas the second one concerns the design of PSS from the product point of view.

#### *Designing PSS from the system point of view*

Designing a PSS from a system point means that the designers have first to focus on the system, without thinking to the current products or services already existing to fulfill the customers' needs. As mentioned by Morelli [12], in that case:

- The design of a PSS is a proposal of a new combination of technological artifacts on the basis of functional parameters selected by the designer;
- The interaction between the designer of the service and the customer is not mediated by the industrial artifact.

This approach is necessary to really propose innovative solutions and to create new added value. The EU SusProNet research project identifies state of the art in PSS and creates a network of PSS practitioners whom develop this approach [13]. In this project, tools and methods are essentially developed to define the PSS system as illustrated by the MEPSS methodology [14].The method consists in making a strategic analysis to understand the original system, exploring the opportunities via idea generation , developing the PSS idea and then preparing the implementation of PSS. The final output of the method consist in the detailed assessment of the future PSS without any proposition concerning the technical solutions for products or services that have to be developed.

Moreover, this system oriented approach is very useful to better consider life cycle aspects of the product or service during the design process. This is why many researches are sustainable product systems oriented [15-18]. Indeed, services are not necessarily more sustainable than products, but if carefully designed, the offers of services can result in significant environmental benefits, such as reduced resource use, waste production and emissions [19] or social benefits concerning the conditions of work in the company or in sub contract, the impacts of company activities on local and global communities, the compliance with legislations, etc [20].

#### *Designing PSS from the product point of view*

The notion of service was neglected by designers and engineers for a long time because it is considered as immaterial and is not related to technical requirements, in spite of the direct correlation between physical products and services [12]. A first approach for designers was to linked services to the consideration of the product life cycle. Indeed, by considering the product life cycle some services were shown as important aspects like maintenance, remote monitoring, teleservice, planning and controlling of the disassembly process, training, etc [21-24]. But, this approach only realised an adaptation of the existing product.

Now, designers really consider that services and products have to be developed with an integrative manner. They particularly focus on Industrial Product-Service-Systems ($IPS^2$) concept, defined as a new product understanding consisting of integrated product and service shares. $IPS^2$ comprises the integrated and mutually determined planning, development, provision and use including the option of partial substitution of products and services over the lifecycle. This integrated understanding leads to new, user optimized solutions concerning production machines or technical product service systems [25].

Nevertheless, when designing a PSS, whatever is the adopted point of view, everyone agree with the fact that the value of the future PSS will have to be higher than the value of products and associated services. But is the PSS value really considered to guide the design process? In the last section, we will present definition of the value that should be considered during the design process of PSS.

## 2.2 Value considerations during the design of PSS

However are the elements of the final solution (a physical product, a service or a PSS), customers want that this solution fulfill their needs. A value will be allotted to a solution by the customer if it satisfies him. This concept of value will constitute the central element within the framework of the design of the PSS, which combine both physical products and service units. Indeed, during the design process, it is necessary to validate the fact that the value provided by the PSS is higher than the value provided by existing products and services. So, PSS engineering is considered as a novel engineering discipline for producers to increase value combining service units and products. But the value consideration depends on the point of view one can adopt, that is why the notion of value must be defined.

### *Value and product engineering*

During the design process engineers use the Value Analysis method to control their life cycle costs [26]. In this method, the value is perceived as the ratio between function and cost [27] or between quality and costs (quality = satisfaction provided/satisfaction needed):

- Two means exist to increase the value of the PSS from the industrialist point of view) : with same costs, one can propose more functions and thus sells the PSS to the customer with an higher price ; with same functions, one can propose manufacturing solutions at lower cost;
- Two means exist also to increase the value of the PSS from the customer point of view: For a specific function, reduction of costs is necessary; for the same cost, the product must have more functions.

Therefore, both customer and supplier would gain from cost reductions derived from improved resource efficiency. For the supplier, this includes improved customer relationships, value-added services (sub-contracted activities), ensured material input and the opportunity to attract new customers. The customer can benefit from outsourcing of non-core activities, integrated supply chain management and reduced costs [19].

