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MODEL-BASED FRAMEWORK FOR MANAGEMENT OF PSS DESIGN KNOWLEDGE

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ABSTRACT

Product-Service Systems (PSS) are regarded as a new business concept for manufacturing firms to enhance the value of their products and build up strong relationships with their customers. Since both tangible products and intangible services are included in design object, a design solution of PSS has various alternatives especially in conceptual design phase. PSS design therefore requires a broader range of knowledge to generate several ideas for its design solution.

In this paper, for the purpose of supporting idea generation in PSS conceptual design phase, a knowledge management framework is proposed. The basic idea of the proposed method is managing and providing knowledge collected from PSS cases. The proposed knowledge management framework is defined by reference with the three design models of PSS: life cycle model, product-service function model, and actor network model. The effectiveness of the proposed method is presented on the basis of the application to an example: PSS using agricultural machinery in a developing country.

Keywords: product-service systems, knowledge management, service design

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1 INTRODUCTION

Because of intensified global competition, manufacturing companies have to provide high value-added solutions and build up strong relationships with customers. In this context, the concept of Product-Service Systems (PSS), which are characterized by a combination of tangible products (e.g., a car) and intangible service shares (e.g., a maintenance service) (Mont, 2002; Tukker, 2006), is attracting much attention, especially in developed countries. For the design, development, and operation of an effective PSS, it is important to search for value provision opportunities in the entire product life cycle and offer appropriate services to customers at each opportunity.

As pointed out in product design research, design knowledge obtained from past product cases provides helpful information to designers, especially in the conceptual design phase (Yoshikawa, 2000). Thus, many studies in the product design area have focused on knowledge-based design support (e.g., (Altshuller, 1997; Roth, 1982)).

Compared to product design, a broader range of knowledge is required in PSS design because both products and services are included in the design space. To identify an appropriate design solution or to enhance the quality of a design solution, designers should have considerable design knowledge, and they should consider various alternatives for design solutions.

In this paper, for the purpose of supporting idea generation in PSS design, a framework to manage and reuse design knowledge is proposed. The method supports the acquisition of new PSS design solutions by integrating knowledge collected from PSS cases.

2 THEORETICAL BACKGROUND

2.1 Definition of PSS

Currently, there is no commonly accepted definition of PSS. With respect to some definitions in studies on PSS (Mont, 2002; Tukker, 2006; Meier, 2010), the terms related to PSS used in this paper are defined as follows:

- PSS:
  Social systems to enhance social and economic values received by each actor in the network through the mutual provision of a product, service, or Product-Service (PS)
- PS:
  An integrated combination of tangible products and intangible services
- Actor:
  An individual, group, or organization that is actively engaged in the PSS (e.g., a provider, partner, or customer)

2.2 Conceptual Design of PSS

Some studies have addressed the conceptual design of PSSs; these studies emphasized that designers have to consider what should be offered to the customer and how to realize this offering in the conceptual design phase of the PSS (e.g., (Shimomura, 2009; Müller, 2009)). In this section, representative models used in PSS conceptual design phase are reviewed.

2.2.1 Life cycle model

As mentioned above, for the design of an effective PSS, it is important to search for value provision opportunities in the entire life cycle of the core product. Here, core product means a product which has high relevance for the final PSS value generation (Müller 2009). Tan et al (Tan 2008) emphasized that two life cycle systems should be considered in PSS design to analyze customer needs: product life cycle (PLC) and customer activity cycle (CAC) in product use.

- Product life cycle
  Like human beings, products also have a cradle-to-grave cycle (i.e., raw material extraction, production, transportation, use and ultimately disposal). A PLC of a core product can be modelled as shown in the left-hand side of Figure 1 (Yoshikawa, 2000).

- Customer activity cycle
  Vandermerwe has proposed the CAC as a scheme to describe a customer's activity in product use or service reception (Vandermerwe 2000). The feature of this scheme is that it describes the activity as a cycle, which is divided into three stages: pre, during and post (the right-hand side of Figure 1). By describing the customer's full sequence of activities, activities where the customer could be better supported become apparent.

By using both two cycle models, designers can inclusively analyze customer needs for the core product.

