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A Framework for Designing Complex Product-Service Systems with a Multi-Domain Matrix

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***Abstract*—**Offering a Product-Service System (PSS) is a well-accepted strategy that companies may adopt to provide a set of systemic solutions to customers. PSSs were initially provided in a simple form but now take diversified and complex forms involving multiple services, products and technologies. With the growing interest in the PSS, frameworks for the PSS development have been introduced by many researchers. However, most of the existing frameworks fail to examine various relations existing in a complex PSS. Since designing a complex PSS involves full integration of multiple products and services, it is essential to identify not only product-service relations but also product-product/ service-service relations. It is also equally important to specify how they are related for better understanding of the system. Moreover, as customers tend to view their purchase from a more holistic perspective, a PSS should be developed based on the whole system's requirements, rather than focusing only on the product requirements or service requirements. Thus, we propose a framework to develop a complex PSS that is coordinated fully with the requirements of both worlds. Specifically, our approach adopts a multi-domain matrix (MDM). A MDM identifies not only inter-domain relations but also intra-domain relations so that it helps to design a PSS that includes highly desired and closely related core functions/ features. Also, various dependency types and rating schemes proposed in our approach would help the integration process.

***Keywords*—**Inter-domain relations, intra-domain relations, multi-domain matrix, product-service system design.

I. Introduction

As customers' demand for diversified and personalized products has been increasing, manufacturing companies have strived to extend their business models to incorporate product-service systems (PSS). The PSS approach is a competitive strategy that companies may adopt to offer a set of product and services as a whole [1]. It is also considered as a means to achieve sustainable production and consumption, which can bring benefits to both manufacturers and customers [2].

Before the PSS concept emerged, manufacturers have attempted to add value simply by including some services within their offerings [3]. This change is commonly termed as servitization. The PSS approach, however, goes beyond this change and, instead, aims at providing an integrated and systemic solution to customers [4]. Today, companies offer a variety of PSSs in which multiple products and services are complexly integrated.

In the process of transformation towards a PSS, some frameworks or methodologies have been proposed in literature to support the PSS development. The PSS development poses a significant challenge to a company since both product and service should be simultaneously considered to satisfy the requirements of customers [1]. It means that the relations between product design, service design and customer needs should be examined all together. In addition, it is essential to identify product-product/ service-service relations as a complex PSS is composed of multiple products and multiple services. Unfortunately, most of the existing frameworks or methodologies fail to model various relations existing in a complex PSS. Consequently, we introduce a framework to design a complex PSS based on the requirements of both product design and service design.

Our approach employs a multi-domain matrix (MDM) to decompose, relate and integrate multiple services and products for the complex PSS design. A MDM is an extension of design structure matrix (DSM) modeling in which several DSMs and domain mapping matrices (DMM) are represented simultaneously [5]. A MDM is useful in that it identifies not only relations within a domain but also relations across different domains. Therefore, the MDM approach helps to create a PSS with highly desired and closely related core functions/ features enabling the synchronized product and service development. Also, utilization of various dependency types and rating schemes are proposed in our approach for more effective and efficient integration.

II. Product Service System

In general, a PSS is regarded as a competitive proposal intended to provide customers with integrated solutions fitting their very individual needs instead of buying standardized physical products [6]. A PSS also offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity [4]. The underlying rationale for a PSS is utilizing the knowledge of the designer-manufacturer to both increase value as an output and decrease material and other costs as an input to a system [4].

Although many literatures have discussed the concept and benefits of a PSS, only a few of them conduct an in-depth study on the PSS design. Since a PSS is a dematerialized and complex system, the PSS design poses a significant challenge to a company. Companies frequently design a PSS as they develop a product, but this approach may be unsuitable [1]. A PSS is not merely a product with some services added or a service with an

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additional product; it is an integrated product and service offering in which factors in both domains are closely interconnected. In this regard, holistic approach is necessary to understand and capture such characteristics and reflect them in PSS design/ modeling [7].

There are several models and methodologies for the PSS design. For example, [8] offers a four-axis model for auditing a PSS; [7] proposes a structural model that entails the specifications which have to be provided in order to compose a PSS-portfolio. Most of the models are specifically customized for the PSS design, but their high level of abstraction prohibits an easy adoption in industrial enterprises [9]. The methodologies for the PSS design are generally existing ones for either product or service design and often tailored to specific projects. For instance, [10] outlines traditional tools that can be used when dealing with specific aspects of the design activity focused on PSS.