### *Value and service engineering*

Service engineering has been developed in order to increase the value of service [28]. In Service/Product Engineering, value is defined as the change of a receiver's state that he/she prefers, so that function is just a realization method to provide the value in SPE. Values and costs are key factors of the method and elaboration of solutions, while in functional analysis value is analyzed after the development of solutions. Thus, Service/Product Engineering uses value as a starting point of the design process. In that case, to increase the value of the PSS, designers have to increase the level of satisfaction of the customers.

### *A proposition for the consideration of the PSS value*

For many companies, financial savings and revenues generated from shifting to services oriented solutions is the most important driver. But there are also researchers that state that environmental improvement is the main driver for the shift towards service oriented solutions [15, 17], while increasing the potential for reuse, refurbishment, upgrading of products and recycling of materials. Indeed, if the example of a producer that owns the product all along its lifecycle is considered, it can be easily imagined that product updating, take back and recycling processes will be more economic and easier to manage. In that case, life cycle strategies can ensure the reduction of material use in the production of new products and ensure a secondary source of raw materials directly from the market. That means that in the ratio function / cost defining the value we should have:

- The functions needed to satisfy both customer's needs and needs of those involved in the life cycle of the PSS (manufacturers, recyclers, …);
- Costs are not only financial. Indeed, these costs are related to the negative aspects of the PSS. Within the framework of a service of hiring of bicycles, for example, the customer has to go to the hiring point to take a bicycle. This displacement is regarded as a cost for the customer.

Consequently, to realize the evaluation of the PSS value designers will probably use transversal methods like Life Cycle Analysis (LCA) and Life Cycle Costing (LCC). But these tools are not already well adapted to make an evaluation of the value of the PSS early during the design process.

Thus, the design of PSS could be based on the definition of the system or on the definition of the product. We think that these two approaches are complementary but the system approach seems to be more efficient to support the PSS definition within an integrated manner. On the other hand, the designers cannot be satisfied with the current approach, because they have to follow an integrated approach until the realisation of the final technical solution. Therefore, our proposal is to adopt a functional and system thinking for the design of PSS that leads to the final definition of the technical solutions. To achieve it, an approach based on the functional analysis approach and on the Agent based model [6] is proposed in the next paragraph. This approach will support the considerations of the aspects related to the value of the PSS.

# 3 THE PROPOSED APPROACH FOR PSS DEVELOPMENT

The proposed approach is separated in two steps: first, an overall system analysis that will lead to the definition of the elements of PSS (elements of PSS can be either physical objects or service units) and secondly a detailed design phase to define technical solutions.

So, a first analysis of the whole system is realised by focusing on functional aspects. Several steps are necessary to identify the functions and the associated criteria necessary to evaluate the PSS value:

- Analysis of customers' needs and people involved in the PSS (or having an influence on it): characterisation of agents and value provided are identified;
- Translation of requirements into external functions: service functions (external functions) required by customers are detailed and defined with criteria, level and allowance. Moreover, they will be enhanced by value/costs identified in the previous step;
- Definition of the technical functions and of the corresponding solutions that realise the external functions. Here, the definition of the technical solutions consists in the definition of main elements of PSS. These elements are specified and chosen according to different use case scenarios.

So, outputs from this first step of the design process are elements that will fulfil technical solutions. In addition, detailed specifications will be attached to each element. Afterwards, the detailed design phase is possible and also separated in different steps:

- Extraction of needs for each elements: specifications taken from FBD are an important contribution;
- Translation of external functions into technical functions;
- Detailed design of solutions and components.

This second development stage is quite similar to "classical" product design process despite the fact that the detailed assessment of the elements already exists in relation with the scenario retained for the future PSS.

