Qualitative Simulation for Early-Stage Service Design

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Abstract

Currently, the importance of services is widely accepted in various industries. Given this background, fundamental research on service engineering is carried out quite actively. Service engineering seeks to provide design methodology for services from an engineering perspective.

In product and service design, designers are generally forced to spend a lot of redesign works if design changes occur at a late stage of the design process. Thus, it is important for designers to validate design solutions in the early stage(s) of the design process by using simulation methods. However, simulation models in the existing methods are built with quantitative information. In the early stages of the service design process, most of the information about a design solution is still not defined; therefore, it is difficult to obtain sufficient quantitative information. For obtaining such quantitative information, service providers need to offer a designed service to their customers as a trial, which impose much effort for building quantitative simulation models. In order to reduce such risks, this research applies a qualitative simulation method, which can be used to analyze the behavior of systems with fuzzy qualitative information. In this paper, we propose a method to build a qualitative simulation model with the design information available at the early stage(s) of the service design process. This method would enable designers to evaluate a design solution in the early stage of a service design process and would increases quality of the service design.

Keywords:
Service Engineering, Qualitative Simulation

1 INTRODUCTION

With the global economy beginning to mature, several industries have started to regard services as an effective way of enhancing customer satisfaction. The service industry accounts for more than 70% of the workforce and gross domestic product (GDP) in Japan, the United States, and the European Union [1]. Of late, some manufacturing companies have been making a fundamental shift from selling only physical products to providing services.

Until recently, research on services was conducted mainly in the marketing or management field, and rational methods for realizing services with high productivity were still in the research phase. Recently, researchers have begun to examine services from an engineering or scientific perspective rather than from the traditional marketing or management view. For example, in Japan, Shimomura et al. conducted a study to design services from an engineering viewpoint. This research belongs to the “Service Engineering [2-3]” series. In other regions, especially Europe, product-service systems (PSSs) [4] are considered the new business model that will help manufacturing firms gain competitiveness. A PSS consists of tangible products and intangible services, which are designed and combined so that they are jointly capable of fulfilling specific customer needs. Studies in service science, management, and engineering (SSME) [5] have been conducted mainly in the context of the United States. SSME proposes a scheme to create the basis for systematic service with knowledge integration.

In general product and service design, designers would need to spend a lot of money and time if design changes occur in the final stage of the design process. In order to obviate design changes, simulation methods are effective in predicting problems that could be happen in the last stage of the design process. This approach would enable designers to address these problems and decrease redesign works. Thus, it is important for designers to evaluate design solutions in the early stage(s) of the design process by using simulation methods.

While existing simulation methods are effective for decreasing reworks, difficulties remain in the construction of simulation models. In the extant simulation methods, the simulation models are built with quantitative information. In the early stages of the service design process, most of the information about the design solution is still not defined. In addition, services are produced and consumed simultaneously in many cases. That is, services only exist while offering goods to or conducting some activities for the customers. This characteristic of services is called “simultaneity” [6]. In order to obtain quantitative information for constructing simulation models, service providers need to offer a designed service to customers as a trial and evaluate a current service. Thus, service designers must invest a lot of time and effort in building the quantitative simulation models.

In contrast, some prior researchers in the field of product design applied the concept of qualitative simulation [7] to the conceptual design of products [8–9]. The qualitative simulation method can be used to analyze the behavior of systems with fuzzy qualitative information. This qualitative information is useful for evaluating the behavior of physical features in the early stage(s) of the product design process. In order to address the difficulties associated with constructing quantitative simulation models for a service design, this paper applies qualitative simulation methods to the service design process. In particular, this paper focuses on building a valid simulation model. The proposed method could enable designers to evaluate a design solution in the early stage(s) of a design process.

2 SERVICE DESIGN PROCESS AND SIMULATION

2.1 Service design process

Fig.1 V-model representing the service design process

In the service design process, such as IT-enabled service, the V-model [10] is widely used. The V-model is a process model that shows the correspondence between the design and development process and the test execution phase in a V shape (Fig. 1). In Figure 1, the design and development phase are shown on the left-hand side of the model. In the Define Service Requirements phase (the second stage on the left-hand side), the customer requirements, business targets, and service levels are defined according to the results of the previous phase (Define Customer Business Requirements). The third stage, i.e., the Design Service Solution phase, focuses on designing the system architecture. In this phase, an overview of the service solution that includes availability management, capacity management, and cost of providing service is developed. Subsequently, in the Design Service Release phase, the fundamental policy and procedure into the real environment are defined. Finally, in the Develop Service Solution phase, the detailed service design and all the required coding are conducted.

