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A method for analysing conceptual design process of product-service systems

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ABSTRACT

One of the major features of product-service systems (PSS) design is a variety of design elements. This makes its design process complex and obscure. This study aims to develop a method for analysing how the design process influences the features of design solutions in the conceptual design of PSS. In this study, protocol analysis is applied to plural PSS design sessions. Simultaneously, their design solutions are evaluated relatively based on several aspects. Their design processes are analysed in connection with the above evaluation results. The findings obtained by using the proposed method will contribute to creating practical design guidelines for superior PSS development.

1. Introduction

The concept of product-service systems (PSS), hybrid solutions including products and services that create higher value for customers, has been regarded as an important business strategy for established manufacturers to increase their competitiveness and sustainability [1]. Establishing design methodologies for PSS has become a much-discussed endeavour that enables such a manufacturer to generate a valuable new PSS or improve the possibility of a PSS in a systematic way. In the last decade, many researchers have conducted studies on PSS design methodologies (e.g., [2–4]) that provide both elemental technologies (e.g., design models, methods, and tools) and structured processes of how to utilise them.

This article focuses on the conceptual design phase of PSS, the most significant process because it can determine the superiority of the final design solution. In the PSS conceptual design phase, designers must handle a variety of design elements, such as product functions, service processes, and stakeholder networks [3]. This makes the design process more complex and obscure as compared with traditional physical product design processes. At the same time, features of a design solution are generally influenced by its design process. However, there have been few studies to clarify the relationships between features of a PSS design solution and its design process.

The final goal of this study is to develop a practical PSS design support guideline that will help designers generate good PSS design solutions that have certain desired features. As a first step towards achieving that goal, this article proposes a method for analysing PSS conceptual design processes. In this method, a design experiment, a proven approach used in product design studies, is adopted. Towards the end goal of analysing PSS conceptual design processes, this article additionally proposes a PSS design process visualisation scheme that has both abstract and specific points of view. The effectiveness of this visualisation scheme is demonstrated by the application.

The remainder of this article is organised as follows: Section 2 introduces existing studies related to this article. Section 3 provides a detailed explanation of the proposed method. In Section 4, settings and primary results of the PSS design experiments are reported. Section 5 discusses key findings of the experiments along with remaining issues related to this study, and Section 6 concludes this article.

2. Related studies

2.1. Design experiments

In the domain of product design, empirical studies have been conducted to explore the nature of design (e.g., [5,6]). A design experiment is one approach used in these studies. A typical design experiment is carried out as follows [5]: Two or more designers form a design team to solve a design problem. The important point is that designers must discuss everything they consider while designing. This is the method, called protocol analysis, that was originally used in psychology. Protocol analysis enables researchers to obtain data regarding designers' thoughts during the design process. For example, Takeda et al. [5] carried out several design experiments to formalise a logical design process. In these studies, they found that design processes are composed of design cycles, which include units of awareness of the problem, suggestion, development, evaluation, and conclusion. Gero and McNeill [6] argued the importance of structuring protocol data in order to analyse design processes specifically. They proposed a coding scheme of protocol data. Encoded protocol data were visualised and analysed using time-axis activity charts. The coding scheme

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and charts made it possible to capture design-process trends in a quantitative way.

2.2. PSS design experiments

Few empirical studies have looked at PSS design using the method of design experiments. Sakao et al. [7], arguing that there is a lack of deep insight into PSS design processes, carried out PSS design experiments. The protocol data obtained in the experiments were analysed using a coding scheme that extends the aforementioned coding scheme [6] to divide the obtained information into eight proposed PSS design elements: Need, Value, Deliverables, Lifecycle activities, Actors, Core products, Periphery, Contract elements, and Finance. This study developed the hypothesis that PSS design follows a general process of problem solving, and that PSS design begins with Need and Value, mainly addresses Lifecycle Activities with particular dimensions addressed for solutions, and ends with Value. On the other hand, Lee et al. [8] analysed PSS design processes focusing on team interactions. They proposed another coding scheme that specialised in visualising interactions between members of the design team. The result of their analysis revealed that each team member took leading roles in different design activities in the PSS design process based on his or her individual knowledge and expertise.