## 3.1 Study of global system

### *Customers' needs analysis and people's involvement*

PSS in many cases includes other agents than a customer and a provider to be operated. For instance, an agent who manages or maintains provided physical products is set up between the provider and the customer. For the good work of the whole business, it is critical that all the involved agents find a balance between the value they receive and the costs they support. Thus, evaluation of such feasibility is needed. Flow Model and Scope Model [7] are adopted for this purpose. The former represents the agents participating in the service, while the latter describes all the value and cost (represented as RSP [7]) of a receiver in a specified range in the service.

Let us consider a launderette service as an example. Agents are in this case an end user washing clothes, a manufacturer of washing machines and a launderette operator. A Scope Model between the operator and the end user describes the end user's value such as cleanness of clothes, his/her cost such as paid money and the waiting time. Another Scope Model between the manufacturer and the operator includes the operator's value e.g. availability of a washing machine as well as its cost e.g. space for placing a washing machine. By describing these models, PSS designers can evaluate the feasibility of the service as a whole and operate (add or remove) value/cost in a Scope Model if an agent finds its value too low as compared to its cost. Thus, it is necessary for designers to grasp all the relevant value/cost (RSP) of each agent in the service because their insufficient description leads them to fail in good design. For this purpose, a "Scenario Model" is adopted and represents two kinds of information:

the properties of a service receiver (agent description) and his behaviour when receiving the service. The former is represented by an application of the concept called Persona [29] in which two types of information are identified:

- Demographic data: age, gender, professional carrier;
- Psychological data: personality and life style.

The latter is described as a transition graph. In this graph, a node represents a state of a receiver and an arc refers to a transition between two states (either temporal or causal). By using this transition graph, the receiver's final goals, and their activities can be described. RSPs are a partial set of parameters for a state selected by designers. Thus, Scenario Model allows designers to describe all the RSP with the grounds behind those RSP of service receivers.

#### *Translation of requirements into external functions*

Once values and costs are identified, external functions expected by the customer must be defined. External Functional Analysis will support the emergence of external functions provided to the customer by the product (or the service or the organisation) to satisfy his/her needs. For each phase of product life cycle (use, manufacture, maintenance, recycling, etc…) an analysis must be carried out. The "product" is, at this point, considered as a black box that can satisfy customer's needs and those of the professionals involved in life cycle [30]. The graph of interactors is used to express these needs that are service functions and constraints:

- The interaction functions (IF), which correspond to the services provided by the product during the product life cycle;
- The adaptation functions (AF) that reflect reactions, resistances or adaptations to elements found in the outside environment;
- The constraints are defined as a design characteristic, effect or provision for design, which is made compulsory or forbidden for whatever reason.

These functions are obtained from systematic analysis of the possible relations between:

- The different elements of the outer environment via the product for IF;
- The elements of the outer environment and the product being designed for AF.

Moreover, designers have to characterise outer environment (that are quite similar to agents in the flow model) in order to take into account each function expected by them. The contribution of values and costs identified in the previous phase is important because they help the characterisation of the different external functions.

#### *Definition of the technical functions and of the corresponding solutions*

Engineering designers can not directly find technical solutions related to the external functions. An intermediate step is necessary in order to "translate" external service functions into technical functions before the definition of solutions. This step can be achieved by an Internal Functional Analysis and supported with a FAST diagram and a Functional Bloc Diagram (FBD). 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. For instance, a maintenance service is involved in the launderette. If a failure occurs on a washing machine either users inform maintenance service by means of a free of charge phone number, or the tenant calls the service to fix broken machines. In that case, links are different between the elements of the PSS solution and specifications on all elements are also modified. The FBD also enables to represent relations between elements. Consequently, it enables designers to develop and optimise the scenario for maintenance, or any others service activities. Afterwards, a crucial phase of characterisation of elements and links is necessary to detail specifications that will be used for the development of physical objects and technical service units.

