Service Engineering: a novel engineering discipline for producers to increase value combining service and product

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Service Engineering: A Novel Engineering Discipline for Producers to Increase Value Combining Service and Product

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Abstract:

In order to pursue sustainability, commercial activities between the supply and demand sides must be somehow changed. In the context of eco-design, producers must need a much bigger framework than is available in current eco-design techniques. This calls for establishing a new discipline. This paper aims at proposing a novel engineering discipline for producers toward sustainable production and consumption, Service Engineering (SE). For the sake of this, the scheme of SE is first explained. Second, a methodology of modeling and designing services, and a computer-aided design tool called Service Explorer, are presented. Third, they are proved to be effective through two applications. In SE, positive and negative changes of consumers are modelled as value and cost, respectively. In addition, the model to describe a target consumer is provided for grounding the identified value. A design methodology including the identification of value with realization structures is also provided. Furthermore, SE allows designing services in parallel with products. In the application to service redesign of an existing hotel in Italy, it was demonstrated that the presented methods and tools facilitate designers adding new value like the view of outside through a window in energy-saving structure. It was also proved to deal with both products and services through generating a solution called "cash-back per non-wash" system for washing towels. The other smaller-scaled application to design of renting home appliances revealed that they support to determine a property of an adopted physical product like the size of a TV set depending on target customers' properties effectively.

Keywords: Design, Value, Service, Product, Consumer Model

1. Introduction

Sustainability is a challenge for people on our planet. International organizations such as the United Nations have recognized the need to tackle this issue. As a result, the "Agenda 21" [1] was developed at the Rio Earth Summit, with an objective "to promote patterns of consumption and production that reduce environmental stress and will meet the basic needs of humanity". In 1994, the Oslo Symposium [2] pointed out the necessity to link production to consumption with a working definition of sustainable consumption which is used by many researchers and organizations including OECD [3, 4]. However, very few industrial activities are practiced in a form of sustainable production linked with sustainable consumption. One of the greatest barriers preventing producers and consumers to go for it is obviously just that producers are profit organizations and consumers demand based on their needs. Even many of the eco-efficient services with more success are suggested to be not necessarily driven by environmental considerations [5]. The problem can not be solved unless commercial activities between the supply and demand sides are somehow changed.

A number of producers' activities can be seen as successful sustainable productions if the supply side alone is focused. A number of methodologies and tools for eco-design of physical products have been developed (e.g. [6-9]) and a lot of eco-designed products are released on the market. However, very few of those methodologies and tools have succeeded in incorporating the needs of consumers effectively. Consequently, eco-designed products are not necessarily accepted by consumers at present [10]. The case where producers succeed in releasing eco-products that are well accepted by consumers in contrast, –often ends up with "more consumption of sustainable products" [11]. Producers should be more careful of consumers' needs if they pursue profitable activities through sustainable consumption.

What kind of discipline do those producers pursing sustainable production linked with sustainable consumption call for? A much bigger framework is obviously needed, because a business model must be changed ultimately. It may be impossible to tackle this problem by only one of those disciplines such as engineering, marketing, and management. Thus, establishing a new discipline is crucial to solve this problem and this will be a new academic discipline.

This paper aims at proposing a novel engineering discipline for producers toward sustainable production and consumption, Service Engineering (SE). It should be an engineering discipline because engineering lies in a core of producers' activities. To do so, the scheme of SE [3] is first explained. Second, a service model, a method of designing services, a computer-aided design tool called Service Explorer, is presented. Third, those methods and tools are verified to be effective through applications.

The rest of this paper consists of the followings. Section 2 explains missing points of current eco-design techniques. Then, Section 3 presents the discipline, SE, including the methodologies and the tool. Section 4 demonstrates their application to two service cases. Section 5 discusses how SE is effective and innovative, and Section 6 concludes the paper.

2. Limitations of current eco-design techniques

A number of methodologies and tools for eco-design of physical products have been developed (e.g. [6-9]) and production industries have succeeded to release a lot of eco-designed products on the market as they got more environmentally conscious. However, very few of those products so far achieved sustainable consumption accepted by consumers. Namely, the present sustainable production in many cases does not accelerate sustainable consumption. One of the reasons is that they regard an activity of incorporating environmental consciousness as an appendix to designing physical structure for a requested functionality.

Producers should be more careful of how to carry out business activities of sustainable consumption. To do so, the concept of value is among the crucial pieces, because value is the interface between consumers and producers. This concept coupled with the antonym term, cost, in the eco-design context is further explained using a metaphor in Figure 1. It should be noted that the cost in this case does not mean only monetary cost but includes environmental burden as well as various costs such as money and time. The plate is a design object, while two bars fit through the holes of the plate represent axes of value and cost. The holes have a small play around the bars. If only environmental burden is tried to be lowered, the cost is decreased by only a little (Transformation 1). Imagine a notebook made of high-rate recycled paper but quite easy to be torn. Manufactures try to decrease the environmental burden by selling this type of notebook, but it is not realized due to its lowered value. An example for the second type, which is favorable from the ecological viewpoint, is introduction of energy saving functionality. Namely, the economic value on consumers is automatically increased while the environmental burden is decreased. In order to increase the value without the immediate influence from the cost reduction, a new value must be added (Transformation 3). This type of support is the first point that current eco-design techniques lack.

