Innovative design method for a valuable product-service system: concretizing multi-stakeholder requirements

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Abstract

As one of the differentiation strategies towards the strained global competitive market, the concept of Product-Service System (PSS) is emerging. Product-Service System (PSS) is a concept of service system, which is represented with functional deliveries from a provider to a receiver in which products and/or services are the devices for transmitting the functions. In general, actual PSSs in business are forming a complicated consortium in which various multi-stakeholders are involved. The success of product/service design relies in great measure upon the accurate understanding and satisfying of multi-stakeholder requirements, but none of the available PSS design methodologies touch upon how to incorporate and realize the multi-stakeholder requirements in PSS design. This paper intends to fill in this research gap by proposing a practical method to capture and analyze the dependency of multi-stakeholder requirements to enable the development of valuable PSS design which satisfies these requirements. The rationality of PSS design is measured using Life Cycle Costing (LCC) in order to ensure the realization of multi-stakeholder requirements persist to lay within the company's capabilities. The proposed method was found effective in a case study application to concretize multi-stakeholder requirements in design embodiment of PSS offering. The complex requirements from multiple stakeholders were structured and reflected in the PSS design structure.

Keywords: Multi-stakeholder requirements, Product-service system, Design, Life cycle costing, Multi-domain matrix

1. Introduction

The rapid growth of manufacturing industries, particularly in developing countries where productions are significantly cost efficient, have forced manufacturing companies in developed countries to seek other competitive advantages. Selling the product with high quality, functionality, and reliability is no longer a decisive factor of company success. As one of the differentiation strategies towards the strained global competitive market, the concept of Product-Service System (PSS) is emerging (Baines et al., 2007; Mont, 2002; Tukker and Tischner, 2006). PSS is a business model which focuses on the provision of integrated products and services, designed to fulfill customer's needs in an economically, socially, and environmentally sustainable manner (Annarelli et al, 2016). Under this concept, manufacturing companies add services not as an "add-on" of their physical products, but more as a bundle of the total offering. The inclusion of services enables a PSS company to deliver high added value through co-creation with multi-stakeholder (Sakao and Lindahl, 2015). The transactional exchange between company and customer is transformed into a long-term relationship focused on integrated product-service offering which involves intermediate agents, such as the third party service provider. Hence, the term of multi-stakeholder is used to stress out the participation of multiple parties in the system, not merely company and customer.

There have been many methods, techniques, and tools proposed for PSS development or design to support the transformation towards PSS. Qu et al. (2016) reported 148 articles related to PSS design methodologies have been published in more than 10 prominent journals over the past 16 years. In spite of its considerable quantity, there are only eight well-represented PSS design methodologies in the literature which have intensively reviewed by Vasantha et al.

(2012). Furthermore, PSS design is argued has achieved its research maturity (Qu et al., 2016), however some issues remain unsolved in this research area which call upon further development. One of those important issues is the concretization of multi-stakeholder requirements involved in PSS (Song, 2017; Beuren et al., 2013; Vasantha et al., 2012). Whereas value co-creation with multi-stakeholder is the foremost notion of PSS concept and the key of a new source of competitiveness for the company.

As a customized integration of products and services co-created with multi-stakeholder involvement, PSS requirements are strenuous to be captured, analyzed, and forecasted (Song, 2017). While the precise identification, rational analysis and effective realization of the requirement are precarious processes to achieve satisfied PSS design solution. The success of product/service design relies in great measure upon the accurate understanding and satisfying of multi-stakeholder requirements (Berenbach et al., 2009). The previous studies have emphasized the importance of correctly comprehend and fulfill the PSS design's requirement (foremost from a customer perspective), but none of these methodologies touch upon how to incorporate and realize the multi-stakeholder requirements in PSS design. Moreover, conflicts potentially arise among stakeholder's requirements considering each stakeholder has a distinct value proposition which may contradict among each other (Brujen & Herder, 2009; Song, 2017). It makes the identification and realization of multi-stakeholder requirements more important yet challenging.