### 3.2 Detailed design of PSS elements

The contribution of the system analysis is to give specifications for each element involved in the system. Functional bloc diagram is interesting because it supports the mapping of elements and leads to detail specifications for links and elements that will be used for the particular development of elements. The design process of elements is based on those specifications. Phases and tools are similar to those employed for the study of the system but the analysis is now more focused on physical objects or technical service units. As specifications have been detailed in a global system including physical products and service units, arrangements between the agents have been done. Consequently, each element have been characterised in a global way and the design process of each of them is quite optimized for the system. Costs and values brought during the development of the system have been taken into consideration and had an influence on functions.

# 4 MODELISATION OF THE VÉLO'V EXAMPLE

This model will be employed with the PSS Vélo’v. Vélo’v is a rental bike system installed in Lyon, France since May 2005. This service enables customers to rent a bike in order to move in the city and he/she is only charged for the use-time. To use a bike, customers rent a bike from a place (e.g. the central station) and bring back this bike to another place (e.g. the city hall). The customer must buy a card (short or long lasting card) and then register in a station (identification through this card), choose a bike, use it and bring back to a station. About 250 stations are spread in the city every 300 meters and this service is becoming very popular (in 2006, an average of 15,123 bike hires per day and 11,300,000 km covered [31]).

## 4.1 Which are agents involved in the service and what are customers’ requirements?

Flow, Scope and Scenario Models were used to describe value/cost (RSP) provided by the PSS to all the related agents. Note that costs are “negative” values. Figure 1 depicts the described Flow and Scope Models. Note that the two gray agents in Figure 1 are “outsiders”, who in this case do not participate in the service but only affects the service.

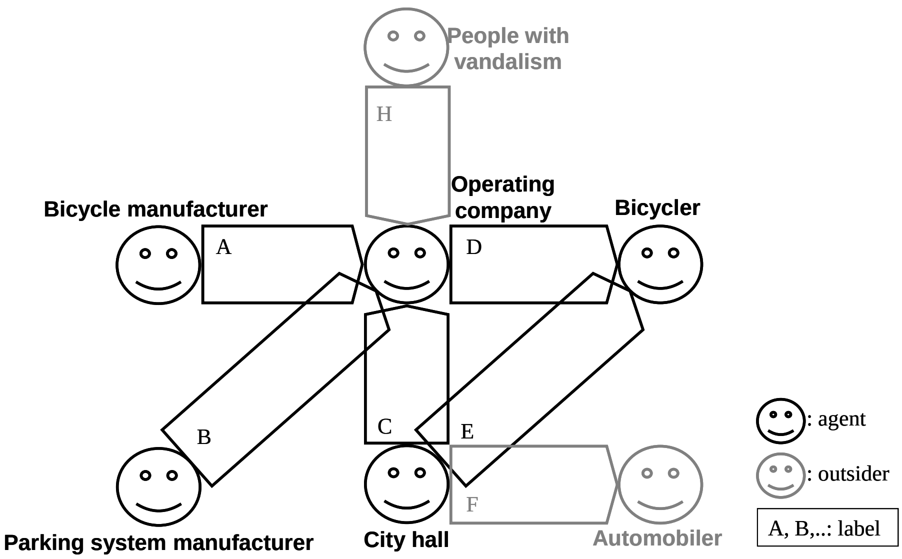


*Figure 1: Description of a Flow Model of the example service*

The Scope Model will focus and study each relation in order to highlight values/costs of receiver.

### *Contribution of scenario model for emerging values and costs*

Figure 2 describes the Scenario Model of the bicycler (the end user of this service). When the bicycler uses the Vélo’v service, several activities are made to use bicycles. For each of these activities, it is possible to identify values and costs. As seen in Figure 2, for instance, when receiving the bicycle, the bicycler recognizes a positive RSP named “Availability in station” and a negative RSP, “Effort for receiving bicycle”.