III. Matrix-Based Approaches

A. DSM

A design structure matrix is a system modeling tool that provides a simple, compact, and visual representation of a system, comprised with the system elements and their interactions [11], [5]. A DSM is represented as a square matrix with both row and column labels indicating the elements of a system. An off-diagonal mark signifies the dependency of one element on another [11].

Although a DSM is particularly well suited to applications in the development of complex, engineered products, it has been used in a variety of contexts, including project planning, project management, systems engineering, and organization design [11]. It has also been widely used to address complex issues in various fields, such as health care management, financial systems, public policy, natural sciences and social systems [5]. Different types of DSMs can be employed for different purposes. For example, while a component-based DSM is useful for modeling system component relationships and facilitating appropriate architectural decomposition strategies, a team-based DSM is beneficial for designing integrated organization structures that account for team interactions [11]. In general, a DSM approach to system modeling and analysis involves the following three steps [11]:

1) decompose the system into elements;
2) understand and document the interactions between the elements (i.e., their integration);
3) analyze potential reintegration of the elements via clustering (integration analysis) [12].

As described above, a DSM is a powerful tool for system modeling. When it comes to managing complex product development projects, however, a DSM needs to be extended to two or more domains in which complexity arises. Product development projects are dynamic ones in which different domains are interwoven and effective management requires understanding how they interrelate and influence each other [13].

B. MDM

The fundamental limitation of traditional DSM analysis is that it only focuses on dependencies and flows of information in one domain [13]. That is, the relationships between the domains cannot be identified with the traditional DSM analysis. Thus, an additional matrix that maps one domain to another is required. This matrix, termed a domain mapping matrix, is rectangular in shape, whereas a DSM is square. A DMM is advantageous in that it can capture the dynamics between different domains, identify relations and dependencies, and point out information that needs to be exchanged [13]. A combination of DSMs and DMMs forms a multi-domain matrix, proposed by [14]. Each single-domain DSM is on the diagonal of the MDM, and the off-diagonal blocks are DMMs [5].

Product development projects generally involve five different domains [13]: the product (or service, or result) system; the process system (and the work done to get the product system); the system organizing the people into departments, teams, groups, etc.; the system of tools, information technology solutions, and equipment they use to do the work; and the system of goals, objectives, requirements, and constraints pertaining to all the systems. Other traditional domains of interest to PD projects are customer requirements, product functionality, design parameters, product specifications, and product architecture [15].

There are some approaches that combine several matrices as a MDM. The K- and V-matrix connects elements of the market complexity (implied in a DSM) with elements of the product complexity (implied in a DSM) by a DMM [16]. QFD is a well-known analysis technique that presents a series of matrices sequentially relating customer demand via engineering specifications to parts specifications and to production process variables and thus to production operations planning [17]. Each house of QFD includes a DSM and DMMs. Connectivity maps combine two DMMs in order to compute a third one [18]. Unfortunately, none of these methods provides possibilities for a holistic consideration of the aspects of complexity in product development [19].

A MDM approach provides a more integrated view on product development. It analyzes dependencies that exist both within and between domains and this enables integration of the individual systems into a cohesive system [13]. It also provides managers with highly improved decision support and visibility into the total project system and at the same time enables information from different domains to be communicated by a variety of project participants [13]. In sum, a MDM approach increases our knowledge and understanding of complex systems [13].

IV. MDM Approach for PSS Design

A. Overview

The PSS-oriented framework should be different from the conventional product-oriented framework. Designing a successful PSS is often far more difficult than developing a single product due to complexity that stems from many sources. In order to manage the complexity of a PSS, the design framework should include a more comprehensive and systematic tool that can visualize, analyze and improve a system. A MDM approach is particularly useful for designing a complex PSS for the following reasons:

- A DMM includes several domains which separately reflect distinctive characteristics of products and services. That is, product elements are grouped into one DSM and service elements are grouped into the other. Moreover, other important domains (e.g., customer needs) that have significant influence on the PSS design can be added.
- Analysis of DSMs identifies relations within the domain. A complex PSS may consist of multiple products and multiple services and even if the PSS only includes a single product, the product may have a variety of features. Thus, it is crucial to determine relations within the product domain or service domain.
- DMM analysis identifies and analyzes intertwined relations across the domains. It allows simultaneous consideration of customer needs, products, services and even other important domains for the PSS design.
- Utilization of appropriate dependency types and rating schemes enables effective and efficient integration.
- With the MDM approach, a combination of DSMs and DMMs, a PSS can be designed from a holistic view, which can lead to the development of a successful PSS that includes highly desired and closely related core functions/ features.

