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DIRECTIVES TO SUPPORT THE DESIGN OF CHANGEABLE (I)PSS

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Abstract

Product service models (PSM) benefits are not limited to its providers and costumers, but the whole society might also take advantage from its sustainability impact. Achieving these benefits, though, require changeable product service systems ((I)PSS). Changeability means the (I)PSS' modules have built in robustness against small use variations, adaptability to use changes, and flexibility to further updating and upgrading. In order to face this design challenge and support early modular design decisions, this paper defines a set of design directives based on the here proposed AEIOU variables (Acceptance, Ephemerality, Importance, Operational, and Urgency). This paper's second contribution is a modification from the Value Function Deployment (VFD) technique. While the original VFD is a Lean Product Design and Development (LPDD) technique that supports decision making until releasing the design to production, the adaptation, which includes the AEIOU variables, extends this capability to the whole (I)PSS lifecycle. To illustrate and show the viability of the work, a fictional product development case and related design decision scenarios are discussed.

Keywords: Conceptual design, Lean design, Product-Service Systems (PSS), Value Function Deployment (VFD)

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1 INTRODUCTION

The Product Service Model (PSM) is a business approach where manufacturing firms' revenue shift from only selling physical products to also selling services, where value delivery ranges from more product to more service shares (Thölke et al. 2001; Baines et al. 2007; Meier et al. 2010). In business-to-business applications the PSM is called Industrial Product-Service Systems (IPS2), while in business-to-consumer (B2C) it is called Product-Service Systems (PSS). In this paper, these applications are referenced indiscriminately as (I)PSS.

"An IPS2 is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system" (Meier et al. 2010).

"A PSS is a system of products, services, network of players and supporting infrastructure that continuously strive to be competitive, satisfy customer needs and have lower environmental impact than traditional business models" (Goedkoop et al. 1999).

PSM benefits, therefore, are not limited to the (I)PSS' providers and customers, the whole society might also take advantage of its sustainability impact, since it can both potentially reduce resources consumption and pollution (Tukker, 2004). In PSM, the interrelations between the physical product and the non-physical services need to be considered proactively during the development process (Aurich et al. 2006). (I)PSS are indeed complex systems, design of which must take into account products, services, support systems, business elements, and the work flow and interactions amongst them (Vijaykumar et al. 2012).

Greater benefits from PSM derive from setting long-term relationships between (I)PSS providers and customers. Long-term relationships are leveraged by changeable (I)PSS architectures, where changeability means the system's modules have built-in robustness against small use variations, adaptability to different use experiences and new technologies, and flexibility to updating and upgrading (Richter et al. 2010). Adaptability reduces the need of (I)PSS changing due to external changes, while flexibility means quick and easy updating and upgrading of the impacted modules/parts. This poses an additional challenge for the designers who need to consider actual and future use scenarios and possible technology evolution, thus requiring decisions about the right (I)PSS built-in options as early as during the conceptual design.

This paper seeks to define a method to address early modularization decisions by considering changeable (I)PSS architectures. The method considers performing a lean product design and development (LPDD) process, and is based on using the here proposed AEIOU variables (acceptance, ephemerality, importance, operationality, and urgency) together with an adaptation of the Value Function Deployment (VFD) technique:

- LPDD is a relatively new approach. It has presented very good practical results (Al-Ashaab et al. 2013; Liker and Morgan 2006; Holman et al. 2003; Radeka, 2013); particularly the use of Set-Based Concurrent Engineering (SBCE), and has presented good results when managing multiple design options (Ward et al. 1995; Sobek at al. 1999; Ward, 2007).
- The AEIOU variables support modular architecture definition decisions. These decisions include deciding which pulled value best fit to either product or service (I)PSS modules, and when during the lifecycle it should be incorporated to the offered (I)PSS.
- While the original VFD is an LPDD technique to support SBCE decision making during the conceptual design (Pessôa et al. 2008; Pessôa and Trabasso, 2017), the here proposed VFD adaptation can support (I)PSS design change decisions during its lifecycle. The adapted VFD is the backbone that supports the method's execution.