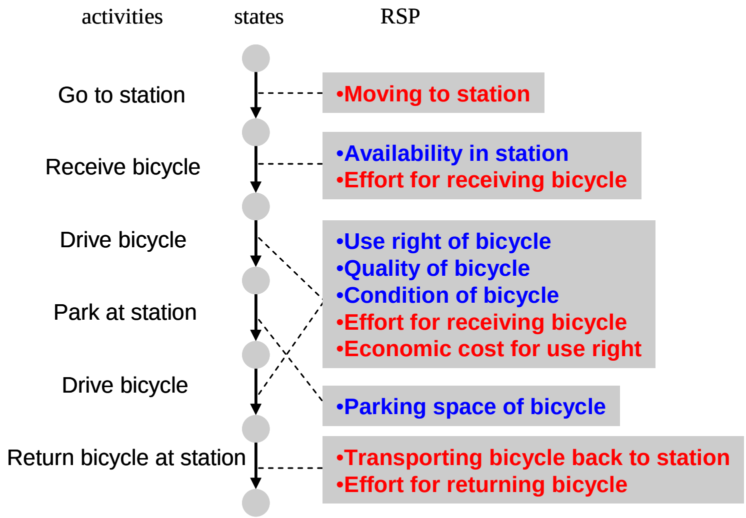


*Figure 2: Scenario Model of the bicycler*

By describing a Scenario Model for each agent in Figure 2, designers could identify the associated value/cost as shown in Table 1.

*Table 1: Partial table of values and costs identified*

| Scope model | Value | Cost |
|---|---|---|
| A | Ownership of bicycle<br>Quality of bicycle<br>Condition of bicycle<br>Available time excluding maintenance | Economic cost for bicycle<br>Economic cost for maintenance<br>Time for making design specifications<br>Time for delivery of new bicycle<br>Risk of bicycle being stolen |
| C | Parking space | Economic cost for parking space<br>Efforts for application |
| D | Use right of bicycle<br>Quality of bicycle<br>Condition of bicycle<br>Availability in station<br>Parking space of bicycle<br>No ownership of bicycle<br>No fear about theft of bicycle | Economic cost for use right<br>Moving to station<br>Effort for receiving bicycle<br>Transporting bicycle back to station<br>Effort for returning bicycle |
| H | | Damage on bicycle |

The aim of the designer is to enhance values while avoid costs. All of these RSP will influence the choice and criteria of functions. For example, if designers want to reduce the cost for the bicycler relative to “moving to station”, they will reduce as much as possible the distance between bicycler and service (provided at first by stations). Compromises must be discussed and found between a huge numbers of stations, which would lead to an expensive cost for operating company but a very important incentive to use the service, and a too low distribution of stations among the city that would be cheaper for company but that will not promote the service.

## 4.2 Translation of requirements into external functions

In order to highlight customers’ requirements and external people who could have an influence on the PSS, graph of interactors will be used. First of all, designers have to identify and describe the outer environments that can have an influence or that are put in relation through the PSS. Agents identified in flow model are outer environment. But others “non-financial” agents are assimilated to outer environment influencing the design of PSS. For example, climate (rain, snow, low/high temperature, etc.) will influence the PSS. Moreover, PSS must respect the others road-users of the city.

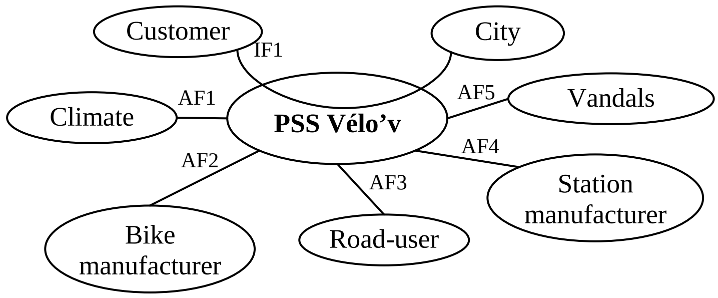


*Figure 3: Graph of interactors of Vélo'v Example*

As shown in Figure 3, external functions can then be described:

- IF1: the PSS enable customer to move in the city;
- AF1: the PSS must resist to climate;
- AF2: the PSS must be manufactured by bike manufacturer;
- AF3: the PSS must be seen and not disturb others road-users;
- AF4: the PSS must be manufactured by station manufacturer;
- AF5: the PSS must resist to vandals.