2.2 Existing Service Simulation

As was mentioned in Section 1, designers would need to spend a lot of time and money if design changes happen in the later phase, i.e., the right side of the V-model. Thus, it is important for designers to predict problems that could occur in the last stage of the design process; subsequently, they need to take measures to prevent such problems. A number of computational simulation technologies have been developed for predicting problems and evaluating design solutions [11–14].

Petri net models [15] are widely used to visualize service behaviors. For example, Yamaguchi developed a modeling method for analyzing the workflow in a restaurant. In this context, a Petri net simulation is useful for evaluating the effectiveness of introducing an information and communications technology system to the workflow [11]. Hatakeyama developed a simulator called “TEMPO SYSTEM” that analyzes a customer’s purchasing behavior in a fast-food restaurant by using Petri net models. Further, Tsubouchi developed a simulator to enhance the efficiency of operating on-demand buses that people use for ride-sharing by using a reservation system [13].

In the extant research on PSS design, some simulation and modeling methods have been investigated. For example, Meier proposed a PSS simulation method for predicting the business growth of companies [16–18]. Akasaka proposed a modeling and simulation method to design PSSs that could realize high values for each stakeholder [16]. These prior studies aimed at delivering a design and engineering approach for dynamic PSS business models using system dynamics (SD) [19].

3 APPROACH OF THIS STUDY

In the existing simulation methods, the simulation models are generally built with the quantitative information that can be obtained from the results of service offerings in a real situation.

One problem with existing simulation methods is that it takes a lot of time and cost to obtain the quantitative information required for the simulation model. In contrast, qualitative simulation is a simulation method that can be used to analyze the behaviors of systems with fuzzy information. The qualitative simulation method is expected to predict service behaviors in the early stage(s) of service design, when it is difficult to obtain the quantitative information required for the simulation model.

This paper applies the qualitative simulation method to the service design process to ensure efficient service design.

3.1 Qualitative Reasoning

Qualitative reasoning is an area of artificial intelligence that provides the means to formally represent reasoning with conceptual knowledge. Qualitative reasoning has proven to be a cost effective, reliable, and efficient means of analyzing the behavior of systems without numerical information. The qualitative prediction of behavior is conducted by reasoning about the physical world that changes over time. This prediction is called qualitative simulation. In the qualitative simulation model, the state of each parameter consists of the qualitative value and the derivative value. The qualitative values are expressed by a finite number of landmarks; the derivative values are expressed by a qualitative value: “increases,” “decreases,” or “becomes stable.”

3.2 Qualitative Process Theory

In a series of studies, Forbus developed a process-based approach for qualitative reasoning, called the qualitative process theory [20]. A typical example of such processes is heat flow or movement.

According to the qualitative process theory, there are two causal relations between parameters: direct influence and indirect influence. Direct influence I+ (Q2, Q1) causes the parameter Q2 to increase if Q1 takes a positive value.

Indirect influences correspond to relationships between two parameters that represent some mechanisms for the process. They set the derivative of the target parameter depending on the derivative of the source parameter. An indirect influence P+ (Q2, Q1) causes the parameter Q2 to increase (decrease) if another parameter Q1 increases (decreases). Therefore, indirect influences are referred to as qualitative proportional relations.

A qualitative reasoning engine generally takes as input a scenario that describes the initial state of the system. Subsequently, the qualitative engine produces a state graph that qualitatively captures the distinct states of the system. A state graph consists of a set of states, i.e., state transitions. Thus, a state graph shows a set of possible paths of system behaviors. A state transition specifies how one state changes into another state. A sequence of states connected by state transitions is called a behavior path. The following example describes a qualitative simulation for heat flow (Fig. 2) [21].