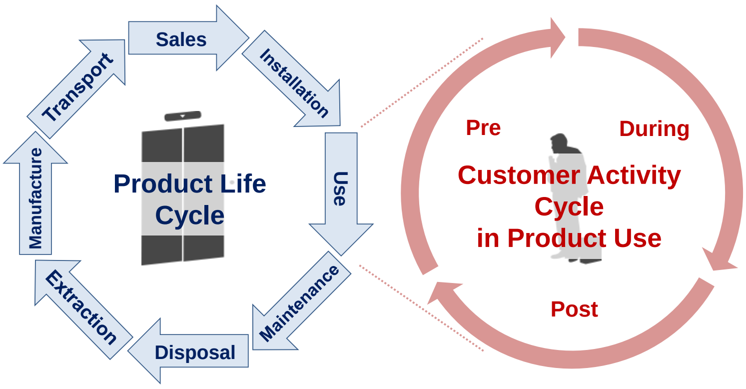

Figure 1. Two cycle models to analyze customer needs for a core product

2.2.2 Product-Service function model

To model and design offerings in the PSS (i.e., PS), the concepts of function and entity, which are originally used in product design methodologies (Pahl, 1996; Umeda 1996), have been highlighted in many studies of PSS (e.g., (Shimomura, 2009)). "Function" is an abstract concept, which represents what should be offered to fulfill the customer's needs. "Entity" is a specific measure to realize a function; namely, it represents the resources required to prepare, operate, and maintain the PSS offering (e.g., staff, technicians, machinery, and facility). Figure 2 shows an example of a model that represents the offering to satisfy a need "security and safety of the service".

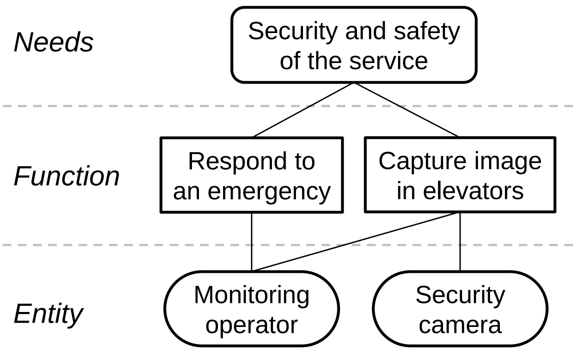

Figure 2. Function model to represent offerings in a PSS

2.2.3 Actor network model

To provide PSS, many kinds of resources are required. Therefore PSS is seldom delivered by just one party; instead, it often requires a network system of actors for provision (Tan, 2008). This "system", which consists of various actors who provide/receive products and services, exactly corresponds to the last "S" in the term "PSS". By modeling the system of actors and the relations between them, an overview is created of how the actors are organized to provide the PSS. This enables the designer to clarify the mutual flows of product-service provision, material, information, and money. Figure 3 shows an example of an actor network model (Shimomura, 2009; Tan, 2008).

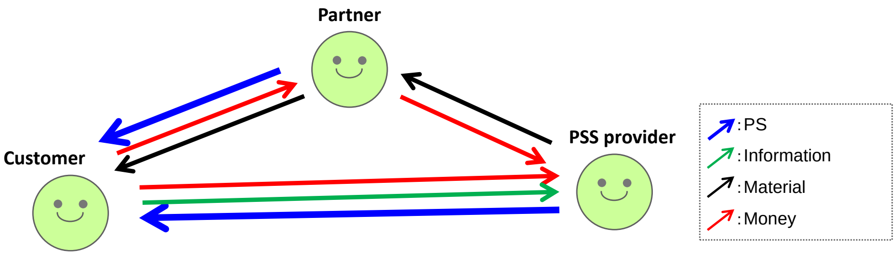

Figure 3. Actor network model to represent overview of PSS provision

2.3 Scope of this study

In order to support PSS designers effectively, it is important to represent and manage knowledge on the basis of appropriate models of the target for design support. In this study, we focus on the combination of the three design models mentioned in Section 2.2: life cycle model, PS function model, and actor network model. Here, the design operations using these three models are specified. The term “design operation” means the derivation of one concept from another concept in the design object. There are mainly following two design operations among these three models.