B. Procedural Steps

In this section, the procedure of multi-domain matrix construction for complex PSS design is proposed shown in Fig. 1, and each step is described below:

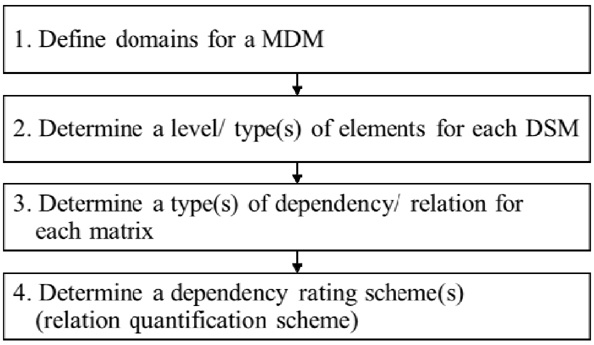

Fig. 1 Proposed procedure of multi-domain matrix construction for complex PSS design

1) Define domains for a MDM: complex PSS design involves at least four different domains (Fig. 2), which are customer needs, service function, product feature and technology. These domains are adopted from layers of the integrated product-service roadmap suggested by [20] with slight modification; the regulation/ standardization layer is omitted, and technology and service infra/ system layers are merged into the technology domain here. Although the purpose of the roadmap is planning of a PSS over a specific time frame, the basic notion is the same as the PSS design.

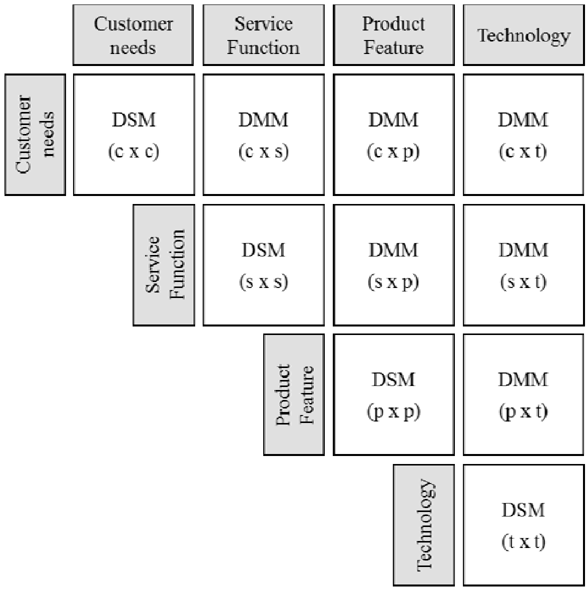

Fig. 2 Four domains of complex PSS

2) Determine a level/ type(s) of elements for each DSM: the level of elements in a DSM can be determined depending on the development phase in which the proposed MDM-based approach is to be utilized or the purpose of design. Similarly, the element type(s) can be determined based on the focus of the PSS design.
3) Determine a type(s) of dependency/ relation for each matrix: there can be one or multiple dependency types depending on the nature of the system. For a PSS-based MDM, a simple dependency type, such as correlation, can be used for all matrices or a specific dependency type(s) can be defined for each matrix.
4) Determine a dependency rating scheme(s): different rating schemes have been used to construct component-DSMs in previous literature, ranging from simple binary ones to ones that discriminate between different dependency types [21]. Various rating schemes can be used when modeling a PSS with the proposed MDM approach, but it has to be ensured that the rating scheme is appropriate for the chosen dependency type.

V. CONCLUSION

This paper proposes a comprehensive framework to design a complex PSS in which multiple product and service elements are intertwined. To design a truly integrated PSS which satisfies various customer needs, it is necessary to understand the relations within and across products, services and customer needs. This work is a contribution to this problem and provides a guideline to utilize a MDM approach as a solution. On the other hand, there are some parts to be improved. The most important future task is to elaborate the framework by providing possible options for constituents of the proposed MDM. Furthermore; the proposed DMD can be applied to a real world case in order to confirm validity and usefulness of the framework.

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