This paper intends to fill in this research gap by proposing a practical method to capture and analyze the dependency of multi-stakeholder requirements to enable the development of valuable PSS design which satisfies these requirements. The rationality of PSS design is measured using Life Cycle Costing (LCC) in order to ensure the realization of multi-stakeholder requirements persist to lay within the company's capabilities. The effectiveness of the proposed method was validated by a case study application in an actual PSS business model which delivers functions of purifying polluted water. The remainder of this paper is structured as follows. Section 2 presents the theoretical framework of the proposed method. Section 3 proposes the design method and the tool, while Section 4 provides a case study application of the proposed method and tool. Section 5 discusses the result of the case study application, and finally, Section 5 concludes the paper and present the future work.

2. The theoretical framework for innovative PSS design

2.1 PSS design methodologies

Since its origins, PSS has attracted the interest of researchers in the design field. The high number of contributions comprises as a series of methods, guidelines and tool reflects the great concern to the topic (Annarelli et al, 2016). Using the life cycle perspective of PSS engineering, PSS design represents the Beginning of Life (BOL) of the system which composed of requirement management, concept generation and evaluation, design embodiment and evaluation, detailed design, test and final design (Cavalieri and Pezzotta, 2012). The early stage of PSS design, namely requirement management and concept generation, is the pivotal process as it gives the foundation to the subsequent design stages.

In requirement management, Aurich et al. (2006) emphasized the importance of customer demand identification to capture PSS design requirements. Sakao and Shimomura (2007) identified stakeholders and generated their requirements using the Flow Model. Berkovich et al. (2014) proposed a requirements data model for PSS development named RDMod. The RDMod enables the description of different types of requirements and relationships among them, which facilitates structuring requirements and finding potential conflicts. Whilst Song et al. (2014) have incorporated the value of stakeholders' requirement into their proposed PSS innovation management framework.

Design concept generation and embodiment are built upon the identified requirement. This fact underlines the necessity to accurately capture the requirements. Incomplete or incorrect requirements have a negative consequence on the success of product/service (Berenbach et al. 2009). Aurich et al. (2006) used service modeling and realization planning to realize customer requirements. While the view model was used to generate a realization structure of functions to satisfy a Receiver's State Parameter (RSP) (Sakao and Shimomura, 2007). Furthermore, Shimomura et al. (2009) extended and combined service blueprint and the view model as a means to mutually link service content (view model) and service activity (service blueprint) to design product and service activity collaboratively and concurrently to escalate the customer's value.

Many researchers have pointed out the importance of stakeholders' requirements and realization in PSS design, yet none of the previous research has provided a practical method of how to actualize multi-stakeholder requirements into design structure concretely. It contradicts with the main premise of value co-creation in PSS, where the value is not

delivered by the company to the customer, but rather co-created with the active participation of customer and other involved stakeholders (Green, Davies and Ng, 2017). This paper takes advantage of the research shortcoming by capturing and managing the multi-stakeholder requirements concretized in the design structure. Multi-Domain Matrix (MDM) is used as a foundation to identify the dependency of multi-stakeholder requirements towards design concept generation and embodiment in a manageable fashion.

2.2 Motivation to utilize MDM as a reference framework

The Design Structure Matrix (DSM) is a straightforward and visual representation of a system (sometimes refers as a domain) in the form of a simple square matrix. DSM represents each element of a system and the interaction among them. Due to its graphical nature of display format, the underlying benefit of DSM is it presents a great compact, scalable, and readable presentation of the system (Eppinger and Browning, 2012). This modeling technique can be utilized as a means of designing, developing, and managing a complex system (Bartolomei et al., 2012). Because of its ability to present a complex system in a simple form, DSM is commonly used in multiple project management (Danilovic and Browning, 2007).

