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DEVELOPMENT OF A SYSTEM FOR KNOWLEDGE-BASED PRODUCT-SERVICE SYSTEM DESIGN SUPPORT

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Keywords: service engineering, product-service system, design support system, design knowledge management

1. Introduction

Our society's limitations of natural resources, energy supplies, and capability to accept industrial waste have led to serious problems related to producing and disposing of artifacts. We have to immediately search for solutions or business models to realize a sustainable society. In this context, services are becoming increasingly important in the manufacturing industry, since a longer life or more added value of a product can be achieved by offering services (e.g., a maintenance service) combined with a product (e.g., a car). As a result, new concepts such as the Product-Service System (PSS) [Tukker 2006], which is defined as consisting of products and services designed and combined so that they jointly are capable of fulfilling specific customer needs [Mont 2002], have been attracting much attention, especially in developed countries.

As pointed out in the product design research, knowledge obtained from past products and cases provides helpful information for designers [Yoshikawa 2000]. Therefore, many studies in the product design area focus on knowledge-based design support (e.g., [Umeda 1996]).

Compared to product design, a broader range of knowledge is required to PSS design, since both products and services are included in its design space. Therefore, providing knowledge to designers is the key to enhance the quality of design solutions in PSS design. However, few methods and tools for knowledge-based support for PSS design have been proposed.

In this paper, a method for knowledge-based PSS design support is proposed. The proposed method is on the basis of the research on Japanese Service Engineering, which provides design methodology of the integrated provision of products and services [Shimomura 2009]. In addition a prototype of computer-aided design (CAD) system to realize knowledge-based PSS design support is developed. The method and system support the acquisition of new PSS design solutions by integrating knowledge accumulated in a knowledge base. It is noteworthy that this system is not automated design system but a cooperation system that can solve design problems by interactions between designers and the system.

The reminder of this paper is organized as follows. Chapter 2 explains a definition and modeling methods of service proposed in Service Engineering, which is a fundamental concept of this study. In Chapter 3, a knowledge-based design support method is proposed. Its overview is reported in 3.1. 3.2 explains a scheme to represent knowledge, and 3.3 reports a scheme to provide knowledge to a designer. Chapter 4 reports the implemented prototype system for knowledge-based design support. Chapter 5 explains the results of an application of the developed system. Chapter 6 discusses the virtues and remaining issues of this research, and Chapter 7 concludes this paper.

2. Service engineering

2.1 Fundamentals of service engineering

The authors have carried out fundamental research on Service Engineering in Japan, which aims at providing design methodology of services from an engineering viewpoint [Shimomura 2009]. In Service Engineering, a service is defined as an activity between a service receiver and a service provider to change the state of the receiver. According to our definition, a service is offered to realize the receiver's state change, and when the state changes to a new desirable one, the receiver is satisfied. Therefore, changing a receiver state is equal to fulfilling a customer need in this context. This definition includes a broader sense than the typical definitions in the service marketing field, which are used to clarify the difference between services and products (e.g., [Lovelock 1999]). In this definition, we regard a service as a combination of service activities and physical products [Shimomura 2009]. The term service used in this study, therefore, corresponds to PSS.

2.2 Service design

In a series of Service Engineering studies, methods to design a service have been proposed. It is noteworthy that a term service means a combination of service activities and physical products as mentioned above. Figure 1 shows the overview of service design methodology proposed in Service Engineering. A service is modeled as a functional structure that satisfies customer needs, and specific entities and their activities/behaviors are associated with the functional structure [Shimomura 2009]. Here, entities include both physical products and human resources, which correspond to product share and service share in PSS context.
In short, a service can be designed through phases of "development of functional structures" and "embodiment of functions," as shown in Figure 1.

