Evaluation of "Design Loops" to Support the Design of Product Service Systems: A Case Study of a Helium Liquefier

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Abstract

In this paper a specific evaluation for the PSS during the early design phase is presented, taking into account:

- the scenarios that supports the definition of the architecture of the whole system and the interactions between the user and the system
- the performance of the considered system assess with specific PSS criteria (economical and environmental)

Our proposition consists in the evaluation of the design loops that are constructed jointly with the scenarios describing activities and with the PSS architecture. This evaluation phase is part of a methodology that is being developed to design global and optimized PSS.

Keywords:
Product-Service Systems, scenarios, FBD, design loops, PSS criteria

1 INTRODUCTION

Shifting from product selling to service providing is not so easy to realise. Enterprises have to reconsider their organisation and their business model based on mass production. To facilitate this transition, it is thus necessary to bring a methodology to support engineering designers during the design process of Product-Service Systems. This paper highlights that Product-Service Systems are influenced by several factors that were not necessarily included during the design of products.

During a design process, there is a co-evolution between the definition of the design problem and the definition of solutions. Designers consider the expression of the needs of the various actors of the product lifecycle. Then, they try to translate them with functions, constraints and assessment criteria. One objective is to construct step by step the relations between needs and constraints, functions and solutions, in order to evaluate the design choices and to finally obtain the best compromise for the finale solution [1].

In the case of the design of Product Service Systems (PSS), another dimension must be added: the PSS organisation. Indeed, PSS are composed of physical objects and service units that relate each others even if finally it would be different teams that will develop these products or services. So, to have a competitive PSS, designers must:

- consider carefully and early in the design phase the interactions between those elements;
- be able to evaluate the organizations that result from their design (organisational) choices.

That means that the design of the architecture of the PSS has to be considered and a specific method has to be used to identify and capitalise value criteria that characterise the resulting organisation. Our proposition consists of a jointly use of scenarios and design loops during the conceptual design phase of PSS. In the next sections the concept of scenario and design loops that are uses and the retained formalism is explained. Then the evaluation of design loops will be detailed to show how it can support the design of PSSs. In the final section, an industrial case of a helium liquefier is studied to validate our proposition.

2 PROPOSED ELEMENTS FOR THE PSS EVALUATION

2.1 The use of scenario during the PSS design process

Three main reasons are identified to justify the use of scenarios during the PSS design process:

- to present and situate solutions: scenarios present the activities realized (by the customer or a product) in a particular context;
- to illustrate alternatives of solutions: for one activity, the engineering designer can think about several solutions;
- to identify the potential of solutions: the presentation of scenarios to customers can enable them to assess if one solution is better than another one.

Scenarios are stories in which agents and actors realise tasks and activities, in a particular goal within a particular context [2]. In MEPSS methodology [3], use scenarios are included into the development phase. The aim is to explore opportunities for developing new product-service systems according specific customers' needs. But scenarios can be seen differently according the people because they are highly context dependent. Scenarios can also be used to describe machine state [4]. From the state of machine components, scenarios describe the technical consequences on the functioning of the machine. Thus, scenarios can detail the activities that are performed into the system. So, to go deeper into the system description once main elements of the system (physical objects and service units) have been identified operational scenarios can be used in order to describe the internal functioning of the system.

For these scenarios, we have chosen a representation used in the SADT method (Structured Analysis and Design Technique) also used in the IDEF0 methode

(Integration DEfinition for Function modelling). SADT is based on the description of activities (see figure 1). These scenarios must lead engineering designers to propose a chain of activities to transform system elements from an initial state to a final state [4]. In this representation, principles of solutions and constraints can be identified. The inputs are related to the state of the elements of the system that can be either physical objects state or service unit state. This description also joins the scenarios of machine state realised by [5]. Some inputs can also be related to information. Thus, the description of the internal functioning requires identifying objects state but also the information required to start a particular activity (e.g. engage maintenance activities).

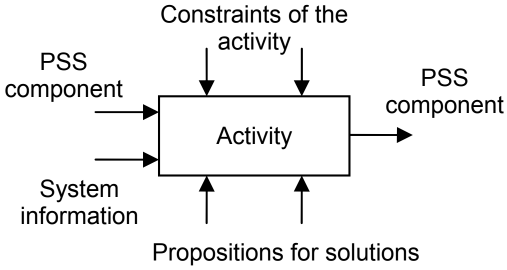

Figure 1: The SADT formalism, adapted for the description of a scenario.