When a DSM is mapped with another DSM, the representation matrix is called Domain Mapping Matrix (DMM). The DMM reflects the relationship of an element in a domain to another domain. If a DSM captures the internal relations within a domain's elements, DMM captures the relationship with the external domain. While Multi-Domain Matrix (MDM) represents two or more DSMs simultaneously (Eppinger and Browning, 2012). The series of DSM, DMM, and MDM allow the representation of complex system jointly with the important interactions of each element of the system in a simple and elegant fashion (Yassine and Braha, 2003). Considering its properties and capabilities, this approach is appropriate for presenting and structuring the complex of multi-stakeholder requirements.

Some applications of DSM have been found in the design research field due to its capability to facilitate the understanding of dependency among requirements and the realization concept to satisfy the requirements (Sakao et al., 2017; Sawai et al., 2017; Lindemann and Maurer, 2007). Sakao et al. (2017) employed DSM to develop service modules for PSS customization. DSM was used to define interactions between service components in a pair-wise comparison. Sawai et al. (2017) introduced a structuring method that enables a comprehensive understanding of customer need, physical functions, entity structure and correspondence relationships among them, which reflects the diversification of customer needs in the design of an industrial robot. In this method, dependency relationships between the same domain (for example: between customer needs) are presented in DSM, while correspondence relationships between different domain elements (for example dependency between customer needs and physical functions) are represented in DMM. By clustering each domain element of DMM, it is possible to construct a design module in consideration of dependency relationships among customer needs, physical functions, and entities.

Principally Sakao et al. (2017) and Sawai et al. (2017) have a similar intention and research approach but differ in objectives, scope, and elements utilized. Sakao et al. (2017) only utilized DSM to map the interaction of single domain which is service component to develop service modules, while in the research done by Sawai et al. (2017) they used all the series of DSM, DMM, and MDM to map the interaction of customer needs, physical functions, and entity structure. Their objectives are similar in the area of design modularization, yet Sawai et al. (2017) focused on product architecture of industrial robot but Sakao et al. (2017) specifically focuses on the PSS provision.

The research done by Sawai et al. (2017) has given great emphasis to the interaction among stakeholder's requirements, however in this case only a single stakeholder (customer) is considered which is completely different with PSS characteristic. The interaction among customer's needs is utilized as a basis to create the module of an industrial robot. The modularization of product architecture enables the company to provide the customization product which satisfies the customer need in a maintainable and compatible manner.

The relationship between the two elements represented in DSM is assigned using a pair-wise comparison. In Binary DSM, the level of interaction is measured in a scale of 1 or 0. There is no granularity level of interaction. An element has a dependency on another element, or not. In numerical DSM, interaction is presented in ranking with a predefined scale. Another alternative to assign relationship is using composite DSM where the ranking of interaction is combined with more than one dimension to each interaction between two components (Sakao et al., 2017; Eppinger and Browning, 2012). In general, assessing the interaction among elements in DSM is challenging. If the assigned scale is not well justified, it may lead to an ambiguous and inaccurate system representation. To prevent the inaccurate degree of

interaction assignment, this paper utilizes IDEF0 as a modeling technique to represent interaction among requirements in a more systematic way.

The IDEF0 is a well-known function modeling method designed to model activity, action, and decision of a system in structured graphical form (Kim and Jang, 2002). In the role of an analytical tool, IDEF0 enables the identification of function performed and elements necessary to perform it. Hence, IDEF0 model is frequently used in the initial step in system development. The application of the IDEF0 model in this paper has two major goals. First, the basic IDEF0 syntax assists the identification of function and entity needed to realize the requirement. The original notation of control, function, and mechanism represents the requirement, function, and entity in PSS design structure, respectively. A function is a realization method to provide value and satisfy the requirement, while an entity is defined as physical component(s) and/or service activity(s) which realizes a function (Sakao and Shimomura, 2007). In addition, input and output in the IDEF0 syntax represent a sensible sequence of predecessor and successor functions. This representation in another way reflects the relationship among requirements. Considering this fact, utilizing IDEF0 helps to clarify the relationship among requirement, function and entity in a more structured way. Thus, the modeling of requirement using IDEF0 provides the input information for the development of MDM.