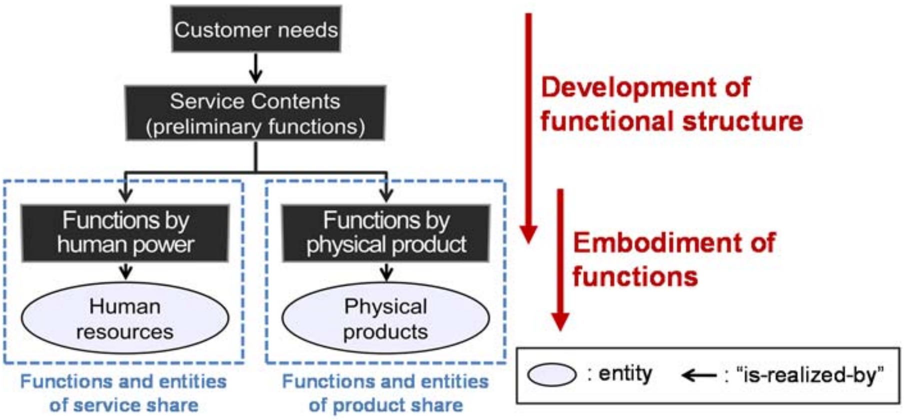

Figure 1. Overview of service design methodology proposed in service engineering

2.2.1 Service function model

A service function model represents the realization structure to fulfill customer needs. As shown in Figure 2 (a), this model consists of functions, which are described as "verb + noun," e.g., "serve + a cup of coffee," and entities that have been used in product design methodologies (e.g., Pahl 1996, Umeda 1996]). In this model, preliminary functions that fulfill customer needs are described and then deployed into sub-functions. Human resources (e.g., staff and customers) and physical products (e.g., machines and facilities) are associated with the lowest-level functions as function carriers.

2.2.2 Service process model

In the service marketing field, a service blueprint method is the most common method used by marketers to visualize service activities in a sequential manner [Shostack 1982]. In Service Engineering, the concept of service blueprint has been extended as a service process model that

includes product behavior and its relationship to service activities as well as the connection between activities/behaviors and customer needs/values [Shimomura 2009] (Figure 2 (b)).
A service process model consists of an interrelated activity blueprint and behavior blueprint. Some activities/behaviors in the activity/behavior blueprint are related to functions in the function models. By connecting the function model and the process model, it is possible to identify what activities/behaviors of the entities realize each function.

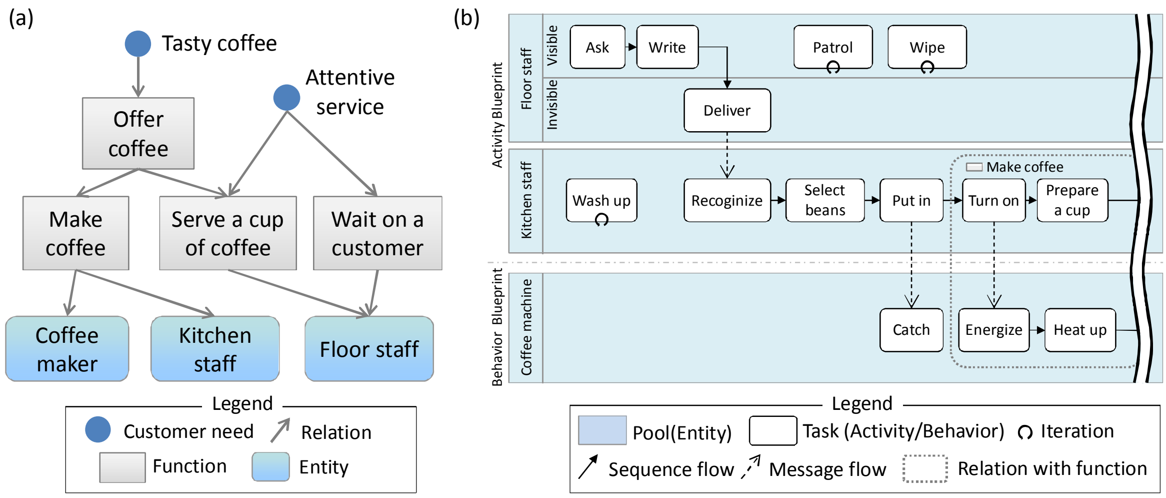

Figure 2. Models of coffee shop service, (a) Service function model, (b) Service process model

2.3 Service CAD

We have developed a computer-based service design support system (service CAD) called Service Explorer [Shimomura 2009] based on the definitions and methods outlined above. The system was initially developed as a service CAD prototype when we first began investigating Service Engineering and first released to the public in 2004.