These functions reflect the external view of customer and also of the provider of this PSS. If this representation would be used in a case of typical rental bike system, the graph would be quit similar. But, in that case, as traditional bike are rented, the level of criteria associated to functions would be different (i.e., resistance to vandals, distance to the station…). That is why it is important to highlight the added value of the PSS (in the case of Vélo'v well spread distribution in city, no fear about theft of bicycle, etc) and to take it into account when characterizing the external functions.

## 4.3 Which are technical functions and solutions employed?

External functional analysis is used to characterize the functions expected by the customer. Criteria, level and allowance must be respected by engineering designers during the design process. In order to detail solutions used to fulfill customers' requirements, internal functional analysis is used to describe the core of PSS. Both FAST diagram and Functional Bloc Diagram are necessary.

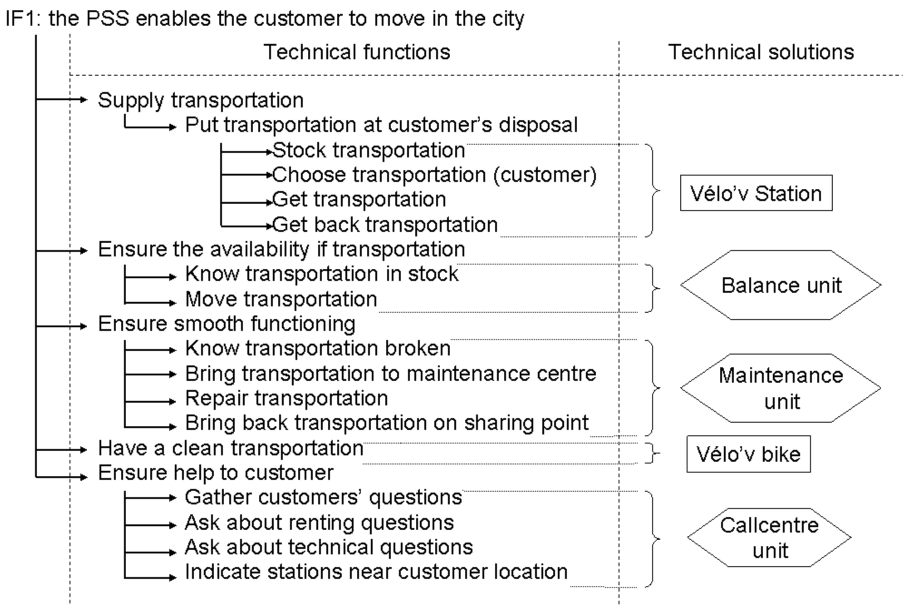


*Figure 4: Elaboration of technical solutions*

***Elaboration of solutions***

In the Vélo'v example, the function expected by the customer is to move in the city. But this "external function" can be detailed in several technical functions and solutions. As shown in Figure 4, the FAST diagram details these functions and the technical solutions employed to fulfil them. In this representation, rectangle represent physical objects and hexagon the technical service units. Once potential solutions emerged, the designer must link them.

***Functional Bloc Diagram: mapping the interaction between elements***

Elements of PSS emerged from FAST diagram. But as said previously, the overall organisation between elements is a key factor for PSS. Thus, physical objects and technical service units are linked. The aim of the Functional Bloc Diagram is to map these interactions. In the case of Vélo'v, links will emerge from the scenario described earlier. This is not only the scenario of customers that is important, but also the scenario of all agents involved in the PSS. A specific scenario must be described for the maintenance service: how is the information transmitted to the maintenance service unit, are bikes fixed directly on station or are they brought back to a workshop, etc. Once this scenario is validated, links between elements can be drawn (see Figure 5).