2.3 LCC applications in PSS context

Cost is certainly an essential consideration for manufacturing companies to direct and manage their business. Many cost-based decision applications are a prevalent sight in manufacturing companies' business process, e.g. decision related to pricing policy or company main performance indicator. Apparently, cost persists as an insightful source for decision-makers to evaluate, control and develop the business to be more effective and efficient. In consequence, it is very reasonable if a manufacturing company have a big interest to clearly understand the benefit promised by the PSS business model in terms of cost saving as well as profit earning. There has been considerable research done to endeavor this mission. LCC is one of the most widely applied approaches in PSS research topic to evaluate the benefit of PSS in the financial perspective.

Life cycle cost or life cycle costing is a prominent concept in the decision-making process especially in the evaluation of new investment (generally related to the asset acquisition) since the mid-1970s. In the traditional manufacturing company, LCC analysis focuses on the optimization value of money in the ownership of physical assets by considering all the related costs occurred during the product life cycle. In terms of the decision-making process, this concept drives to the long-term outlook or full lifecycle phase of an investment instead of only striving to save money in the short term by acquiring an asset with lower initial purchasing cost (Swarr et al., 2011; Rebitzer and Hunkeler, 2003).

By delivering a PSS offering, the company is no longer only dealing with the cost drivers to produce the physical product, but also has the responsibility to maintain the successful delivery of function throughout the life cycle of the product by performing a necessary service activity. Many researchers have believed and discussed the usefulness of LCC and have implemented it in industrial case studies within PSS context (Sakao and Lindal, 2015; Lindahl et al., 2014; Settanni et al., 2014; Datta and Roy, 2010; Erkoyuncu et al., 2009; Aurich et al., 2006). In particular, Sakao and Lindahl (2015) have proposed a method to improve PSS offering based on LCC. The proposed method allows the evaluation and improvement of PSS design based on a cost perspective. Considering its predominant benefit, it makes LCC analysis a fitting concept to support the realization of multi-stakeholder requirements remains beneficial in terms of an economic parameter. This paper intends to exploit the advantage of LCC as a cost evaluation to support the concretization of PSS requirements. This paper enhances the previous proposal of Sakao and Lindahl (2015) to be combined with the inclusion of the multi-stakeholder requirement in the development of a valuable PSS design.

3. Innovative design method for valuable PSS design

3.1 Overview of the method

The proposed method is built upon two well-established frameworks in the design field which are further enhanced to answer the research objective. The combination of dependency analysis using MDM to concretize multi-stakeholder requirements in conjunction with life-cycle costing to improve design structure based on cost perspective is expected to facilitate PSS company to design a valuable PSS. The word "valuable" represents two substantial premises of this paper. The realization of multi-stakeholder requirements enables to escalate the value proposed to PSS stakeholders, since the

scope of stakeholder is expanded, not merely customer but also other important related parties. The consideration of multi-stakeholder requirements in the early stage of design is consistent with the fundamental notion of PSS concept where a company does not deliver value but value is co-created with multiple stakeholders. Hence, multi-stakeholder requirements are indisputably important to be realized. The second premise is; the valuable design also implies that the realization of the complex requirement is managed within the company's capabilities which is reflected in the total cost of design structure. The proposed method affords the opportunity to improve inefficient or unfeasible design structure based on a cost perspective. Eventually, those two premises make the proposed method innovative.

The proposed method is composed of 3 main sequence steps as shown in Fig. 1. Step 1 aims to identify multi-stakeholder requirements, analyze the dependency among them, and finally provide a cluster of requirements and the associated functions and entities, namely an initial design structure. In Step 2, the cost of the initial design structure, which is composed in Step 1, is calculated using LCC. Finally, design improvement is introduced in Step 3 based on the cost distribution of the initial design structure by taking advantage of the exchangeability of entities.

The uniqueness of the proposed method particularly lies in Step 1, where multi-stakeholder requirements are analyzed and incorporated in the overall design structure. Dependency analysis among a cluster of requirements, function and entities simplifies the process of generating design concept while maintaining the effort to satisfy the complex of multi-stakeholder requirements. The vague relationship assignment for an element within the domain of requirement, function, and entity is resolved by the adoption of IDEF0. While the adoption of LCC in the proposed method enables to ensure the design structure is financially reasonable. Each step of the proposed method is further explained in sub-section 3.2 – 3.4.