This paper is structured as follows. Section 2 presents the Product-Service Models (PSM) and lists the characteristics that impact the (I)PSS design and development. Section 3 shows the traditional VFD and shows its limitations to tackle (I)PSS design and development characteristics. Section 4 describes the proposed method. An application example is discussed in section 5. Section 6 presents the final remarks.

2 (I)PSS DESIGN AND DEVELOPMENT

The (I)PSS success relies on the lifecycle-long relationship between its supplier and customer (Meier et al. 2010). This relationship acts like a fulcrum, by guaranteeing both the flow of money and information that will enable and sustain the PSM:

- From the supplier point of view, the longer the relationship the higher the profit from setting the structure to support the customer's use. This relationship creates a customer–supplier intimacy and mutual dependence, which supports a learning process where the suppliers better understand the product use and the market (Meier et al. 2010).
- From the customers point of view, longer relationships mean suppliers' better understanding of their needs and accurately providing the right (I)PSS. These (I)PSS release customers from the responsibilities of asset ownership (Baines et al. 2007) and from capital lock-up and knowledge restrictions to using newer and even more complex technologies.
- From the society perspective, longer relationships might preserve the usability of the (I)PSS and prolong the product's lifecycle. Once the ownership remains with the supplier, there is greater motivation to establishing closed loop recycling management with reuse services (Mont, 2002; Seliger, 2007). The (I)PSS supplier can optimize the use phase by applying sharing mechanisms that reduce individual cost and risks (Meier et al. 2010).

Successfully delivering these benefits requires tackling the following PSM characteristics identified from the literature, which directly impact the (I)PSS design and development:

1. Mutually determined and complex integration of product, service, and infrastructure shares;
2. Design scope is enlarged to the complete value chain, and the whole lifecycle;
3. Broader services perspective to satisfy customer value;
4. Customers and suppliers co-creation role is determinant during the design;
5. Support sensing and responding strategies, with self-reinforcing value cycles;
6. Early designed adaptable and flexible architectures; and
7. Design built-in options;

In distinction from physical products, the integrated development of the mutually determined product and service shares is essential for (I)PSS, resulting in the necessity for integrating corresponding product and service design processes (Aurich et al. 2006; Schweitzer and Aurich, 2010). Particularly in the case of IPS2, an exact separation between product and service is no longer feasible, neither during concept development nor during the delivery phase (Meier et al. 2010). As a consequence, the (I)PSS design scope is enlarged to the complete value chain and the whole lifecycle, requiring a holistic design approach integrating economic, environmental, and social considerations (Aurich et al. 2006; Meier et al. 2010; Vijaykumar et al. 2012).

In PSM, the perspective of services is also broader than the traditional way (Vijaykumar et al. 2012). While in the traditional approach, a service is a set of activities which intends to keep products functionally available, in the PSM perspective, a service is a set of activities which intends to satisfy customer value. Thus, the service part in the (I)PSS comprises (Mont, 2002; Mont, 2004): (1) making products available to the customers (marketing, sales-service, sharing, leasing, etc); (2) prolonging product life cycle (maintenance and upgrading); and (3) closing the product material cycle (revalorizing, taking products back, secondary utilisation of usable parts in new products, recycling or safe product disposal). According to Aurich et al. (2006), technical services such as maintenance, retrofitting, refurbishing, or user training can significantly influence the economic and ecologic performance of high quality investment goods, thus providing new and advanced user benefits. These services also support the constant flow of feedback information from the after-sales and end-of-life in a way to keep adapting the (I)PSS and supporting the long-term relationship.

Identifying and developing close collaboration with the main stakeholders in the business relationships is also a key to better serving the customers and creating long term relationships. Indeed, value is defined by and co-created with the customers. Haeckel (1999) points that this is beyond being customers oriented, but requires collaborating with and learning from customers and being adaptive to their individual and dynamic needs, where firms move from practicing a "make-and-sell" strategy to a "sense-and-respond" strategy. This argues for thinking in terms of self-reinforcing "value cycles" rather than linear value chains, where firms are in a process of continual product, service, and value chain development (Day, 2007).