It is obvious that value is a concept varying from one consumer to another. Thus, consumer modeling utilized for the following design activities is automatically crucial. This will be the second missing piece, since most of current eco-design deals with a flat recognition on various consumers.

The last point to be argued is that there exists too much focus on physical products without an emphasis on services provided together. Here, another metaphor with the same physical structure in Figure 1 comes on the stage (See Figure 2). Two bars represent product and service, which are regarded as important factors constituting a design object. If only a product or service is designed, the total value is not increased considerably (Operation 1 and 2, respectively). By designing a set of product and service, the total value gets higher effectively. It is true that many methods dealing with service in eco-design exist (e.g. [12]). However, very few have tackled so far establishing a method and tool that pursue providing a high value for customers by designing services in parallel with designing products. It is also important to pay attention to the general trend that services instead of physical products get more wanted as economies mature (e.g. [13]).

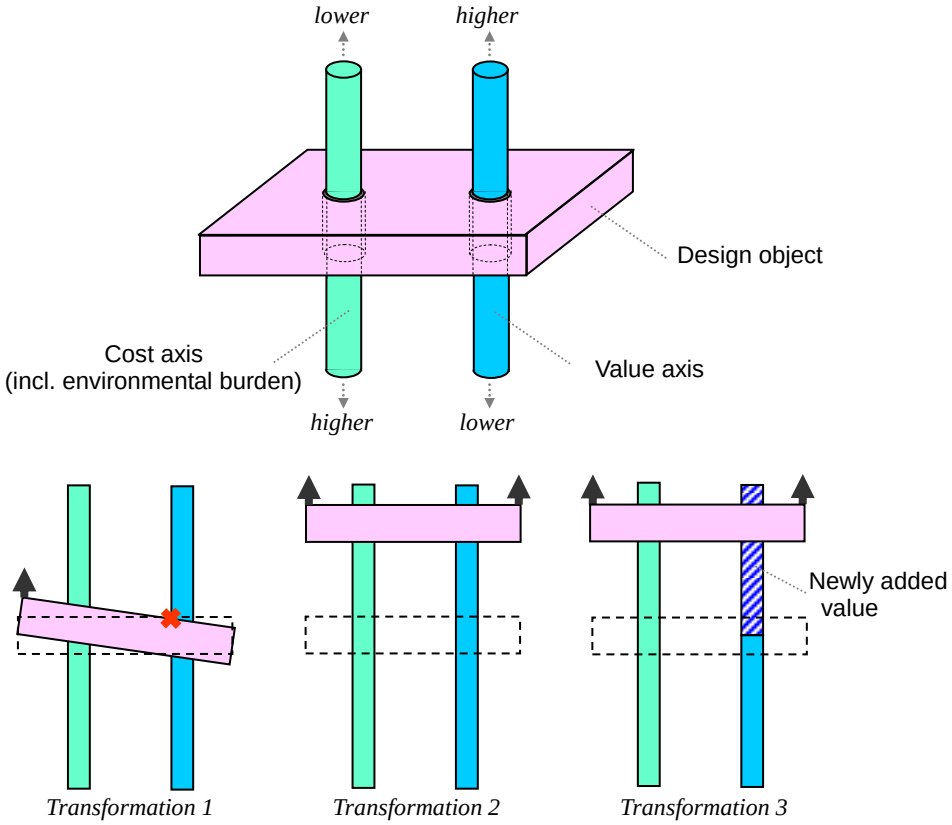


Figure 1: Three types of changing consumptions

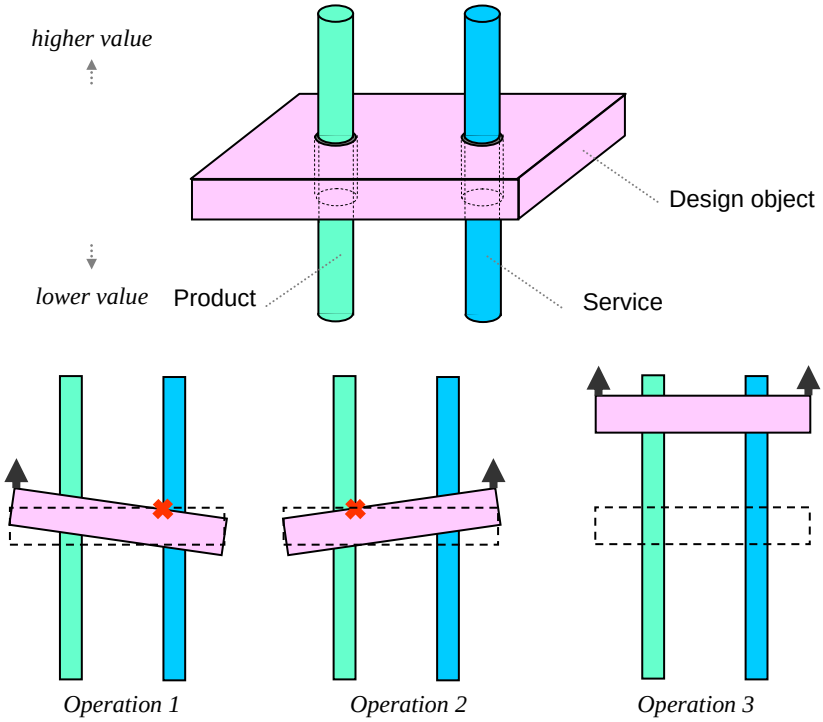


Figure 2: Design operations with constraint between product and service

3. Discipline of Service Engineering

3.1. Fundamental of Service Engineering

A service is defined as an activity that a provider causes, usually with consideration, a receiver to change from an existing state to a new state that the receiver desires, where both a content and a channel are means to realize the service [14, 15] (See Figure 3). Service contents are provided by a service provider and delivered through a service channel. A physical product is either a service content or a service channel. Thus, selling physical products is also regarded here as a service. Hence, a service receiver is satisfied with just contents, which are any of material, energy, and information. A service channel is used to transfer, amplify, and control the service contents.

In this definition, artifacts can be either contents or channels. Artifacts have their own functions, behaviors, and states, and therefore they can be designed with conventional CAD (computer aided design) systems. Hence, a methodology similar to conventional design will be introduced to the design of services.