- Design operation 1: functions are derived from the customer’s needs.
  Designers propose functions to fulfill the customer’s needs which are explored from the entire life cycle (“design operation” 1 in Figure 4).

- Design operation 2: entities and actors are derived from a function.
  Designers associate physical products and/or human resources with particular functions. Then, the suppliers or owners of these entities are derived as involved actors (“design operation 2” in Figure 4).

In this study, these two operations are supported by a knowledge-based approach. To that end, we extract the elements related to the design operations and compose a knowledge management framework from these elements (the center part of Figure4).

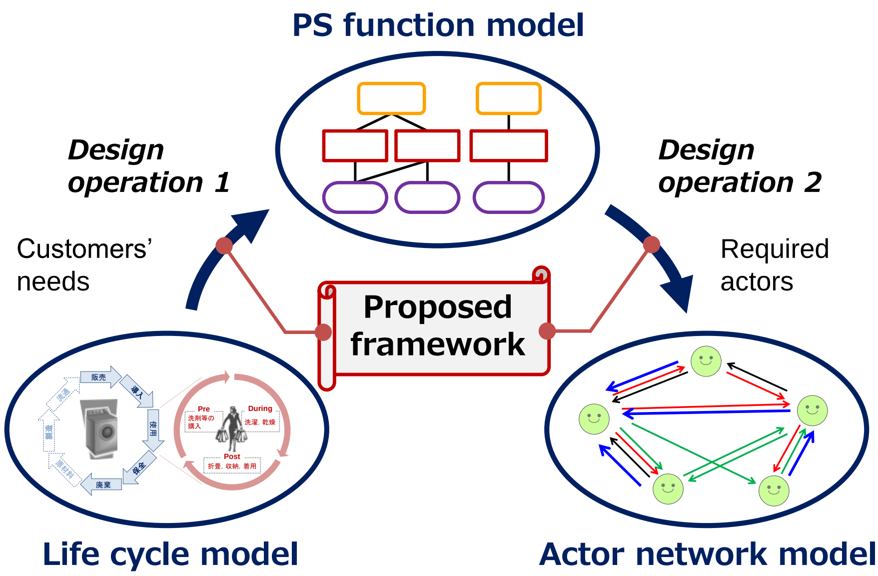

Figure 4. Overview of this study

3 FRAMEWORK FOR MANGEMENT OF PSS DESIGN KNOWLEDGE

3.1 Overview

In this study, a piece of PSS case knowledge is represented as the set of four elements: need, function, entity and actor. These elements are extracted from the three design models targeted in this study. Each element has two frames to describe a PSS case. The first frame describes the detailed content of the PSS case. The second frame is aimed at the connection with the tags. These tags are used as keys to search for the desired knowledge.

The remainder of this section explains the kinds of tags that are used to represent knowledge and how each design operation is supported using the knowledge of the operation.

3.2 Design Support for Design Operation 1

The design support for this operation is conducted as follows: Designers search for pieces of knowledge that have similar needs to that of the target need of this operation. Then, they refer to the function included in the found knowledge.

The classification tags to help designers to search for desired knowledge is constructed by using 'what phase of the life cycle was the target of the value proposition?' and 'what type of value was produced?' Namely, the tags contain "value" and "phase".

The tags of "value" is follows Tukker's seven fundamental values produced by PSS (Tukker, 2006). The explanation of the values is shown in Table 1. Based on the life cycle model, the tags "phase" are constructed from the following 10 phases: extraction, manufacture, transport, sales, installation, use (pre), use (during), use (post), maintenance and disposal.

In this study, these tags are associated with "need" in the framework of knowledge representation. Designers search for pieces of knowledge using the tags value (seven types) and phase (ten phases). Then, they refer to the functions included in the found knowledge.

Table 1. Seven types of value produced in a PSS (Tukker, 2006)

Type		Explanation
PI	Performance improvement	Performance, capability, or condition of products or customers is enhanced.
CR	Cost reduction	Purchasing, operating, and managing costs of the product are reduced.
CS	Comfort and simplicity	Customers' lives are made easier.
CV	Convenience	Time is saved, and frustration is avoided.
RR	Risk reduction	The likelihood of accidents involving products and customers is reduced.
EE	Emotional experience	The use of the product or reception of the service increases the pleasure felt by customers.
EF	Eco-friendliness	Negative effects on the environment are reduced.