Effective changing and responding, which sustain the long-term relationships, require an easy to change (I)PSS. Changeability means that the offered (I)PSS must be both, at some level, capable of absorbing changes in the environment and user behaviour without the need of modifications, and have a flexible architecture that facilitates the implementation of eventually needed modifications (Richter et al. 2010). Changeability features should be incorporated early in the design process. In order to enable the flexibility in the PSS value proposition, a real options approach and a scenarios method complement each other by defining alternatives to deal with possible future scenarios (Herath and Park, 1999; Perlitz et al. 1999; Richter et al. 2010):

- On one hand, the product core must be optimized concerning the life cycle perspective, and aimed at meeting individual customer demands while at the same time achieving an optimum balance between product realization time, cost, and quality. As a consequence, life cycle oriented product design is frequently combined with customized manufacturing on the basis of the mass customization paradigm (Aurich et al. 2006).
- Technical services, on the other hand, must be provided with respect to the customers' point of view of the product life cycle. Customers should be supported during product purchasing, product usage, and product disposal. The demands concerning these phases are highly personalized due to the multiple possibilities for using a specific product. Consequentially, they cannot be appropriately met by 'off the shelf services' but require individualized and adaptable solutions, which at the same time fulfil common quality standards. According to Aurich et al. (2006), the definition of life cycle oriented service design schemes can support flexible service adaptation according to individual product usage.

3 LEAN PRODUCT DESIGN AND DEVELOPMENT

Lean Product Design and Development (LPDD) is rooted in the lean philosophy, which advocates full commitment to delivering the pulled value (do the right thing), and yet continuously works on eliminating the waste from the PD process (do the thing right). It has been shown to deal well with options to guarantee timely value delivery (Ward et al. 1995; Kennedy, 2003).
The LPDD does not focus on the speedy completion of individual component designs in isolation. Since even the best alternative from the solution space has some intrinsic risk, LPDD applies the SBCE (among other tools and techniques). SBCE is a technique that guarantees the flow, avoids risk through redundancy and robustness, and allows knowledge capture. Through the use of SBCE, the development team does not establish an early system level design, but instead defines sets of possibilities for each subsystem, many of which are carried far into the design process. These sets consider all functional and manufacturing perspectives, building redundancy to risk mitigation while maintaining design flexibility. The final system design is developed through systematically combining and narrowing these sets; alternatives are eliminated based on the growth of knowledge and confidence. The discarded alternatives are themselves considered learning opportunities (Ward, 2007).

3.1 The Value Function Deployment (VFD)

The Value Function Deployment (VFD) is a technique that applies the lean principles based on value creation and waste reduction, and supports the SBCE strategizing and execution. The VFD is composed of two interconnected matrices, the value identification matrix and the waste reduction matrix (Figure 1). The former provides a straightforward visualization of all the value items pulled by the stakeholders, how each value item can be measured during the development, how the value items correlate to each other, and their relative importance for the development. The latter deploys the value items to the conceptual architecture's value delivery functions, calculates their criticality to apply Set-Based Concurrent Engineering - SBCE (rework avoidance sub-matrix), correlates the functions to the teams responsible to implement them (concurrent engineering sub-matrix), and defines the events that will pull this value from the teams (flow definition sub-matrix). Considering that performing SBCE requires more people in the development teams and upfront investment, the rework avoidance sub-matrix determines the most critical product functions or organizational value chain functions that will get more benefit by developing a set of alternatives. For a complete description of the VFD see Pessôa and Trabasso (2017).