2.2 The use of design loops during the PSS design process

The Functional Bloc Diagram (See an example Figure 2) is a particularly interesting tool to model and analyze PSS architecture during its design. It represents:

- the frontier between the PSS and the outer environments : the two horizontal lines;
- the different components of the product (boxes for products and boxes with round corner for service units) and the interactors existing in the outer environment of the PSS (ellipse);
- the contacts between the components or between components and interactors : the black lines ;
- the functional flows between external interactors that go through components (red flow).
- the technical functions (green loops) that are for example design choices used to assemble components or to put them in position.

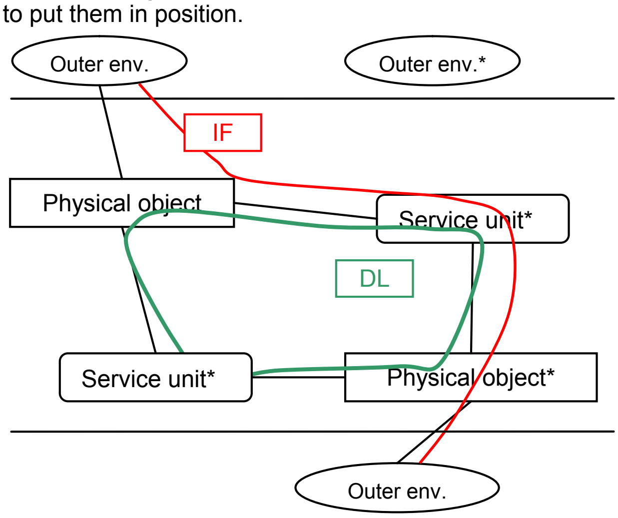

Figure 2: Functional Bloc Diagram representation.

In the case of PSS, the design loops can represent the organizational choices between products and service units. For example, the information about failure is given to a maintenance service unit by the customer or directly by a machine via a specific module. Consequently, it will influence the links between the elements.

To implement the detailed design of PSS elements, the designers need sufficient indications about the elements to design. That is why, in addition to this representation, it is necessary to characterize the links and elements. For example, in the case of a maintenance service unit, it is necessary to indicate how many times maintenance will act, what is the frequency to sent information, how many people will be involved in the call centre to answer customers' questions, etc. This description can be realized in scenarios described in the last section.

2.3 The evaluation of design loops during the PSS design process

The proposed design methodology, based on functional analysis, enables the engineering designers to start from an analysis of the whole system in order to detail the physical objects and service units involved into the system. By this top-down approach, the goal is to keep the links between the different elements during their detailed development. These links are often due to the establishment of a specific organisation between physical objects and services units that fulfil a technical function. For the same technical function, it is possible for the designer to promote either objects or service options: for example, develop an interactive guide to help a customer rather than develop a telephone service which will answer his questions. The designers must therefore put in place the elements necessary to evaluate the system as a whole. To achieve the evaluation of alternative PSS solutions, design choices for technical functions can be compared through the design loops. To evaluate these loops, evaluation criteria must be defined. Moreover, we consider that PSS must be evaluated according the sustainable development. In that sense, several research works were conducted to highlight specific criteria to realise this particular evaluation (see for example [6, 7]).

	External criteria		
	Cost	Availability	NRJ consumption
DL1	X		X
DL2	X	X	
DL3			X

Table 1: Links between design loops and external criteria.

For each design loops, the designer must wonder if the loop has an impact on one of the external criteria identified during the characterization of the service functions of the system. To achieve this linkage, a dashboard in which each design loops, as well as external criteria appear (see table 1) has been defined. The design loops are identified on the rows, while external criteria are ordered by column. A first relation between loops and criteria are identified through "X". If one looks for example the design loop 1 (DL1 in table 1), the designer identified an influence on the cost and energy consumption as "X" appears. Each loop is considered according the potential impact that it can have regarding external criteria. By considering now the various criteria, this column representation allows the designer to see the loops that have a direct influence on it. Looking the energy consumption criterion, DL1 and DL3 are the loops that will consume energy in the system. To carry out the assessment system in relation to this criterion, there is:

$$\text{Energy Consumption} = f(DL1, DL3)$$

To make a thorough evaluation of the system, it is necessary to know the solutions used in the loops. This table will be enriched as the deepening of the design process is realised, especially when describing operational scenarios. To illustrate the construction of the evaluation dashboard presented, the case of an helium liquefier is studied.