2.3. Scope of this article

The studies mentioned in Section 2.2 [7,8] provide us with important insights and hypotheses about the PSS design process. However, they did not mention the relationships between features of the design solution and the design process. To develop effective and practical PSS design support guidelines, a deeper understanding of these relationships is necessary. This is because better design processes vary, depending on the goal to be achieved by the design. For example, a design solution that is highly novel would be different from a design solution with high acceptability. This makes it difficult to select an applicable design process. Therefore, this study aspires to analyse design processes in connection with an evaluation of design solutions.

As Gero and McNeill [6] argued, protocol data provide rich information but are not structured. Schemes to encode and visualise protocol data should be determined in response to the objective of the analysis. Sakao et al. [7] adopt eight PSS design elements in their coding scheme. These elements are abstract and suitable for grasping an outline of design processes. On the other hand, more specific points of view are also required to conduct a deeper analysis of design processes. Thus, the proposal in this study includes a coding and visualisation scheme that has both abstract and specific points of view.

3. Method for analysing PSS conceptual design processes

3.1. Overview

Fig. 1 gives an overview of the proposed method. First, plural PSS design sessions are conducted as design experiments. From each session, output and protocol data are collected. Protocol data are structured and represented as design processes by adopting the visualisation scheme proposed in this study. To realise this scheme, specific PSS design elements for the coding of protocol data are organised. On another front, design solutions are evaluated from a certain or several aspect(s). Finally, the qualitative and/or quantitative differences of each design process are compared in connection with the evaluation results.

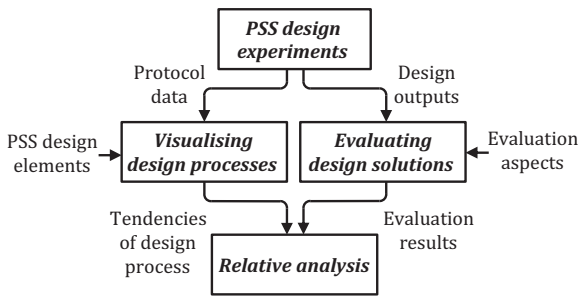

Fig. 1. Overview of the proposed method.

3.2. Organising PSS design elements

To realise a PSS design process visualisation scheme that has both abstract and specific points of view, PSS design elements were sorted and organised. From various journals and conference proceedings, the authors collected papers related to PSS conceptual design. From 50 papers selected, 170 descriptions of design elements in PSS conceptual designs were marked. Using an affinity diagram, we summarised these descriptions of 18 specific PSS design elements and organised them into 6 abstract categories. Table 1 shows the categories and design elements with a short explanation of each.

Table 1
PSS design elements organised in this study.

Category	Design element	Content
Customer (CU)	Customer	Images of the target customer (e.g., segments and preferences)
	Requirement	Specified needs and/or problems that the target customer has
	Customer activity	Customer activities related to the PSS
Value proposition (VP)	Life cycle phase	Life cycle phases of the product that contain value proposition opportunities
	Function	Offerings to satisfy customer requirements
Product-service architecture (PS)	Entity	Concrete products and services to realise the functions
	Configuration	Modules of products and services
	Module interface	Interfaces between modules
	Human interface	Interfaces between the customer and modules
Actor network (AN)	Partner	Companies or individuals that must cooperate
	Company role	Activities of the designers' own company in the actor network
	Partner role	Activities of partners in the actor network
	Contract	Contracts between actors
	Profit and loss structure	Streams of money from one actor to another
Process (PR)	Actor interaction	Resource offerings from one actor to another
	Delivery process	PSS delivery process to the target customer
Resource (RE)	Procurement	Procurement channels of resources to realise the PSS
	Allocation	Resource allocation to realise the PSS

3.3. Visualising the PSS design process

Before visualisation, protocol data are encoded using the 18 design elements mentioned in Section 3.2. Coders encode each utterance in the protocol data, reading the speaker's intention. For the sake of consistency, the coding process should be conducted by discussion among several coders [6]. After the coding process, fully encoded protocol data are represented graphically by using time-axis charts. In such a chart, each of the design elements, i.e., coding dimensions, is plotted against time. As shown in Fig. 2(a), each

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