3.3 Design Support for Design Operation 2

The design support for this operation is conducted as follows: Designers search for pieces of knowledge that have a similar function to that of the target function of this operation. Then, they refer to the entities and their actors included in the found knowledge.

In the model introduced in 2.2.2, a function is freely expressed by natural language. This approach can flexibly describe the detail of a function but lead to a different expression of similar functions in some cases (Lossack, 1998). To effectively search for the knowledge as stated above, tags to unify the expression of the function are required.

Thus, the tags associated with "function" are introduced in an input-output approach to function representation (Nemoto, 2012). In this approach, a function is defined as an input-output relation among materials, energy, and signal/information (Pahl, 1996). This approach can help to unify the expression of both the product and the service function, although it limits the flexibility of the description (Nemoto, 2012).

In this approach, the function tags include three elements: input, input/output, and output. Table 2 shows the terms used in each tag.

Table 2. Terms to represent functions by input/output approach

Items	Content
Input/output elements	Materials, energy, and signal/information
Input/output relations	Separate, distribute, import, export, transfer, guide, couple, mix, actuate, regulate, change, stop, convert, store, supply, sense, indicate, process, stabilize, secure, and position

3.4 Summary

As mentioned in this chapter, a piece of PSS case knowledge in this study is represented by a set of four elements: need, function, entity, and actor. The content of each element is described in detailed, and the tags are used to provide support in each support of the three design operations. Table 3 represents a piece of knowledge extracted from a PSS case involving incinerators. In this case, the customer's need was for a lower incidence of sudden failures. The detailed contents are described in the second column of Table 3. The third column denotes the tags associated with each element.

Table 3. An example of knowledge representation (case: PSS of incinerators)

Elements	PSS case knowledge	
	Detailed content	Tags
Need	Lower incidence of sudden failures	• *Phase*: Maintenance • *Value*: Risk reduction, convenience
Function	Design a maintenance plan based on analyzed data	• *Input elements*: Information • *Output elements*: Information • *Input/output relation*: Change
Entity	Staff, maintenance record, database	-
Actor	Heavy industries company	-

4 IMPLEMENTATION

On the basis of the framework described in Chapter 3, a prototype system for knowledge management and design support is developed. Figure 5 shows screenshots of the developed system. This system consists of three modules: (1) a design workspace, (2) a design knowledge base, and (3) a knowledge viewer. The design workspace supports the PSS's design activities, i.e., the operation and integration of the design elements such as functions and entities. This module already provides the main functionality for Service Explorer, which is the CAD system for PSS design (Shimomura, 2009; Hara, 2009). The second and third modules, the design knowledge base and the knowledge viewer, respectively, were additionally developed in this research. The design knowledge base enables designers to edit and accumulate knowledge. The knowledge viewer provides the area to search for and refer to the desired knowledge.

5 APPLICATION TO AN EXAMPLE CASE

5.1 Settings for this Application

The developed system was applied to the design of an example case. For the application, the authors collected and accumulated 61 sets of knowledge from 16 PSS cases obtained from several reports in the literature (Mont, 2000; UNEP, 2002).

Table 4 summarizes the settings of this application. The designer belongs to a virtual company selling agricultural and construction machinery. In this application, the designer aims to design a PSS for a farmer in a certain developing country. The settings for the target customers follow those outlined in a survey report (JETRO, 2012).