Fig. 1 The proposed method - innovative design method for valuable PSS offering.

Fig. 2 Detailed procedure of Step 1.

3.2 Step 1 – clustering PSS design structure

Step 1 is translated into detailed sequence steps denoted in Fig. 2. The process is started by data collection (Step 1.1). A semi-structured interview is done with the company's representative to collect the valuable information related to the PSS ecosystem, involved stakeholders and their requirements. Besides the information, other relevant data are expected to be obtained, such as design engineering drawing of current product architecture as well as cost information of each physical component and service activity. Cost information can be derived from the financial or costing database of the company. For example, it is feasible to understand the related cost of service activities from service partner based on historical data.

Following this step, the flow model proposed by Arai and Shimomura (2004) is used to appropriately map the related stakeholders of the system (Step 1.2) based on the data collection step. This model allows the identification of involved stakeholders in the value chain and how they relate to each other. Generally, stakeholders of a PSS company include but are not limited to the company itself, customer, intermediate agents, service partners or part suppliers. The flow model merely structures the involved stakeholders, yet it is unable to define and manage the realization of the requirements. Hence, the following procedure is undertaken to define and manage the realization of the multi-stakeholder requirements.

After understanding the involved stakeholders and their requirements, Step 1.3 identifies functions and entities of these requirements. The basic notion of the requirement-function-entity relation in view model (Arai and Shimomura,

2004) is used to endeavor the realization of each requirement. However, the original view model does not provide clear and structured means to determine function and entity of a requirement, thus the function modeling of IDEF0 is utilized to identify the related function and entity of each requirement. An identified requirement is considered as a “control” in IDEF0 building block since it serves as a form of input which directs the activity of the process. “The activity of the process” itself represents a function that satisfies the requirement. While “mechanism” as a resource or tool which is required to complete the process reflects an entity. As in IDEF0 where a mechanism can be people with a specific skill, the identified entity is possibly a physical component as well as a service activity. Fig. 3 shows the logic to identify the function and entity of a requirement based on the function modeling of IDEF0.

Fig. 3 The logic to identify function and entity from a requirement using IDEF0 modeling technique and input extraction for MDM construction.

Finally, Step 1.4 is MDM construction. MDM is pivotal to represent the dependency among elements which leads to the clustering of requirement, function and entity. The clustering affords the PSS company systematically comprehends the multi-stakeholder requirements and how to realize them. In MDM construction, a dependency is demonstrated by the binary principle "X" and "blank", where "X" denotes the existence of dependency between two elements. The dependency among elements within the same domain (requirement, function or entity) is represented as DSM, the dependency relationship between different domains is presented as DMM and combination of these matrices composes an MDM. Domain Mapping Logic (DML) proposed by (Maurer, 2007) is utilized to construct the MDM. There are two types of dependency in DML i.e. native dependency and derived dependency. Native indicates the dependency between elements is directly compiled from information acquisition, while derived dependency shows an indirect dependency of two elements as a result of indirectly existing dependency.

By using DML, derived dependency in a DSM is obtainable by the computational scheme of dependency information from other DSM and DMM. Fig. 4 illustrates the logic and data source of MDM construction of this paper. The native dependency occurs in Requirement-Function DMM, Function DSM, Function-Entity DMM and Entity DSM. Unlike the other native dependencies which are identified based on the extraction of IDEF0 model as presented in Fig. 3, the Entity DSM is identified based on information of dependency relation from data collection of existing product architecture and service activities information.