3. Knowledge-based PSS design support

3.1 Overview

This paper proposes a knowledge-based PSS design support system on the basis of the design methodology of Service Engineering. In this study, the embodiment phase, where the variety of PSS design solutions generates, is focused on. Namely, designers support in the embodiment phase is achieved by providing knowledge. The proposed system includes a common framework to represent and manage knowledge concerning both service and product share. This is a novel point of this study to support designers effectively in the embodiment phase.
Figure 3 shows a concept sketch of knowledge-based PSS design support system. This system includes PSS design workspace and knowledge base. A PSS is designed in the design workspace using service design methodology proposed in Service Engineering. The knowledge base consists of knowledge obtained from multiple PSS/service cases. Moreover, a piece of knowledge is described as a set of function and function carrier. A function carrier is structured by specific entities and processes (activities/behaviors). In this paper, this type of knowledge is called "Function Embodiment Knowledge (FEK)." A designer explores the desired knowledge from this knowledge base. The desired knowledge is searched for on the basis of the similarity between the normalized lexical expressions of functions. The lexical expressions of functions in FEK are normalized by using a function vocabulary list. The searched knowledge is provided as the set of FEK. This set of FEK is called a "service design catalogue" in this study. Function carriers selected from a service design catalogue is combined with a service function model described in the design workspace. A PSS design solution is then generated.

The reminder of this chapter explains how to represent the FEK (3.2) and features of the service design catalogue (3.3).

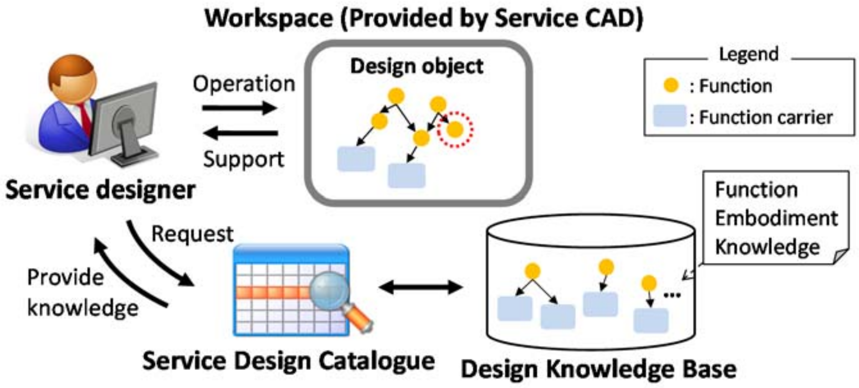

Figure 3. A concept sketch of knowledge-based PSS design support system

3.2 Representation of FEK

3.2.1 Framework of knowledge representation

In the service marketing field, service has been studied with a focus on 3Ps: People, Physical evidence, and Process [Lovelock 1999]. Additionally, Yoshikawa denotes service in terms of "manifest functions" that become manifest through human action or the use of physical products [Yoshikawa 2008]. These studies emphasize the importance of considering (1) entities and (2) processes (i.e. sequences of human activities or product behaviors) to realize functions in the embodiment phase. From these viewpoints, the FEK should include 2 elements: entities and processes.
Meanwhile, in this study, FEK is searched for on the basis of the similarity between functions, as reported in 3.1. In this regard, if the representation of functions is not unified, it is difficult to conduct a thorough and effective search for the functions that have a similarity with the target function [Lossack 1998]. Therefore, using a unified form and vocabulary is required for function representation to increase the efficiency of knowledge search and the reusability of knowledge.
In light of these requirements, we represent a minimum unit of FEK by 3 elements: function (described with a unified form and vocabulary), entities, and processes. The remainder of this chapter explains each element in detail.