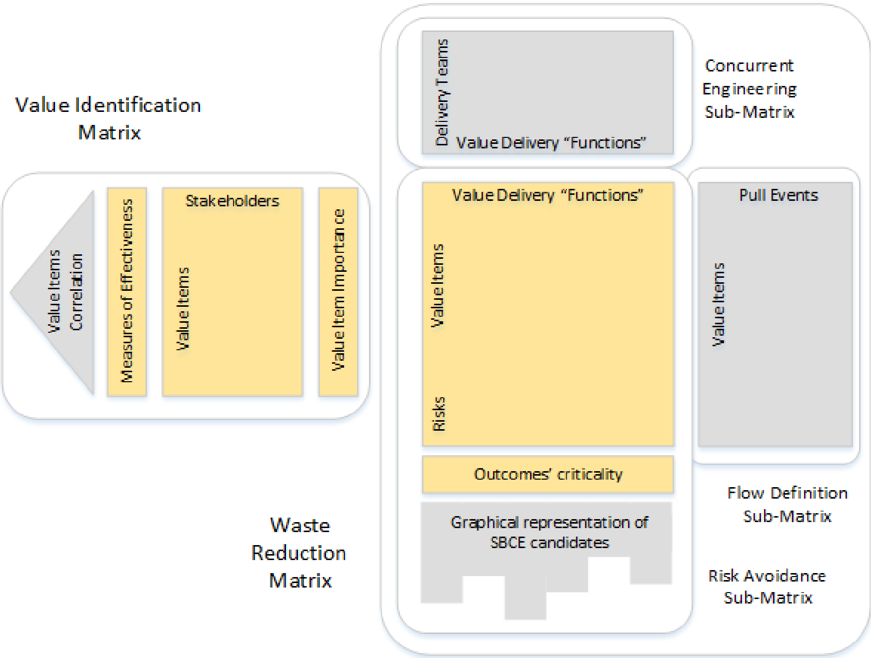


Figure 1. The value function deployment matrices.

We chose VFD because it supports the conceptual architecture definition and fits to the previously identified PSM characteristics (Table 1). This paper's focus is limited to the value identification matrix and the risk avoidance sub-matrix (highlighted in Figure 2).

Table 1. PSM characteristics and the VFD capacities.

PSM characteristics	VFD capacity
1. Mutually determined and complex integration of product, service and infrastructure shares. 2. Complete value chain, and the whole lifecycle design. 3. Broader services perspective.	The VFD is value-based, therefore it does not bound the designed solution to any format, therefore being compatible to designing (I)PSS. Another important aspect is that the decision pro or against an (I)PSS is not predetermined, but emerges from the design process. Furthermore, SBCE alternatives can consider that the same value item might be delivered by different combinations of product and service modules (i.e. in one alternative a particular value item is delivered as part of a product module, while in another alternative it is delivered by a service module).
4. Customers and suppliers co-creation role during the design.	During the VFD filling, not only the customer is required to collaborate actively, but all the identified stakeholders.
5. Support sensing and responding strategies, with self-reinforcing value cycles. 6. Early designed adaptable and flexible architectures. 7. Design built-in options.	The VFD considers the possibility of several alternatives during the design, by using SBCE. These alternatives are then reduced and/or combined during the pull events. Considering estimated value through the lifecycle, extending alternatives and defining pull events beyond the delivery are aspect to be considered during the VFD adaptation.

4 A METHOD TO SUPPORT DESIGNING CHANGEABLE (I)PSS

A lifecycle-long adaptable and flexible (I)PSS requires designed-in options, in a way these options can be executed in the aftersales. Besides maximizing the expected revenue, the designed architecture should reduce environmental impact and support cycle economy. This approach requires extending the SBCE application beyond releasing the design to production. Figure 3 shows this extended SBCE, where besides the options that are considered during the design of the first version of the (I)PSS, other options are kept (doted arrows) for future execution during the remaining lifecycle, in accordance to the feedback received from the customers and from the market (stars).

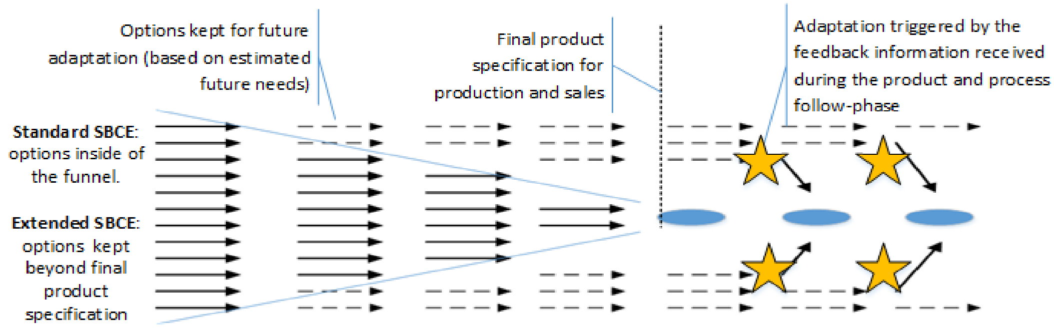


Figure 3. Extended SBCE.