1. After the heater is turned on, the heat flow process causes heat to flow from the heater to the container and the water. This causes the temperature of the container and the water to increase. This behavior may lead to other states (state 2 or state 3).
2. The temperature of the water in the container is now equal to the temperature of the heater. From here on, no further changes can take place.
3. The water temperature reaches boiling point. A new process “boiling” becomes active, which causes the generation of steam. This behavior may lead to another state (state 4).
4. All the water has now turned into steam. The boiling process has stopped, but the heat flow continues. This behavior may lead to other states (state 2 or state 5).
5. If the heater is warm enough, it may ultimately cause the container to melt because the container will reach its melting point. Hence, the simulation stops here.

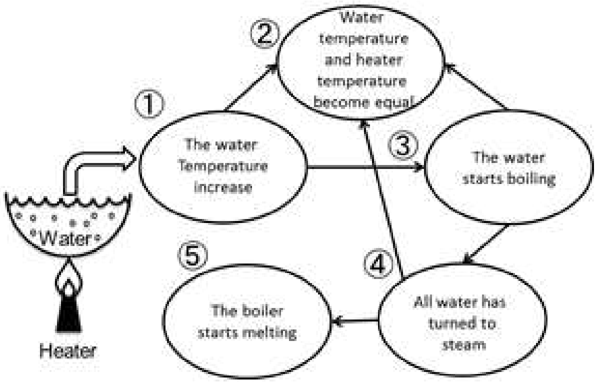

Fig.2 Behaviors of heat flow

4 SERVICE DESIGN PROCESS USING QUALITATIVE SIMULATION

4.1 Overview

In this study, qualitative simulation methods are applied to the early-stage design process to ensure efficient service design.

Figure 3 presents an overview of the proposed design cycle, which consists of three phases: Service Modeling, Behavioral Pattern Classification, and Convergence to the Ideal Behavior. In the Service Modeling phase, the qualitative simulation model is constructed by setting the parameters and qualitative causal relationships based on the service design model. In the Behavioral Pattern Classification phase, the system behaviors that could possibly arise from the qualitative simulation model are produced by the qualitative simulation, and the behaviors are classified. Finally, the designers identify an ideal behavior from among the produced behavioral patterns; subsequently, some conditions or constraints are added to the qualitative simulation model in the Convergence to the Ideal Behavior phase.

To design services efficiently, valid simulation models that reflect the designer’s recognition need to be constructed. Therefore, this paper focuses on Service Modeling and Behavioral Pattern Classification in order to construct a valid qualitative simulation model in stages (red dashed line in Fig. 3).

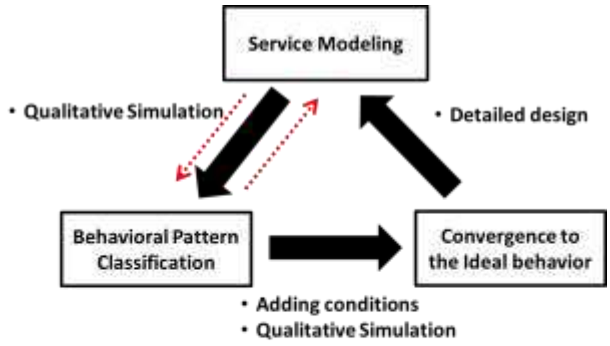

Fig.3 Overview of the proposed design cycle

4.2 Service Modeling

The first step (Service Modeling) of the design cycle is meant for analyzing the service structure. The goal of this step is to construct a coarse qualitative simulation service model. A qualitative simulation model is constructed based on information obtained during the early stage(s) of the design process. In this study, an actor network model [22] that describes the service structure with the elements stakeholder and requirement (Fig. 4) plays a key role. The simulation model is based on the constructed actor network model. The parameters that represent the changeable features in the simulation model are determined by each stakeholder’s requirement(s). In addition, the parameters related to these requirements are also determined. This qualitative simulation model includes direct/indirect influences between the parameters in the manner proposed in the qualitative process theory.