3.2.2 Function

Service function represents what is offered in the service. The major approaches for describing function are either "verb-noun" or "input-output" [Lossack 1998], [Pahl 1996], [Umeda 1996]. The verb-noun approach, which has been used in Service Engineering, is similar to the use of a natural language; it is therefore more flexible and easier to be used by designers. However, this approach leads to a different expression of the same functions. It makes effective knowledge search difficult as stated above. Thus, this approach is unsuitable for knowledge management. On the other hand, the input-output approach, which is used in various fields of design, defines a function as an input-output relation among the material, energy, and signal/information [Pahl 1996]. This approach could help to manage knowledge, although it confines flexibility of description [Lossack 1998].
For these reasons, we adopt the input-output approach to describe function in FEK (Figure 4). Input/output elements consist of material, energy, and signal/information in a traditional way. However, service-typical elements (e.g., human, order, and knowledge) that is not considered in product design are included here (the right-hand side of Figure 4).
In order to normalize the verbs used to express an input-output relation, furthermore, we introduce a function vocabulary list. The functional basis, as shown in Table 1, which was developed by Hirtz et al., organizes the verbs used in the input-output function representation [Hirtz 2002]. It includes specific functions and their synonyms in eight categories (Table 1). In our study, assuming that the

functional basis is available for describing service functions, we use it as the function vocabulary list. This is based on the discussion that both service and product functions are similarly regarded as “desired state changes” [Yoshikawa 2008].

In summary, a unified representation of function is realized by using the “input-output approach” in combination with the “function vocabulary list.” When FEK are collected from service/PSS cases, a verb-noun function is translated to input-output function by referring to the function vocabulary list. In other words, a function in FEK is described by 3 elements: input/output elements (material, energy, and signal/information), and a verb (from the function vocabulary list).

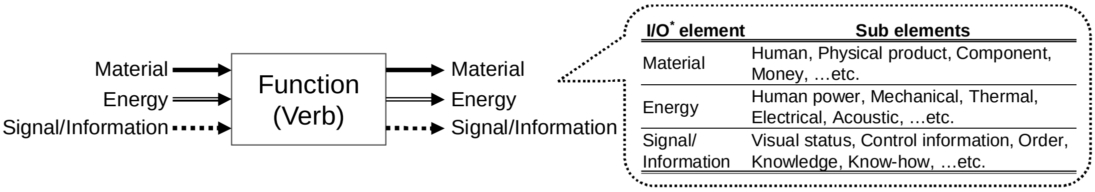

Figure 4. Input-output function representations for service design

Table 1. Function vocabulary list from functional basis proposed by Hirtz et al. [Hirtz 2002]

Class (Primary)	Secondary	Tertiary	Correspondents
Branch	Separate		Isolate, sever, etc.
		Divide	Detach, isolate, etc.
		Extract	Refine, filter, etc.
		Remove	Cut, drill, etc.
	Distribute		Diffuse, dispel, etc.
Channel	Import		Form entrance, allow, etc.
	Export		Dispose, eject, etc.
	Transfer		Carry, deliver
		Transport	Advance, lift, etc.
		Transmit	Conduct, convey
	Guide		Direct, shift, etc.
		Translate	Move, relocate
		Rotate	Spin, turn
		Allow DOF	Constrain, unfasten, etc.
Connect	Couple		Associate, connect
		Join	Assemble, fasten
		Link	Attach
	Mix		Add, blend, etc.
Control Magnitude	Actuate		Enable, initiate, etc.
	Regulate		Control, equalize, etc.
		Increase	Allow, open
		Decrease	Close, delay, etc.

Class (Primary)	Secondary	Tertiary	Correspondents
Control Magnitude (Continued)	Change		Adjust, modulate, etc.
		Increment	Amplify, enhance, etc.
		Decrement	Attenuate, dampen, etc.
		Shape	Compact, compress, etc.
		Condition	Prepare, adapt, etc.
	Stop		End, halt, pause, etc.
		Prevent	Disable, turn-off
		Inhibit	Shield, insulate, etc.
Convert	Convert		Condense, create, etc.
Provision	Store		Accumulate
		Contain	Capture, enclose
		Collect	Absorb, consume, etc.
	Supply		Provide, replenish, etc.
Signal	Sense		Feel, determine
		Detect	Discern, perceive, etc.
		Measure	Identify, locate
	Indicate		Announce, show, etc.
		Track	Mark, time
		Display	Emit, expose, etc.
	Process		Compare, calculate, etc.
Support	Stabilize		Steady
	Secure		Constrain, hold, etc.
	Position		Align, locate, etc.