In order to support the SBCE, the original VFD uses only the "importance attribute" to rate the value pulled by the stakeholders (Figure 2). A particular value delivery function is considered critical to the development success if it supports delivering more value and has higher associated risk. This rationale is useful to perform the traditional SBCE until releasing the product design for production. Designing (I)PSS and keeping and managing options after the (I)PSS sales require further information: How likely the customer behaviour or the technology might change and thus require changes in the (I)PSS? Is the customer ready to accept the (I)PSS as we propose it? Is the technology mature enough/does the company master the technology that better deliver the pulled value? How soon does the customer expect to have the pulled value delivered? Indeed, Pessôa and Becker (2017) list several aspects to be taken into account when shifting to the PSM business model and that can affect the (I)PSS design and development.

In order to address these analyses, the proposed method defines a VFD filling sequence based on the AEIOU variables. These variables support the modularization during the conceptual architecture design, where: (A) acceptance: favourable reception or approval by the customers of an alternative for providing a particular function; (E) ephemerality: the likelihood of change due to changes in the customer behaviour (E-beh) and/or technology (E-tec); (I) importance: the importance given to each value item by each stakeholder; (O) operationality: how easy it is for the company to produce a particular alternative (i.e. the related technology might not be dominated by the company, thus imposing additional risks); and (U) urgency: how soon the customer expects a certain value item to be delivered. Table 2 presents how each variable should be interpreted.

Table 2. Using the AEIOU variables.

Code	Description
A	Alternatives with less acceptance risk by the customers are preferred, and indicates choosing the right (I)PSS type. It can also indicate the need of educating the customer about the benefits of the proposed alternative before adopting a more radical (I)PSS type.
E-beh	Ephemeral customer needs should be addressed to services and segregated into modules that are easier to change and with less coupling to the remaining of the system (i.e. software).
E-tec	Ephemeral technologies should be addressed to services and segregated into modules that are easier to change and with less coupling to the remaining of the system
I	Value items with higher importance must be preferred whenever there is conflict with other value item. Lower importance value items might not be incorporated into the PSS
O	The easier to become operational the less risky is the alternative. An alternative with higher O might be preferable for guaranteeing the timely release of the first (I)PSS version, while lower O but better alternatives could be pursued for later (I)PSS upgrades.
U	More urgent value items should be delivered in the earlier version of the (I)PSS.

The proposed method to support designing changeable (I)PSS is composed of the following VFD filling steps (Figure 4), which are a variation from the traditional VFD filling procedure presented in Pessôa and Trabasso (2017):

1. List all the relevant external stakeholders (i.e. user, customer, shareholder/sponsor, etc.) and internal stakeholders (i.e. suppliers, design and development team, production, development partners etc.) related to the (I)PSS lifecycle's phases.
2. Identify the value pulled by these stakeholders. Since the value initially understood from the

stakeholders might not be clear, the development team must work on clarifying that into unambiguous value items.