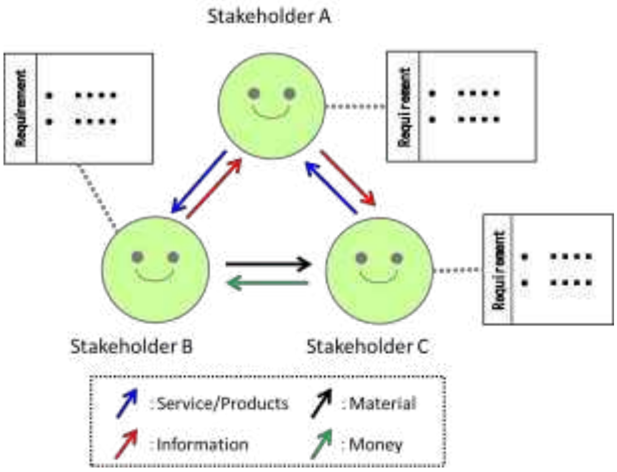

Fig.4 Actor network model

4.3 Behavioral Pattern

For the simulation, the initial state of the system needs to be defined. According to the initial values of each of the parameters, the possible system behaviors are produced by qualitative simulation.

The state graph and the histories of each parameter’s value are shown in Figure 5. The produced behaviors are classified into various patterns based on the final state of the parameters (Fig. 5). By referring to these results, the designers confirm whether all of the assumed behaviors were produced. If the assumed behaviors are not produced, the designers restructure the simulation model and simulate it once again. A simulation model is ensured validity in the different stages through Service Modeling and Behavioral Pattern Classification.

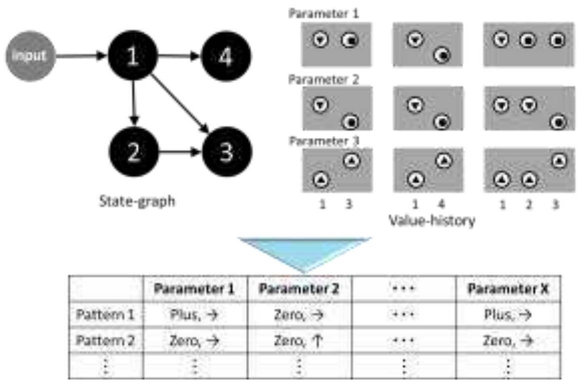

Fig.5 Classifying behavioral patterns

4.4 Convergence

Based on the simulation results, the designers select one ideal behavior from all the behaviors. The ideal behavior represents a tentative design solution that could satisfy the stakeholders' requirements from the service. In order to ensure convergence to the ideal behavior, the designers seek conditions (e.g., constraint conditions between two parameters or initial condition); subsequently, these conditions are added to the simulation model. These conditions correspond to the design guideline. This addition enables the simulation model to produce the ideal behavior. If the simulation result satisfies the designer's ideal behavior, the simulation model indicates progress in service design.

5 APPLICATION TO SAMPLE CASE

In this section, the proposed design cycle—especially the Service Modeling and Behavioral Pattern Classification phases—was applied to a sample service case. This application has two purposes. One is to construct a valid simulation model. The other is to determine whether the assumed behaviors will be produced. The example used in this study involved a car sharing service (CS). Car sharing is a business where the users share their cars with registered members.

5.1 Modeling of Car Sharing

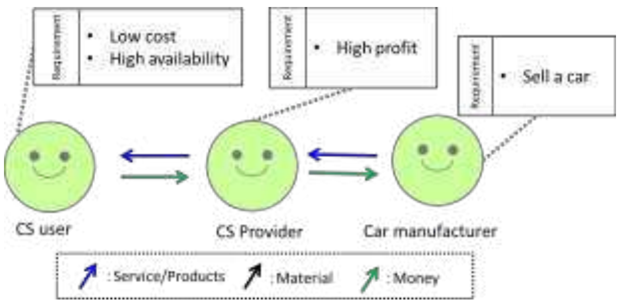

Fig.6 Result of the actor network model

First, the structure of car sharing was modeled using the actor network model. Figure 6 illustrates the result of the actor network model. As shown in Figure 6, the stakeholders include the car sharing user (CS user), the car sharing provider (CS provider), and the car manufacturer. Each stakeholder has his/her own requirements. The CS user's requirements include low cost and high availability; the CS provider's requirements include high profit; and the car manufacturer's requirements include high amount of sales.