3.2.3 Entity

Entity means human resources and physical products that construct a service, e.g., staff, technicians, machinery, and facility. Here, human resources correspond to service share, and physical products correspond to product share in PSS.

As mainly discussed in Ergonomics researches, humans and physical products (i.e., service and product share in PSS context) have some differences in their features; for instance, flexibility of communication, variety of performance, tiredness, etc. Thus, it is essential that service designers select appropriate entities for each function, taking into consideration the different features of humans and products. In this study, therefore, not only a name of entity but also a type of it are described in FEK, since they become one of guideposts when designers select entities.

3.2.4 Process

A service delivery process is a series of tasks that provide value to customers. Service function becomes manifest through service delivery processes. Namely, service delivery process represents how to provide functions or values.

In this study, knowledge concerning processes is described in the form of the service process model, i.e. tasks and that orders, reported in 2.2.3. This is because process knowledge represented with this form can be understood easily without specialized knowledge [Shimomura 2009]. This intelligible form is appropriate for knowledge-based design support from the following two reasons:

- General representation form that does not depend on a specific domain
  Service includes a wide variety of corporate activities. It is therefore supposed that FEK apply to various domains. Consequently, a general representation form that does not depend on a specific domain is appropriate and useful.
- Various participants in PSS/service design
  To design a PSS or service, various departments such as marketing, product planning, product design, and software development divisions, need to participate in design cooperatively. Therefore, the important thing is that all participants understand and use FEK rightly.

3.2.5 Summary

As reported in this chapter, a minimum unit of FEK is represented with 3 elements: function, entities, and processes. Namely, FEK is represented and collected in the form shown in Table 2. A function carrier, i.e., entities and their activities/behaviors, are accumulated together with a function manifested by them. This enables service designers to search for function carriers based on the similarity between functions.

Table 2. Representation form of FEK (Function Embodiment Knowledge)

Items		Contents
Function	Input Elements	Material, Energy, or Signal/Information
	Function	Verb (from the vocabulary list)
	Output Elements	Material, Energy, or Signal/Information
Function carrier	Entities	Entity Name, Type (Human or Physical Product)
	Processes	Activities/Behaviors (Tasks and that order)

3.3 Service design catalogue

A service design catalogue provides a list of FEK as catalogue style. The theoretical background of this method is "design catalogue" proposed in product design research [Pahl 1988]. The design catalogue is a collection of working principles for product design and regarded as a useful tool to support development of a design solution.

Figure 5 is an example of a service design catalogue. This catalogue provide several kinds of knowledge concerning "Web server", "Electronic medical chart", and "Refrigerator," that makes a function "store something (materials, energy, or information)" become manifest. By referring to several kinds of FEK in service design catalogue, designers can select appropriate function carriers or acquire new creative ideas to develop design solutions.

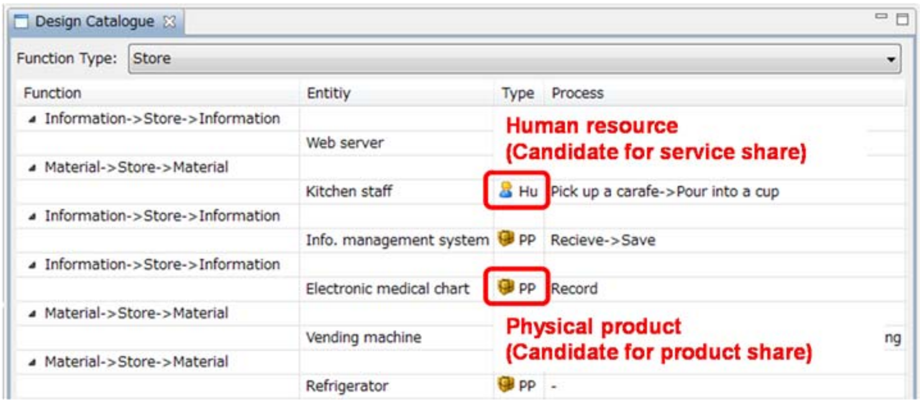

Figure 5. An example of a Service design catalogue

4. Implementation of knowledge-based PSS design support system

On the basis of the approach reported in Chapter 3, a prototype of knowledge-based PSS design support system is developed. This system consists of three modules: (1) Design workspace, (2) Design knowledge base, and (3) Service design catalogue viewer. The design workspace is to support service/PSS design activities, i.e., operation and integration of design elements such as functions and entities. This module has been already implemented as a main functionality of Service Explorer. The second and third modules, design knowledge base and service design catalogue viewer, were newly developed in this research. The design knowledge base enables designers to edit and accumulate FEK. The service design catalogue viewer visually provides a service design catalogue to designers.