3. Relate the identified value items and the stakeholders using the variables I, U, and (E-beh) ratings (the traditional VFD only uses I). Each stakeholder might rank each variable as high, medium, low, or no (h, m, l, -). Although U, and (E-beh) do not impact the criticality, they affect design decisions. Items with lower U might be considered to have its delivery postponed to further (I)PSS upgrades/updates. Items with higher E-beh should be implemented in less coupled modules, which are easier to remove or change in the future, In the case of low U and high E-beh besides postponing, careful value item monitoring is required, once it might quickly become obsolete.
4. Perform a functional analysis for defining the essential functions and the level at which the problem is to be addressed. The essential functions are those that the product, system, or service to be designed must satisfy, no matter what physical components, service processes, or business model might be used.
5. Link the value items to the functions according to the traditional VFD, which shows the rate a particular function contributes to deliver each value item (h-high, m-medium, l-low).
6. Identify possible implementation alternatives to perform the functions (using, for instance, a morphological chart), and grade them according to the variables A, E (E-tec) and O. These variables define different risk dimensions related to the function's alternatives. A particular alternative, for instance, might present the best value delivery capacity, but might bring more risk to develop or might require educating the customer. As a consequence from these ratings, the development team needs to balance the expected change before obsolescence (related to E-tec) and expected revenue, the time needed to educate the customer (related to A), and expected costs, and the time needed to master a technology or process (related to O) and expected revenue.
7. As in the original VFD, the functions that embed more value and are more risky are considered critical and therefore better candidates for SBCE.

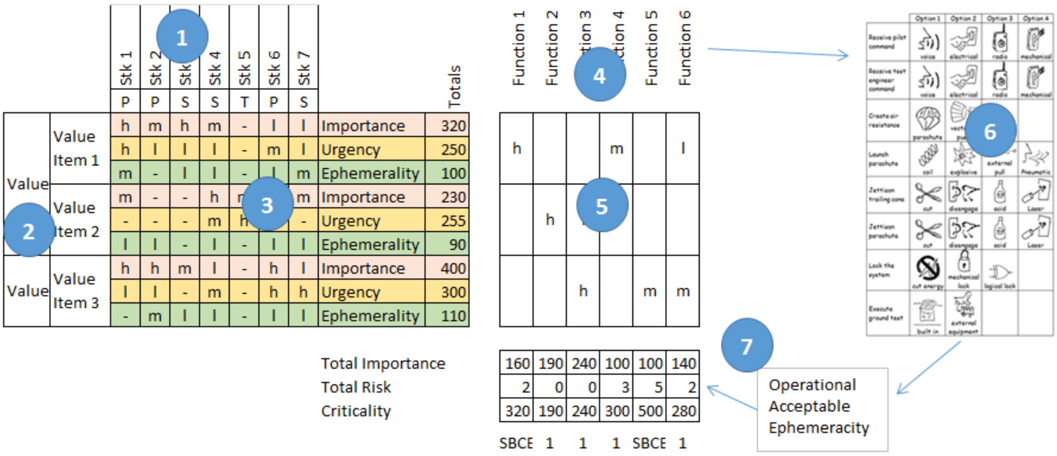


Figure 4. Filling the modified VFD.

5 EXOS-K PROJECT

The Exos-K is a fictional case that illustrates the paper's proposed method application. It's main goal is delivering an immobilization product for a forearm fracture treatment while improving the patient comfort and quality of life, and allowing the easy inspection of the affected area by the doctors/nurses. Note that the term "product" here is being used in a relaxed way since it is still flexible to accommodate different possible solutions and can refer to the orthopaedic cast, the equipment to make the cast, an IPSS, etc. To understand the value the product should deliver, the following stakeholders related to the product lifecycle were taken into account:

- Patient: in this group the needs from both the injured person and/or the person who pays for the treatment were considered. Even though the hospital/clinic is the company's direct customer, the patient is the final customer and who pulls the complete value chain.
- Doctor: the doctors pay a key role, particularly in terms of innovative products, as they prescribe the possible treatments and must feel confident about the company's product efficacy.

- Hospital administration: these are the direct customers and the product must please the final customer, the doctors, and fit its business model and logistics.
- Nurse/Operator: these are the professional who manipulate/operate the product in order to both perform the immobilizations and remove the product from the healed forearms.
- Radiologist: this group includes all the imaging professionals; imaging the forearm might be necessary to confirm the healing of the fractured bone before removing the product.