Based on the constructed actor network model, the parameters for the simulation model were determined according to each stakeholder's requirements. For instance, "Pay for the use of cars" in the simulation model was set as a parameter to represent the qualitative state of the CS user's requirement "Low cost."

Subsequently, the parameters were connected to one another with causal relationships, and the simulation model was constructed. The result of the simulation model is shown in Figure 7. For instance, "Profit of the CS provider" increases if the qualitative value of "Pay for the use of cars" is positive. Therefore, there is a positive direct influence (I+) between "Pay for the use of cars" and "Profit of the CS provider."

On the other hand, the CS provider considers buying more cars to expand his/her business as profit increases. Therefore, "Sell a car" is proportional to "Profit of the CS provider;" i.e., there is an indirect positive influence (P+) between "Profit of the CS provider" and "Sell a car."

Each parameter has qualitative values and derivative values as quantity spaces. In this paper, two qualitative values, namely, "Plus" and "Zero" or "High and Low", are set to express whether or not the amount existed. For "CS availability", qualitative values {"High" and "Low"} are set to express magnitude of quantities.

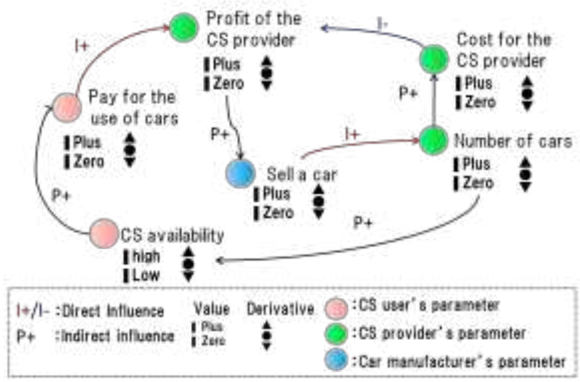

Fig.7 Result of the simulation model

5.2 Behavioral Pattern

The qualitative simulation model was built and the qualitative simulation was carried out using Garp3 [21], which is a software for qualitative process theory-based simulation.

The initial qualitative values of the parameters in the simulation are as follows:

- The value of "Profit of the CS provider" is Plus
- The value of "The number of cars" is Plus
- The value of "CS availability " is low

Table 1 Behavioral patterns produced in first simulation

	Profit of the CS provider	Cost for the CS provider	Number of cars	Pay for the use of car	CS availability	Sell a car
Scenario	Plus		Plus		Low	
Pattern 1	Plus, ↑	Plus, ↑	Plus, ↑	Plus, ↑	High, ↑	Plus, ↑
Pattern 2	Plus, →	Plus, ↑	Plus, ↑	Plus, ↑	High, ↑	Plus, →
Pattern 3	Zero, ↓	Plus, ↑	Plus, ↑	Plus, ↑	High, ↑	Plus, ↓

↑: increase; ↓: decrease; →: stable

In the car sharing example, the qualitative simulation model produced three patterns as service behaviors (see Table 1). For example, Pattern 1 in Table 1 indicates that all the parameters increase. However, in actual business, "CS availability" may decrease, remain stable, or increase depending on the number of CS users. Therefore, we added the parameters "Number of CS users" and "Apply for CS membership" to the model. The result of the refined simulation model is shown in Figure 8. For instance, in the refined simulation model, there was an indirect negative influence (P-) between "CS availability" and "Number of CS users." Table 2 presents the results of the second simulation.

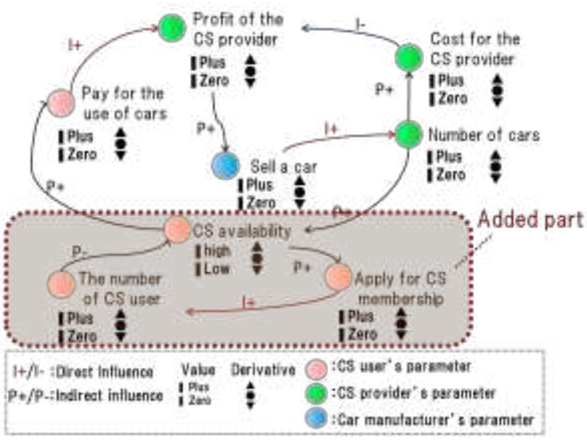

Fig.8 The revised simulation model

The simulation for the reconstructed model produced nine patterns of behaviors as shown in Table 2. For instance, depending on the values of the other parameters, "CS availability" could increase (e.g., Pattern 1), decrease (e.g., Pattern 2), or remain stable (e.g., Pattern 4).