Figure 6 shows a screen shot of the developed design support system. Left-hand side of it shows an execution screen of design workspace and the other side shows service design catalogue viewer.

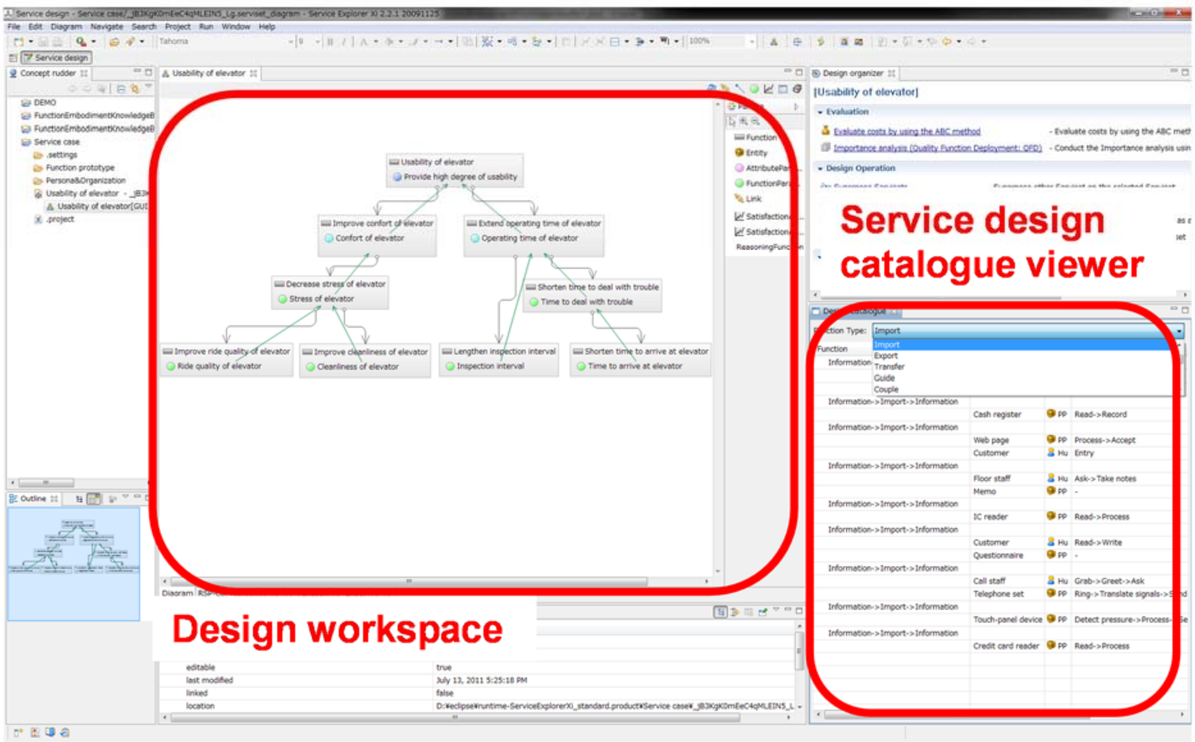

Figure 6. Screen shots of the knowledge-based PSS design support system

5. Application

The developed system was applied to a design of an actual service: an accommodation service in Japan. This applied case is not a general PSS case but has an aspect of the integrated provision of products and services, since it is obvious that both physical product (product share) and human activity (service share) are needed for service offering.

As a preparation of the application, first of all, a design knowledge base, in which a piece of knowledge is described in the form of FEK, was constructed. The FEK was obtained from a lot of service/PSS cases. As a result, about 130 sets of FEK were accumulated in the knowledge base.

In this application, designers conducted an improvement design of this service by using the developed system including the constructed knowledge base. Finally, some design solutions were generated.