Figure 5 shows the filled VFD with the identified stakeholders (1) and the value items they pulled (2) and which are related to the forearm immobilization cast itself and to the systems necessary to producing the cast. The value items were, then, linked to each stakeholder according to their perception of the variables I, U, and E(-beh) by using the same rationale (3). Considering the variable I, for instance, each considered stakeholder has particular needs, thus rating differently the value item's importance. Also, each particular stakeholder has different relevance. The value items prioritization takes into account the combination of these ratings. Therefore, the importance of the value item VIi is obtained as in Equation (1):

$$IMP_{VIi} = \sum_{j=1}^{k} SR_j * IS_j \quad (1)$$

where:

- SRj = is the relevance of the jth stakeholder, ranges from 9, 3, and 1, if the stakeholder was considered as primary, secondary or tertiary, respectively:
- ISj = is the interest from the jth stakeholder on the value item VIi, ranging from 9, 3, 1, and 0, on the case of high, medium, low, and not important for that particular stakeholder, respectively:

When rating the interest to stakeholder consider:

- High: the item falls into a must have category.
- Medium: the item falls into a nice to have category.
- Low: the item relates to the stakeholder (he can perceive it), though he does not care about it at first.
- None: the item does not have any relation to the particular stakeholder.

From the results the following analysis can be made:

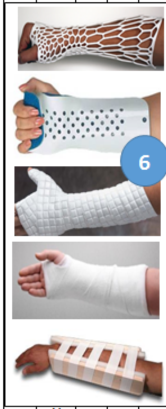
1. Value item 7.3 ephemerality requires an exchangeable module to support changeability.
2. Items such as 4.6, 3.1 and 3.2 are less urgent and should be postponed to later versions of the product. These items could be implemented in an add-on module or segregated into a module that is easier to future. Any planned future add-on module option is managed as a possible option in the extended SBCE (Figure 3).
3. Item 3.2, which also have high ephemerality, should be preferably implemented as a service, being, therefore, easier to update/upgrade.
4. Item 1.6 has potential conflict with items 4.3 and 4.5. In this case item 1.6 prevails, once it is more important.

Seven main functions were identified through functional analysis (4). These functions comprise the complete immobilization cast lifecycle, from designing the cast for a particular patient (note that the design can be a very intuitive task in the case of plaster cast or much more elaborated in the case of 3D printed cast) to its removal and disposal. A maintain function was also considered for keeping the working environment and equipment. These functions were then linked to the value items (5).

Considering the most critical product functions, several casting solutions are possible (6), each of them delivering different value results and imposing different risks (7). Each solution alternative might be more or less difficult to turn operational, be susceptible to technical obsolescence, and/or be less acceptable by the customers. The value items related to the immobilization system were analysed according to the patient (cast) and the hospital/clinic (system) point of views.

Taking the 3D oriented cast alternative, although it got higher acceptability from the customers, it might require additional services to guarantee complete value delivery to the hospital. An (I)PSS offer might bring, for instance, lower cost of services and/or lower cost of maintenance. Value item 5.2 could be also achieved by selling the solution/system use instead of the solution itself. As a consequence different alternatives of "service modules" might be required, since the right immobilization solution might vary for different segments, health systems, and end users.