From these results, Pattern 1 in Table 2 was accepted as a tentative design solution, since Pattern 1 appears to satisfy the requirements of all the stakeholders ("CS availability," "Profit of the CS provider," and "Sell a car"). However, further consideration is required to improve the solution since "Pay for the use of cars" would increase in Pattern 1 as shown in Table 2. As was discussed in Section 5.1, one of the CS user's requirements is low cost. The tentative simulation model in Figure 8 has no parameters and causal relationships that could satisfy the CS user's "Low cost" requirement. A detailed service design is required to address this issue.

6 DISCUSSION

In this paper, a simulation model was constructed based on an actor network model. The initial simulation model in Figure 7 produced a service behavior that was different from the behavior we had assumed. Therefore, we included additional parameters to obtain the assumed service behaviors. It was clear that we needed to add "Number of CS users" and "Apply for CS membership" as parameters related to "CS availability." The reconstructed simulation model in Figure 8 produced the assumed behaviors that exist in actual business situations (see Table 2).

These results indicate that the proposed design cycle enables designers to increase the validity of the simulation model in stages. In this study, the simulation model was restructured by trial and error. Future work could include a procedure for systematically improving the simulation models.

Further, this paper applied the proposed design cycle to a small-scale example. Future work could attempt to apply this design cycle to a large-scale example.

7 CONCLUSION

The purpose of this study was to improve service design quality. We proposed a service design cycle applying qualitative simulation methods to improve the service design process. This paper focused on constructing a valid qualitative simulation model that could yield the assumed behaviors.

In order to evaluate the proposed design cycle, we applied the proposed design cycle to the case of a car sharing service. We constructed a valid qualitative simulation model through Service Modeling and Behavioral Pattern Classification. This application exemplified the construction of a valid simulation model in stages; the results (in Table 2) represent the assumed behavioral that were produced.

The third design cycle (Divergence Behavioral Pattern) needs to be applied to the example case in future work. In addition, future research should attempt to construct a wider-scale service model to ensure efficient design in the early stage(s) of service design.

Table 2 Behavioral patterns produced in second simulation

	Profit of the CS provider	Cost for the CS provider	Number of cars	Pay for the use of cars	CS availability	Apply for CS membership	Number of CS users	Sell a car
Scenario	Plus		Plus		Low	Plus	Plus	
Pattern 1	Plus, ↑	Plus, ↑	Plus, ↑	Plus, ↑	High, ↑	Plus, ↑	Plus, ↑	Plus, ↑
Pattern 2	Plus, ↑	Plus, ↑	Plus, ↑	Plus, ↓	Low, ↓	Plus, ↓	Plus, ↑	Plus, ↑
Pattern 3	Plus, ↑	Plus, ↑	Plus, ↑	Plus, ↑	Low, ↓	Plus, ↓	Plus, ↑	Plus, ↑
Pattern 4	Plus, ↑	Plus, ↑	Plus, ↑	Plus, ↑	Low, →	Plus, →	Plus, ↑	Plus, ↑
Pattern 5	Plus, →	Plus, ↑	Plus, ↑	Plus, ↓	Low, ↓	Plus, ↓	Plus, ↑	Plus, →
Pattern 6	Plus, →	Plus, ↑	Plus, ↑	Plus, ↑	Low, ↓	Plus, ↓	Plus, ↑	Plus, →
Pattern 7	Plus, ↓	Plus, ↑	Plus, ↑	Plus, ↑	Low, ↓	Plus, ↓	Plus, ↑	Plus, ↓
Pattern 8	Plus, ↓	Plus, ↑	Plus, ↑	Plus, ↑	High, ↑	Plus, ↑	Plus, ↑	Plus, ↓
Pattern 9	Plus, ↓	Plus, ↑	Plus, ↑	Plus, →	Low, ↓	Plus, ↓	Plus, ↑	Plus, ↓

↑: increase; ↓: decrease; →: stable

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