5.1 Development of a functional structure

We collected questionnaire data that includes much information on customers' voices. From them several kinds of customer needs to the service, such as "comfortable environment," "attentiveness of staffs," and "memorable dinner," were extracted. In this application, the customer need "comfortable environment" was focused on, since it was regarded as the most important one.

Service content, namely what is offered to customers, was then designed using the service function model to realize "comfortable environment" in the hotel. Figure 7 shows the designed function model. Two functions such as "Provide rooms that meet customers' preferences" and "Provide comfortable hotel life" were considered as root functions to realize "comfortable environment." These two functions were themselves decomposed into several sub-functions. Consequently, eight functions (F1 to F8 in Figure 7) were identified as the lowest-level functions.

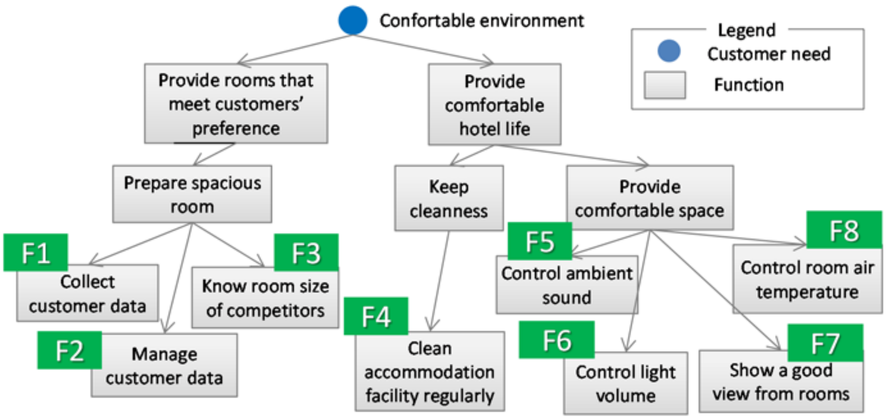

Figure 7. Function model designed in the application

5.2 Translation of function type

The lowest-level functions in Figure 7 were described with the verb-noun approach. These functions were then translated into the input-output functions. Here, the function vocabulary list was used to normalize lexical expression of the input-output functions. The results are depicted in Figure 8. For example, a verb-noun-type function "collect customer data" could be translated into an input-output-type function "import information (customer data)."
This translation was aimed at unifying the function representation form, since the unified form makes it easy to search and find the desired knowledge from the constructed knowledge base.

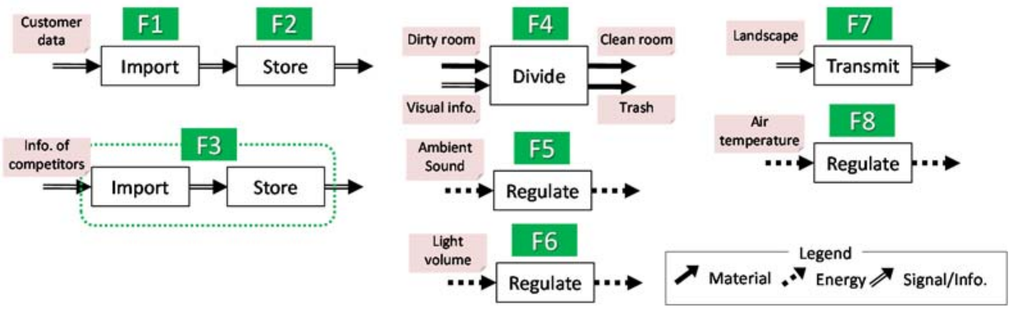

Figure 8. Result of translation of functional type

5.3 Generation of design solutions using service design catalogue

In this step, function carriers were explored from the knowledge base and provided to the designer in the form of service design catalogues. A service design catalogue provides several kinds of function carriers that make a lowest-level function become manifest.
By referring to provided service design catalogues, new design solutions to improve the hotel service were generated.
Design Solution (1): "Electronic chart" to manage customer information
The hotel needs to collect and manage customer data (see F1 and F2 in Figure 7) to provide rooms that meet customers' preferences. Focusing on this, the designers proposed to introduce a customer data management system applying an idea of "electronic chart." This idea was generated by referring to knowledge concerning an electronic medical chart, which is often used to manage patients' information in medical services.
This design solution will be helpful to manage large amount of customer data effectively.
Design Solution (2): "Live sound" BGM (Back-Ground Music)