The only derived dependency is the relation among requirements (Requirement DSM) which is unattainable directly from information acquisition. In order to derive the dependency among requirements, the DML Case 4 (Maurer, 2007) is employed. The dependency among requirements is obtainable by combining the information of Requirement-Function DMM and Function DSM. As a generic approach, Requirement_A is linked to Requirement_B because Requirement_A is satisfied by Function_1 which is the input of Function_2 that satisfies Requirement_B. Concretely, the matrix of Requirement Dependency can be obtained by simple matrix calculation using Eq. (1) and Eq. (2) as follows.

$$X = G \cdot Y \cdot G^T \quad (1)$$

$$Y = G^T \cdot X \cdot G \quad (2)$$

X is the matrix of Requirement Dependency, Y is the matrix of Function Dependency, G is a matrix of Requirement-Function Dependency and G^T is transpose matrix of Requirement-Function Dependency. This process directs to the

construction of an initial module of PSS design structure. Cambridge Advanced Modeller (DSMMatrix), software-based support, can be used to increase efficiency in constructing MDM and clustering the requirement, function and entity.

In this paper, the view model (Arai and Shimomura, 2004) and product architecture model (Sawai et al., 2017) are enhanced to better visualize the design structure. Fig. 5 shows the representation of the design structure in the modified view model. The original view model does not consider the dependency among elements within a domain which is denoted as a cluster (red dash square). The dependency of the original view model is a top-down relation which links a requirement to function and function to an entity. While in this study, the multi-stakeholder requirements are not only derived to be function and entity as the realization endeavor but also are further structured by clustering those requirements based on the dependency analysis to be better managed and satisfied.

Fig. 4 The logic and data source of MDM construction of this paper.

The realization of multi-stakeholder requirements potentially brings specific challenge or conflicts, since each stakeholder has a distinct value proposition which probably contradicts other stakeholders' requirement. By consolidating (clustering) those requirements which have a dependency, the realization of multi-stakeholder requirements is controlled so competitive advantage in PSS development can be realized. Furthermore, compared to the original product architecture model (Sawai et al., 2017), the entity in this research is not limited to the physical component, but also can be service activity performed by human resource with dedicated skills.

Fig. 5 Representation of PSS design structure.

3.3 Step 2 – calculating LCC

Based on the cost information of physical components and service activities obtained during the data collection stage, it is possible to calculate the total cost of the initial PSS design structure using LCC. The calculation of LCC is done based on the company's perspective since the inclusion of LCC is in the corridor to evaluate the design concept feasibility in the financial perspective. The output of Step 2 is the LCC cost distribution to realize the design structure. Since cost

is calculated in the smallest unit analysis which is an entity, the cost distribution reflects the total cost to produce physical component and perform a service activity. The cost distribution hereafter is used as a basis to identify the necessary improvement for more valuable and feasible PSS design. Calculating the LCC of design structure becomes more crucial considering the possibility of realizing the complex of multi-stakeholder requirements may lead to the unprofitable PSS offering from the company's perspective. Step 2 attempts to facilitate the intention to achieve a balance between value realization from multi-stakeholder requirements and cost consequences of that action.

3.4 Step 3 – improving PSS design structure

The necessary improvements of the design structure can be identified by analyzing the highest cost contribution of entity clusters to the total cost of the design structure. This idea is derived from the fact that the company can obtain a financial benefit from the cost saving of inefficient PSS design structure. It is important to mention that all physical components and service activities are exchangeable. It means that an entity such as a physical component is replaceable with another type of entity e.g. related service activity, with the same or even more effective and efficient performance to realize the function. Subsequently, alternative design improvement can be built upon the exchangeability characteristic of an entity. An inefficient entity can be replaced with another entity which gives more value but maintains the performance to realize the associated function. The complete procedure of Step 3 is presented in Fig. 6.

Fig. 6 Detailed procedure of Step 3.

An entity cluster with the highest cost contribution to the LCC total cost is set as the target design structure to be improved (Step 3.1). The alternative design improvement is derived from the exchangeability characteristic of the entity. The inefficient entity may be removed or substituted with another entity (physical component/service activity). However, to avoid the LCC sub-optimization (the change in the entity can be beneficial to the company but unfavorable to other stakeholders), improvement alternative should be built upon the consciousness of relationship of the target entity with associated function and requirement. Hence, set a particular module design structure as the scope of analysis is recommended. Then LCC of improved design is calculated. The final design structure is determined based on the most economic design structure without sacrificing requirement realization. Lastly, the final design structure is presented in the modified view model.