3 APPLICATION OF OUR PROPOSITIONS ON A HELIUM LIQUEFIER CASE

To avoid important losses during the transportation of electricity, researches have been conducted to find out a solution based on superconducting cables. To obtain superconducting characteristics, High Temperature Superconducting (HTS) cables need to have a functioning temperature between 65 and 70°K, rather than few Kelvin degrees for "older" superconducting cables. To obtain this range of temperature, HTS cables are surrounded and refrigerated by liquid nitrogen (LN2). In that project, the developed PSS must provide to the customer the cable refrigeration.

During the conceptual design phase, two scenarios have been developed for the function "to modify the performance of the fridge". For each of these scenarios (figures 3 and 4), the design team has chosen different elements (physical object or service unit). These elements that compose the PSS have contacts, by which the functional flow or design loops go through. The design loops can be drawn to show the organisation between the elements realising the function. The objective is to validate the PSS architecture, the organisation that results from this architecture and the value criteria that characterise the organisation.

3.1 Scenario 1: on-site management system

For this solution, a team of technician is "on site" and is able to modify the fridge performances. The design loop related to the technical function "to modify the performance of the fridge" is drawn in brown in the figure 5. One can see that this team is also implied to repair the equipment (green loop) and for the spare parts providing (grey loop).

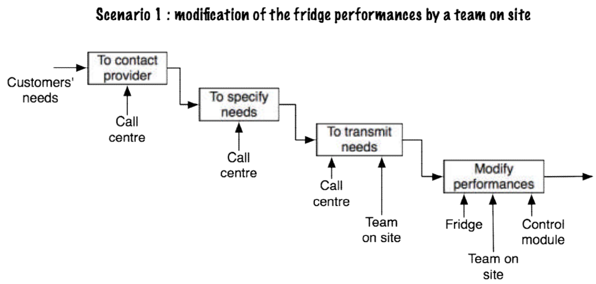

Figure 3: Scenario for an on-site management system.

It has to be said that to simplify the FBD representation the "*" symbol is used. This symbol is present in the outer environment "area of installation" and that when a component of the PSS is in relation with this outer environment, there is also the same symbol in the box that represent the element. For example, if the area of installation has an average ambient temperature of 35°C, the engineering designers will have to consider this criterion during the development of the fridge, pump, etc.

3.2 Scenario 2: remote management system

In the first scenario, the customer contacts the call centre that is only an intermediary which transmits the needs to the maintenance team. In this second scenario, the calls are centralised by a supervision unit. This supervision unit has the ability to make a remote control of the fridge and can directly act on the equipments via a supervision module. So, the fridge is not directly linked to the supervision unit because an intermediary supervision module is necessary. The functional bloc diagram of this scenario has been drawn in figure 6. From these 2 scenarios, the evaluation of the design loops can be realised. The activities performed into these scenarios are not the same that is the reason why the evaluation can not be realised through the activities of the system.

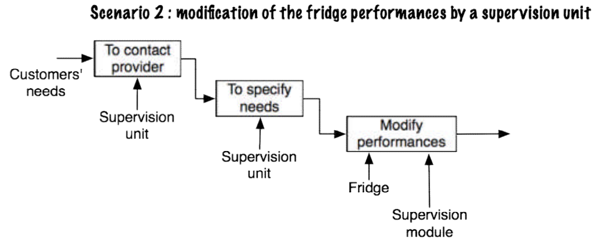

Figure 4: Scenario for a remote management system.

Moreover, the solutions (physical products or service units) are not the same, so an evaluation on the solutions of the system is not pertinent. The only common element is the design loop. Nevertheless, the evaluations of these systems are quite tricky due to the multitude of parameters to take into account and their relationships. To support the engineering designers, a dashboard has been proposed to evaluate both scenarios (see table 2). The advantage of the proposed dashboard is to group all the parameters to be taken into account. In addition, another goal is to lead designers to discuss about these parameters, to formalize and capitalize the parameters.

By this board, it can be highlighted that the design loop "to repair the equipments" has a main impact on the availability of the system. The other elements involved in this loop have also impacts on several criteria. In an on-site management system, the team is in charge of the maintenance of the equipments. Consequently, the emissions of CO_2 are less important than the remote management system where the maintenance unit need to move to the place where equipments have to be fixed. On the other hand, the employment of people on site is more expensive than selective maintenance operations performed in scenario 1. This first linkage enables engineering designers to see the impacts of solutions on the external criteria.