To make a comfortable environment for customers, the hotel plays music at the lobby and restaurant. Normally, this kind of BGM (back-ground music) is played by an audio system with speakers, i.e., physical products. However, in this application, the designers found that such a set of products is not the only way to play BGM. In particular, a new idea of "Live sound" BGM that means BGM played by human (a pianist, violinist, and so on) was generated.
The hotel can provide a special atmosphere by introducing this design solution at the lobby or restaurant, although the realization costs of this must be high.

6. Discussion

6.1 Effectiveness of knowledge-based design support

In this application four designers (designer A-D) were involved in. We conducted interviews to each designer after they conducted the improvement design using the developed system. Their evaluations for the developed knowledge-based design support system are as follows.

- Service design catalogues provided by the design support system were very useful to design a new service. (From all designers.)
- The system enabled us to generate new ideas that we could not find in my brain. (From designers A, C, and D.)
- Service design catalogues offered several kinds of FEK. It helped us come up with a lot of design alternatives. It is expected that the quality of design solutions can be enhanced by using a lot of design alternatives as materials to discuss final design solutions. (From designer B.)
- The more FEK the knowledge base has, the more effective its design support is. (From designers A and B.)

From these evaluations, it was confirmed that the developed system realized an effective design support where the design object was the integrated provision of products and services.

6.2 Developing design solutions considering both product and service

In PSS context, for the purpose of offering flexible and high value-added solutions to customers, it is important for designers to have a way of thinking that "both products and services are means to offer values for customers." Namely, designers should not stick to only product view or service view; but a holistic view is required.
In this research, both products and services are regarded as means of value offerings. The developed system provides product and service knowledge at the same time to designers. This leads designers to have a holistic view when they create solutions for customers, and enables them to develop design solutions considering both product and service views. In fact, the design solutions (2) reported in 5.3 were generated by considering the substitution between a product and service, i.e., from a product (an audio system) to service (live music).

6.3 New idea generation using multiple domain knowledge

As reported above, the developed system was evaluated as useful to generate new ideas that designers could not find in their brains. Such new ideas were mainly derived by FEK extracted from multiple service/PSS cases (e.g., medical, maintenance, Web services, etc.). It has been said in the product design area that providing multiple domain knowledge supports to find new and creative design solutions [Takeda 2003]. Namely, the proposed system is effective for a creative service/PSS design, since it can provide multiple domain knowledge to designers through service design catalogues.

6.4 Remaining issue: need to support the configuration phase

The developed system provides a service design catalogue that includes several kinds of function carriers to realize a lowest-level function. To fulfill the overall function, it is then necessary to elaborate overall solutions from the combination of function carriers, namely configuration of function carriers. In the configuration phase, designers should discuss how to combine product and service shares to maximize the customer satisfaction or to minimize the costs. However, the developed system does not support the configuration phase. Therefore, a method to support the configuration phase should be considered and introduced.

6.5 Comparison with related works

The ontology-based knowledge management has been proposed in some PSS design researches (e.g. [Baxter 2009]). These researches tackle to define generic structures of PSS design elements for the purpose of achieving efficient design knowledge management. However, these researches have not yet provided knowledge-based design support methods and systems based on the ontology.

In contrast, this study concentrates on supporting designers in the specific phase of PSS design procedure, and provides a reasonable tool to support designers. In addition, the proposed knowledge base manages both service and product share on the basis of a common viewpoint "what types of function is become manifest by them." The viewpoint of "function" is very important in the fields of design [Pahl 1996], [Yoshikawa 2000], although the studies on PSS ontology do not consider it.

7. Conclusion

In this paper, we propose a method for knowledge-based PSS design support. The basis of the proposed method is service design methodology discussed in Service Engineering. Furthermore, a prototype of a knowledge-based PSS design support system is developed on the basis of the proposed method. This system supports the acquisition of new PSS design solutions by integrating knowledge accumulated in a knowledge base. The application result showed that the developed system was useful to support a design of the integrated provision of products and services.

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