Group	No.	Requirement	Cast	System	Patient (Pri) I	U	E	Doctor (Pri) I	U	E	Hospital ADM (Pri) I	U	E	Nurse/ Operator (Sec) I	U	E	Radiologist (Sec) I	U	E	I	U	E	Design	Produce	Install	Immobilize	Remove	Discard	Maintain
1. Provide the righ healing tratment	1.1	Ensure immobilization	◆		H	H		H	H		H	H		H	H					270	54	0	M			H			
	1.2	Allow bood circulation (no necrosis)	◆		H	H		H	H		H	H		H	H					270	54	0			M	H			
	1.3	Mechanical protection	◆		H	H		H	H		H	H								243	49	0		H	M	M			
	1.4	X-Ray and MRI transparent	◆					H	H	L	H	H	L				H	H	L	189	38	4		H					
	1.5	Allows skin analysis (necrosis,allergy, etc.)	◆					H	H	L	M	M	L							108	22	4	H						
	1.6	**Child-lock (to avoid self-removal)**	◆		H	H		H	H		M	L								189	34	0	M		M		H		
2. Comfortable	2.1	Lightweight	◆		H	H		M	L		M	L								135	20	0	M	H					
	2.2	Thin	◆		H	H		M	L		M	L					L	M	L	138	22	1	M	H					
	2.3	Smooth touch to the skin	◆		H	H		M	L		M	L								135	20	0	H	M	L				
	2.4	Anti-allergic	◆		H	H		H	H		H	H								243	49	0	L	H		L			
	2.5	Keep the body at a comfortable temperature	◆		H	M		L	M		L	L								99	13	0							
	2.6	**Do not smell badly**	◆		M	L		L	L		L	L								45	5,4	0							
3. Aesthetics	**3.1**	**Discrete / less obvious**	◆		M	L	M	L	L	L										36	3,6	7							
	3.2	**Customizable (colours, shape, ornaments, etc.)**	◆		M	M	H													27	5,4	16							
4. Easy cast operation	4.1	Washable product	◆		H	M	L													81	5,4	2							
	4.2	Easy to dry-up	◆		H	M	L							H	H	L				108	11	2							
	4.3	**Easy to install**	◆		M	M	L							H	H	L				54	11	2							
	4.4	Easy to clean (body)	◆		M	M	L							H	H	L				54	11	2							
	4.5	**Easy to remove**	◆		M	M	L							H	H	L				54	11	2							
5. Provide a business case for all parties	5.1	Affordable cast	◆		H	H	L				H	H								162	32	2							
	5.2	Affordable casting solution		◆							H	H								81	16	0							
	5.3	Use available technology		◆							H	H	L	M	M	L				90	18	2							
	5.4	Low cost services		◆							H	H								81	16	0							
	5.5	Low cost materials		◆							H	H								81	16	0							
	5.6	Low cost maintenance		◆							H	H								81	16	0							
6. Environmentally Friendly	6.1	Recyclable	◆		M	M	L				H	H	L							108	22	4							
	6.2	Easy to clean / no waste generation.		◆							H	H	L							81	16	2							
7. Easy Logistics	7.1	Material shelf-life		◆							H	H	L							81	16	2							
	7.2	Raw material availability		◆							H	H								81	16	0		H					
	7.3	**Compatibility to existing legacy equipment**		◆							H	H	M				H	H	M	162	32	11			L		L		L
																							708	1651	267	524	190	146	80



	Cast	Syst
A	H	L
E	M	H
O	H	L
A	L	M
E	L	L
O	M	H
A	M	M
E	M	M
O	H	M
A	M	H
E	L	L
O	H	H
A	L	L
E	L	L
O	M	L

Figure 5. EXOS-K project example.

6 FINAL REMARKS

The method presented in this work provides a systematic way to address early modularization decisions faced during changeable (I)PSS design. Particularly, seven PSM characteristics that affect the (I)PSS design were identified and considered during the method definition. As results this paper presents two contributions:

1. Defining a method for the conceptual design phase of changeable (I)PSS, which are based on the here proposed AEIOU variables (acceptance, ephemerality, importance, operational, and urgency).
2. Presenting a Value Function Deployment (VFD) adaptation that supports the practical application of the method and that extends the use of Set-Based Concurrent Engineering (SBCE) beyond the design release to manufacturing and sales.

The defined method supports deciding: (1) which value pulled by the stakeholders should be addressed to the (I)PSS' physical and/or service shares; (2) in which (I)PSS release each pulled value should be delivered; and (3) how to approach the defined product and service shares alternatives.

By studying the Exos-K example of a possible application of the method, useful insight was gained about the implications of modularization decisions into the (I)PSS changeability. However, if the concepts presented in this paper are to achieve its full potential, more work must be done. Additional studies are required to more fully capture the relationship among the variables, the method, and the actual decisions in real projects.

The type of analysis illustrated here may outline the study of other issues related to the coupling of (I)PSS development particularities and its impact on modularization decisions. A challenge for future research is to extend this model to explore the consequences of acting on these specific variables (i.e. applying the lean principles and practices) and the expected implications on the (I)PSS modularization. This study uses an example with connections defined by the authors' discretion. Another future challenge is to capture an empirically grounded decision making from (I)PSS experts and practitioners, in order to both validate a general model as well as assess the VFD adaptation usability.

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