To deepen these evaluations, and especially to compare solutions employed to realise for example the reparation of equipments, it is necessary to detail the activities realised by physical objects and service units. If the designer decides to choose the remote management solution, thus the maintenance unit needs to move to the reparation points. The impact of these moves on the "air emissions" depends on the frequency of moves, the length, etc. These parameters are almost dependant on the reliability of the fridge. It can be noted that the resolution of the design problem to choose the best solution is dependant of several factors of the physical objects, the service units and the system. In the case of the availability, it can be noted that it is dependant of:

Availability = f(objects parameters, service parameters, systems parameters)

If one of the parameters is determined (e.g. the maximum number of people involved into the maintenance unit), the reliability of the system can be determined. From this set of parameters, designers must find technical solutions/components that fulfil this reliability. If no solution can be found, discussion and compromise must be realised to increase the number of people involved into the maintenance unit. This approach, conducted during the early design phases of PSSs, leads to improve the time necessary to develop a whole Product-Service System. Actually, by determining parameters of elements involved into these systems during the study of the whole system, several returns during the design process are avoided and designers must investigate new solutions that enable to respect the repartition of the constraints among the elements implied in the design loops.

4 CONCLUSION

A Product-Service Systems is defined as a system made up service units and physical objects. The physical objects are functional entities that carry out the elementary functions of the system, the service units are entities (mainly technical) that will ensure the smooth functioning of the whole system. These elements have relationships and interactions that lead to take into account the specificities of each ones during the design process.

So, this paper explains that a methodology is needed to structure the PSS and its design process. Indeed, while proposing formalism for the scenarios and design loops for the evaluation of the PSS architecture, the information related to the PSS organisation during the design process are defined and capitalized. Thus, the evaluation of the PSS during the conceptual design phase is a mean to make a link between the needs expression and the solutions definition, from the external criteria to the design parameters. It is obvious that the evaluation of PSS solutions from an environmental, economical and technical point of view is crucial to ensure enterprises to switch largely to these solutions. Indeed, because most of companies are based on mass production and selling products it is necessary to reconsider this paradigm [8] particularly to decrease environmental loads. PSS are able to propose new values to customers, to companies and to the society and this paper proposes a first approach to prove it.

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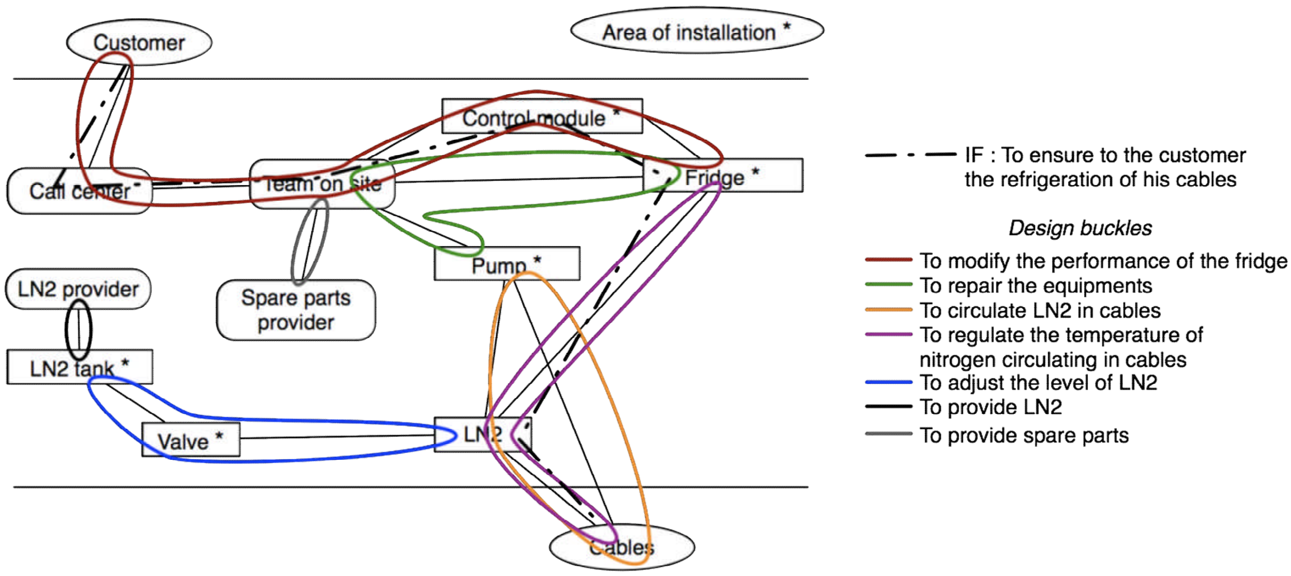

Figure 5: Functional Bloc Diagram related to scenario 1 (see figure 3).