4. Empirical findings from a case study application

The proposed method was applied to a PSS case study in the industry of water purification equipment. The company is a Japanese company which provides a solution related to water purification to the national and international market. The proposed method was implemented in one of the company's PSS projects with the international customer, namely an integrated solution to water bloom in a closed water area. The main feature of this solution is the water purification equipment which generates water flows in the bottom of the water with poor oxygen. The company has high intention to fulfill all stakeholders' requirements to provide high value and maintain a good relationship, however, the company neglects the balance portion between the requirements' features and the resulted costs. During this case study application, the attention was paid to the balance of multi-stakeholder requirements realization and associated LCC, for more valuable

PSS design by carefully manage the multi-stakeholder requirements into design structure. However, due to the space limitations in this journal paper, the presented case study only focuses on the implementation of Step 1 as the main uniqueness and contribution of the proposed method.

Fig. 7 Flow model of the case study.

Based on the data collection stage, five main stakeholders are identified including the interrelationship among them (Fig. 7). There were 23 requirements obtained during the data collection from the aforementioned stakeholders. The requirements were modeled using IDEF0 modeling technique to identify related functions and entities to realize the requirements. Fig. 8 presents an example of constructed IDEF0 of the case study. From this step, 28 functions and 26 entities were identified to concretize the multi-stakeholder requirements.

Fig. 8 The example of constructed IDEF0 of case study.

Fig. 10 The identified design module of RC4.

The constructed IDEF0 model then was extracted to compose an MDM by utilizing the logic shown in Fig. 3 and Fig. 4. While Eq. (1) and Eq. (2) were used to obtain the Requirement DSM hence the complete MDM could be constructed. The Cambridge Advanced Modeller (DSMMatrix) was used to increase efficiency in constructing MDM as well as composting cluster. Fig. 9 presents the partially constructed MDM and cluster development. Based on this clustering result, the complex of multi-stakeholder requirements is structured systematically to be 4 Requirement Clusters (RC) with 9 Function Clusters (FC) and 8 Entity Clusters (EC) to satisfy the requirements. To give an illustration of how to infer the result of the clustering process, Fig. 10 presents an identified design module from Requirement Cluster 4 (RC4): Benefit of the equipment introduction which consists of R20, R21, R22 and R23. The RC4 can be realized by FC3, FC4 and FC5. While to realize these functions, the necessary entity clusters (EC) are EC2, EC3, EC4, EC5, EC6, EC7 and EC8.

Based on this clustering result, the life-cycle cost calculation was performed using the cost database from the data collection stage. In this case study, the provider/company's perspective was used to give a clear cost distribution. The LCC calculation was based on the cost of entities as the smallest unit analysis as well as the cost drivers. The biggest

cost distribution was the potential target to identify design improvement. The sequence steps of the proposed method were found effective to design a valuable PSS. The realization and concretization of multi-stakeholder requirements led to the escalation of PSS design structure to be more valuable for the multi-stakeholder. Furthermore, the proposed method also facilitated the improvement of the design structure based on the perspective of financial (LCC).