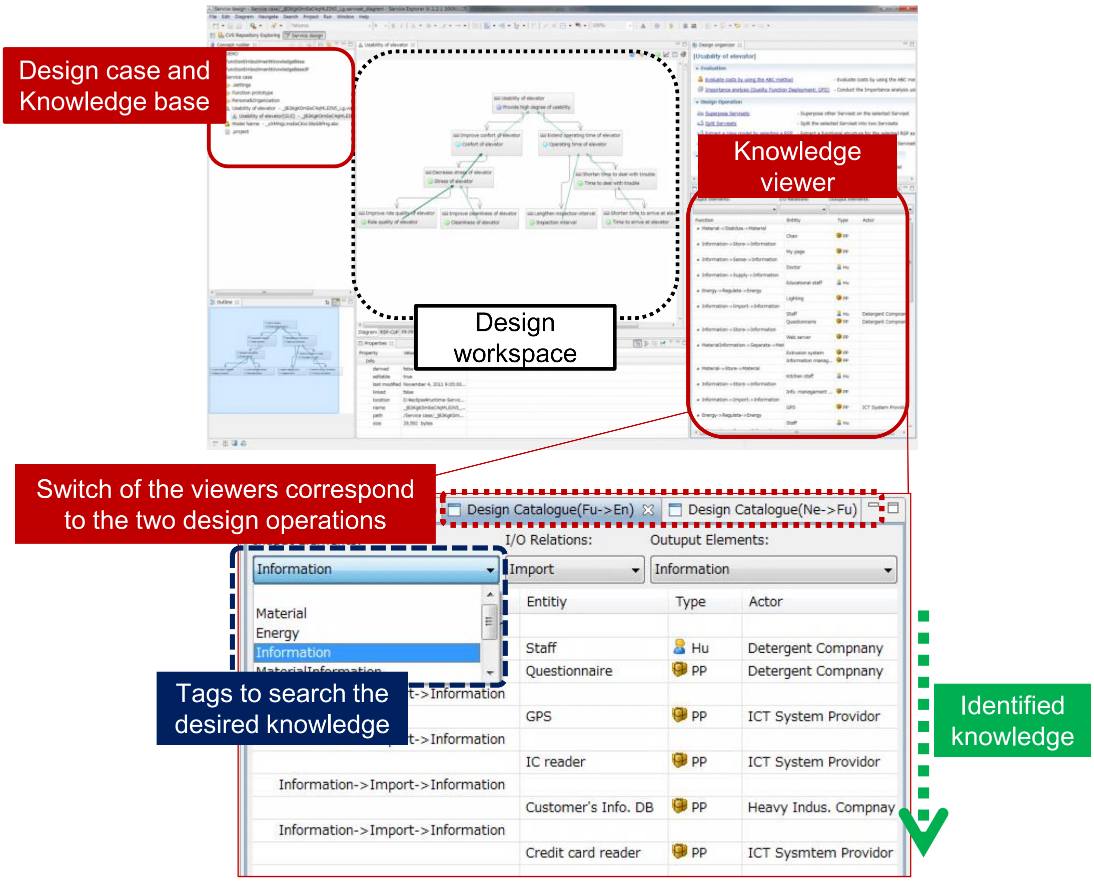

Figure 5. Screenshots of the developed design support system

Table 4. Settings of the provider and the target customer

Actor	Setting
Designer's company	— is a Japanese manufacturing firm producing agricultural and construction machinery — has well-educated and experienced engineers — has a connection with an IT system provider — is aiming at expanding its market share in developing countries
Target customers	— are farmers in a developing country — use low-price but low-quality agricultural machines — are dissatisfied with the operability of the machines — do not have enough machinery and equipment because of operating costs — often incur losses on crops due to quality management problems — do not have enough knowledge to maintain their agricultural machinery — use low-quality agricultural materials — cannot easily access materials in stores

5.2 Application

5.2.1 Step 1: Preparation for the design

In this application, first, the customers' needs were extracted from the image of the target customers described in Table 4 by using the life cycle model. Then, the phase and value tags were connected with these needs. The result of the connection is shown in Table 5. For example, "longer lifetime of machines" (N7) was interpreted as the need for reducing a repairing or repurchase cost of those agricultural machines. Thus, the value tag "CR" and the phase tag "maintenance" were connected.