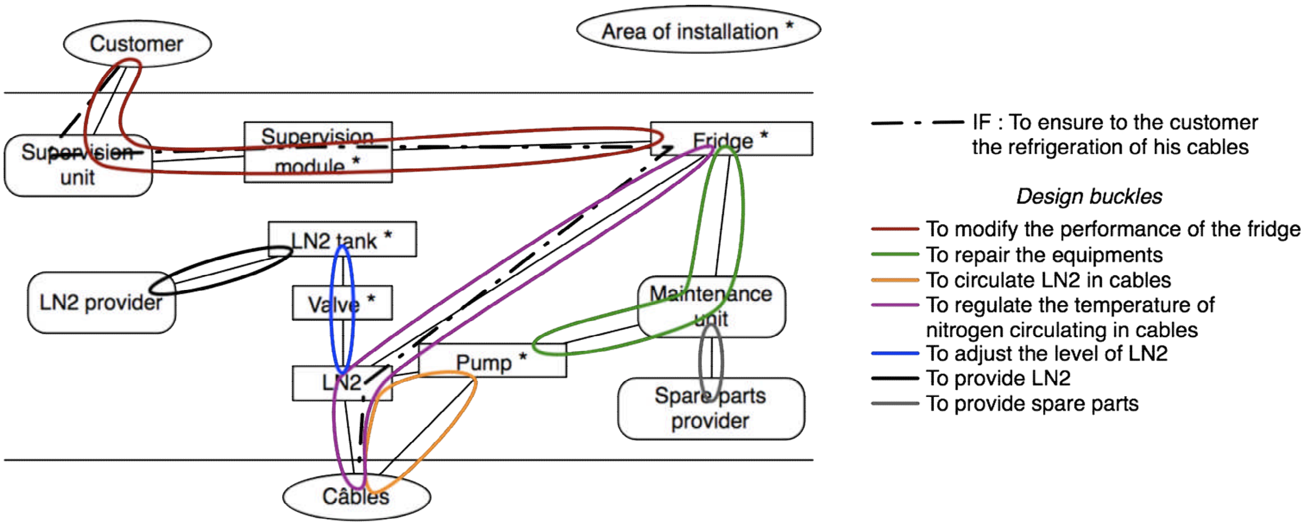

Figure 6: Functional Bloc Diagram related to scenario 1 (see figure 3).

	Design loops	Solutions	External criteria														
			Funct. temp.	Availability	Carnot efficiency	Cost	Cables diameter	NRJ consumpt.	Water consumpt.	Raw mat. consumpt.	Water emissions	Air emissions	Recyclability	Reach norm	WEEE	Average temp.	Humidity
Scenario 1 : remote management system	To repair equipments	Fridge		X	X											X	X
		Maintenance unit		X		X		X				X					
		Pump		X												X	X
	To modify system performances	Fridge	X		X			X	X	X							
		Supervision module	X					X								X	X
		Supervision unit	X			X											
		Customer	X														
	To circulate LN2 into cables	Pump	X				X	X		X			X			X	X
		LN2	X														
		Cables					X										
	To regulate LN2 temperature	Fridge	X		X			X	X	X	X	X	X				
		LN2	X														
	To adjust LN2 level	LN2 tank		X												X	X
		Valve		X												X	X
		LN2		X													
	To supply with LN2	LN2 provider		X		X		X				X					
		LN2 tank		X		X							X			X	X
	To supply with spare parts	Maintenance unit		X													
		Spare parts provider		X													
Scenario 2 : on-site management system	To repair equipments	Fridge		X	X											X	X
		Team on-site		X		X		X				X					
		Pump		X												X	X
	To modify system performances	Fridge	X		X			X	X	X							
		Call centre	X					X									
		Control module	X														
		Team on-site	X			X		X	X								
		Customer	X														
	To circulate LN2 into cables	Pump	X				X	X		X			X			X	X
		LN2	X														
		Cables					X										
	To regulate LN2 temperature	Fridge	X		X			X	X	X	X	X	X				
		LN2	X														
	To adjust LN2 level	LN2 tank		X												X	X
		Valve		X												X	X
		LN2		X													
	To supply with LN2	LN2 provider		X				X				X					
		LN2 tank		X									X			X	X
	To supply with spare parts	Team on-site		X													
		Spare parts provider		X				X									

Table 2: Linkage of design loops and external criteria for scenarios 1 and 2.