MDM		Requirement																Function								Entity											
		R4	R3	R5	R1	R2	R6	R14	R16	R13	R11	R12	R20	R23	R21	R22	F22	F14	F15	F19	F17	F18	F21	F16	F20	E25	E26	E17	E21	E23	E24	E22	E20	E18	E19		
Requirement	R4	Operating cost reduction		x	x	x	x		x	x	x	x	x	x	x	x	x		x	x					x												
	R3	Adoption of reliable equipment		x		x	x	x		x	x	x	x	x	x	x	x	x	x																		
	R5	Design cost reduction																																			
	R1	Sales cost reduction		x	x	x	x																														
	R2	Grasp customers' needs		x	x	x	x																														
	R6	Maintenance cost reduction		x	x	x	x																														
	R14	Selection of cheap equipment			x																																
	R16	Achieving water quality standards				x																															
	R13	Using familiar parts			x	x																															
	R11	Using Korean parts			x	x																															
	R12	Using cheaper parts			x	x		x																													
	R20	Unwilling to get in the water							x																												
R23	Making the river landscape better							x																													
R21	Reduction of malodors								x																												
R22	Making the landscape natural									x																											
Function	F22	Maintenance replacement																																			
	F14	Automatic stop of pump																																			
	F15	Pump control																																			
	F19	DO improvement																																			
	F17	Water flow path optimization																																			
	F18	Water circulation																																			
	F21	Ultrasonic irradiation																																			
	F16	Control of ultrasonic generator																																			
	F20	Generation of ultrasonic																																			
Entity	E25	Suction pipe																																			
	E26	Suction cover																																			
	E17	Driving water / air pump																																			
	E21	Sunction pipe																																			
	E23	Fall water prevention chamber																																			
	E24	Drive water piping																																			
	E22	Suction port																																			
	E20	Float																																			
	E18	Ultrasonic generator																																			

Fig. 9 The partially constructed MDM from case study.

5. Discussion

Based on the case study application, the proposed method was found effective to concretize multi-stakeholder requirements in design embodiment of PSS offering. The complex requirements from multiple stakeholders were structured and reflected in the PSS design structure. Even though the proposed method could not directly provide the best PSS design for the company (iterative step is required), it provided a means as a supporting tool for the decision-making process in the company to design the optimum solution in the balance between requirement fulfillment and cost consequence.

Multi-stakeholder requirements, the associated functions and entities constitute a complicated network. Aiming to satisfy all requirements of multi-stakeholder, in some cases, is an unattainable effort by considering the limited resource of the company. In another perspective, the company also highly regards the potential value including financial benefit to prioritizing the requirement to be realized. If the company aims to ensure multi-stakeholder obtains the high value and in the same time enhance the financial benefit of the PSS offering, it becomes urgent to embody a good balance between satisfying multi-stakeholder requirements and the associated costs of the design structure. As the response to these facts, this research supports the PSS company to realize the multi-stakeholders' requirements into a valuable design structure by considering the dependency of each requirement. Being developed based on well-acknowledged frameworks in design, the proposed method is highly applicable in the industry.

In comparison to the previous research (original view model), this paper has filled in the shortcoming of the research by supporting the accurate identification and complete embodiment of requirement from multi-stakeholder in the design

process by adopting the modeling technique of IDEF0. In addition, IDEF0 provides a more reliable basis to identify associated function and entity as well as to assign the interaction between them. As a consequence, more accurate input for the concept generation and design embodiment afford to be obtained. This paper attempts to contribute to the PSS design research, particularly for the early stage of design, by concretizing multi-stakeholder requirements into PSS design structure by properly grasp dependency among multi-stakeholder requirements. Secondly, the method also provides an opportunity for the designer to improve the PSS design by using LCC.

There are some parts of this research which require more attention for further development. One of them is the operational and more quantitative definition of balance design. It is essential to understand to which point the company has to improve the design that gives economic benefit but remain competitive for stakeholders' point of view, in particular for the customer. Because in some actual cases, cost and quality have a trade-off relationship. Another agenda for future research is the consideration of weighting score of cost contribution of each entity to the fulfillment of a particular requirement. Since a requirement is possible to be realized by more than one entity. Hence, more important an entity to support a requirement, it should be more efficient.

6. Conclusion and future work

This paper proposes a practical method for PSS design by concretizing the multi-stakeholder requirements. The dependency analysis using Multi-Domain Matrix (MDM) is combined with life cycle costing afford the opportunity for PSS company to better capture and structure the realization of multi-stakeholder requirements in a manageable fashion. The effectiveness of the proposed method is demonstrated in the application in a case study in water purification equipment company. Future work will include the clarification of the hierarchy of requirements and weighting score of cost contribution of each entity to the overall requirement fulfillment.

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