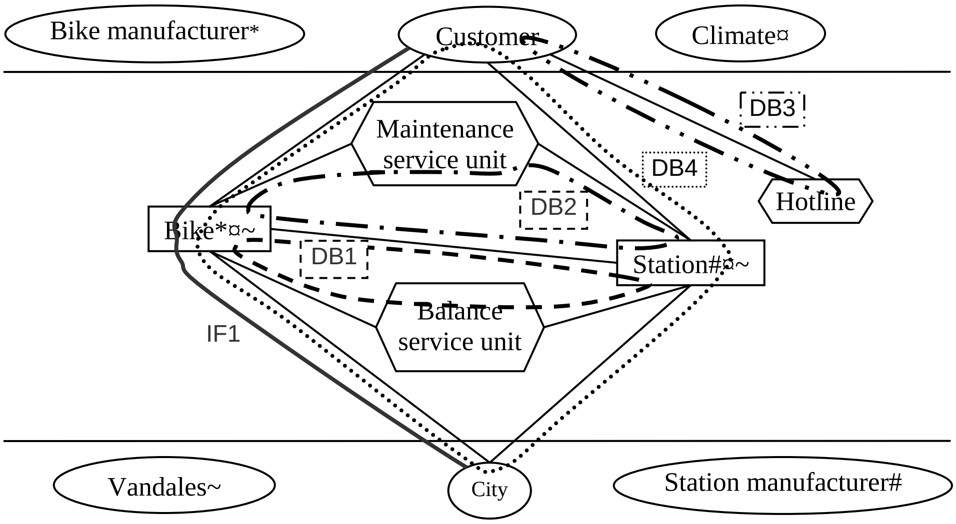


*Figure 5: Functional Bloc Diagram*

The border of PSS is limited in this representation by lines that separate them from the external environment. PSS Vélo'v includes physical objects (rectangle in Figure 5) like bikes and parking stations for bikes, but also technical service units (hexagon in Figure 5) as a maintenance service unit, a balance service unit and a hot line. For example, the maintenance service unit that repairs bikes is linked to the station to take and bring back bikes after being repaired. Moreover, bikes and stations are also linked due to the physical link between the storage area and bicycle when bikes are not used by customers. Consequently, links between physical objects, or between objects and service units can be detailed with FBD. It would be also possible to have link between two services. For example, if the hotline would give information to the maintenance unit about the broken bikes another link would have been added. These links reflect the overall organisation of the system. Interaction function 1 goes from the customer to the city through the bike. But, design buckles represent the technical functions necessary that ensure the realisation of the external functions to satisfy the customers' needs. In the case of Vélo'v, 4 design buckles are drawn on the FBD. These buckles are:

- DB1: Ensure the availability of transportation;
- DB2: Ensure the smooth functioning of bikes and stations;
- DB3: Help customers;
- DB4: Supply transportation in the city.

On the other hand, adaptation function that influence PSS are identified by means of symbol. For example, the climate (symbolised with "¤") will influence the design of bicycles because for example components that will not be rusted will be used. Moreover, manufacturers will have some specifications to be able to manufacture bicycle or stations. Finally, damaged caused by vandals must be limited to decrease maintenance action on bicycle and station. Thus, each elements asterisked with symbols must take into account the outer environment influencing the element.

The next step is to characterise links and elements. Thus, elements and links will be described with specifications that will be used for the detailed design of elements involved in PSS.

## 5 CONCLUSIONS

Researches about the development of service and more particularly about Product-Service Systems are very important. Whatever the adopted point of view to develop PSS is (system or product), the new added value of such service is the key issue. Thus, engineering designers have to consider the PSS value during the development process, but for the moment they are not supported in this task. The method that we propose is based on Functional Analysis and Agent-Based Value Design. This method enables designers to detail values and costs provided by the PSS while considering the functions that will fulfil the expected requirements. This method was illustrated with the Vélo'v case study, and in a next future this method will be applied in an industrial context to define a PSS for a cooling system provider. Future researches will concern a more detailed definition of the PSS value integrating environmental aspects. Specific tools that could help PSS designers to define the final solution should also be identified (FMEA, LCU analysis…).

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