Table 5. Extracted customers' needs and related tags

No.	Needs	Phases	Values
N1	Lower purchasing cost	Sales	CR
N2	Deeper understanding of how to use	Installation, Use(pre)	PI, RR, CS
N3	Better quality of agricultural materials	Use (pre)	PI, RR
N4	Easier access to agricultural materials	Use (pre)	CV
N5	Lower operating costs (electricity and fuel)	Use (during)	CR
N6	Easier management of crops	Use (post)	PI, CV
N7	Longer lifetime of machines	Maintenance	CR
N8	Greater support for machine maintenance	Maintenance	CV, RR

5.2.2 Step2: Design Operation 1.

Next, the designer retrieved pieces of knowledge on the basis of the value and phase tags, and referred to the functions included in the found knowledge. For example, the N2 listed in Table 5 was associated with the values "PI, RR, and CS" provided in the phases "installation and use (pre)." Based on the knowledge search using these tags, the designer identified the knowledge that include similar types of the target need; and the designer could refer to the following functions: hold a training workshop, station engineers who have much experience and knowledge, indicate a rule to be respected, etc. Starting with this example, the designer could find several adoptable functions to fulfill every need, except those related to N1 and N6.

5.2.3 Step3: Design Operation 2.

Then, the designer searched for entities and actors to realize the functions derived in Step 1. The tags of the I/O elements and the I/O relation were used in this operation. For example, the function to fulfill N5 "monitor information on the machine's use" was converted into the function "imports (I/O relation)" a kind of "information (I/O elements)." By conducting a knowledge search using these tags, the designer identified the following entities: questionnaire, wireless device with GPS, and customer's information database. As the designer's company has a connection with an IT system provider (Table 4), the designer decided to adopt a system that included the customer's information database and wireless device to realize the function, the logic being that the system could be developed easily by cooperating with the IT system provider.

5.2.4 Results of the Application

In this application, the designer considered various alternatives through the design supports stated above. Then, the final design solution was generated, as shown in Figure 6.

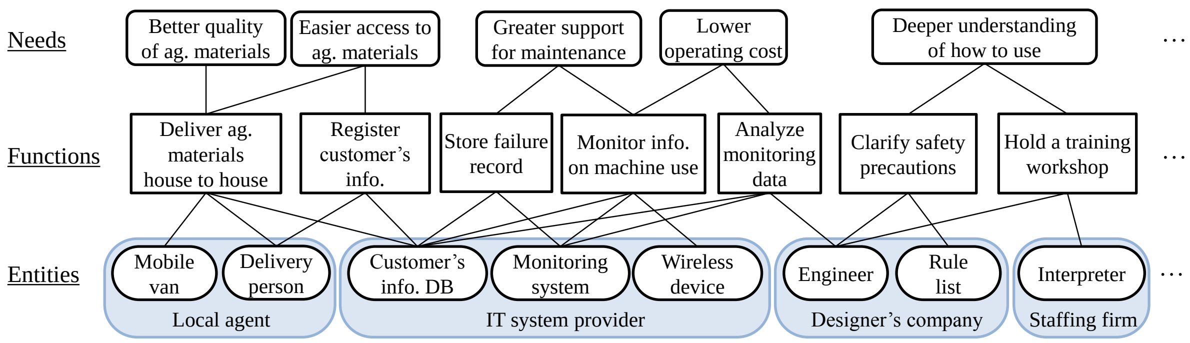

Figure 6. Part of the design solution generated by the application

6 DISCUSSION

6.1 Implications of this study

By using the support for the design operation 1, the designer could identify several functions that fulfilled six of eight needs; and the designer could identify the entities and actors associated with each of the eight functions derived from the design operation 1. From these results of the support for each design operation, the extended method and the developed system realized effective design support for each operation in the conceptual design of the PSS.

6.2 Remaining issue

Designs are based on an iterative procedure of the generation of ideas and the convergence of the generated ideas (Yoshikawa, 2000). This paper developed a method and system for the generation of ideas in PSS design. To enable designers to select the best solution from various alternatives, however, a method for the convergence of ideas is needed. Therefore, future work should include the development of an evaluation method to indicate the best way to select the final solution from various alternatives, so as to maximize the value produced in the PSS.

7 CONCLUSION AND OUTLOOK

This paper proposed a model-based knowledge management framework and developed a knowledge-based design support system based on that framework. The system realized to support the two design operations among the three PSS design model. A piece of knowledge in the framework is represented by a set of four elements: need, function, entity, and actor. Each element is described in detail, and the associated tags are used to ensure effective searches of the desired knowledge. The results of the analysis of the application showed that the proposed framework and system support the two design operations. Future work should include the development of an evaluation method to select the best set of various alternatives.

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