The term "service" has been defined; however, what is Service Engineering (SE)? It is a discipline to increase the value of artifacts and to decrease the load on the environment by reasons of focusing service. Note that SE has both analytical and synthetic aspects. SE aims at intensifying, improving, and automating this whole framework of service creation, service delivery, and service consumption. To increase the total satisfaction of receivers, we can improve functions and/or quality of both channels and contents. Traditionally, engineering design has aimed to improve only function. A better function of a new product, we have believed, makes consumers satisfied. In SE, however, not only the functions of artifacts but also meaning of contents must be matched to the specifications given by receivers. Then the satisfaction of receivers increases.

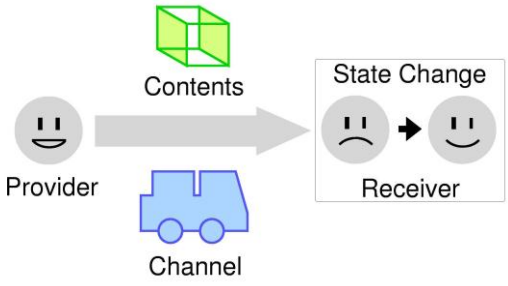


Figure 3: The elements of service [14]

3.2. Modelling methodology

3.2.1. The outline of a service model

The service model consists of several sub-models; "flow model", "scope model", "view model", and "scenario model". The rest of Paragraph 3.2 explains the four sub-models with more focus on the latter two after describing an important concept in the sub-models called "receiver state parameter".

The reason for modeling "receiver state parameter" is as follows. Conventional engineering design regards mainly the performance of physical products: It does not consider the state

change of the receiver. Designing a service must be based on the degree of satisfaction with the state change of a receiver. Therefore, it is necessary to express receiver's state changes.

3.2.2. Receiver state parameter

Receiver state parameters (RSPs) are classified into value and cost depending on whether the customers like them or not. The term "value" here is different from that in Value Engineering [16], where it is defined as function over economic cost. In SE, value is defined as change of a receiver's state that he/she prefers, so that function is just a realization method to provide the value in SE.

Change of a receiver is represented by a set of RSPs. Since an RSP represent quantitative value, based on Boolean logic, multi-value logic, etc., we can compute any comparison between two RSPs. In addition, we introduced an assumption that all RSPs are observable and controllable. This assumption has been unproven with human receivers because we have not had a reliable method to measure consumer behaviours.

RSPs change directly by received contents, whose flow is changed by a channel. Hence, RSPs change indirectly by a channel. A content and a channel are described by content parameters (CoPs) and channel parameters (ChPs), respectively. Both a content and a channel have functions to influence RSPs. A function is represented by its name, Function Name (FN), and by its influence, Function Influences (FIs). Thus, CoPs and ChPs are called Function Parameters (FPs). It should be pointed out that the selection of contents and channels is subjective – and this seems to be among the greatest reason that services have not been sufficiently dealt with as an engineering issue.

For instance, in a service by a cafe, one can recognize positive RSPs such as a taste of coffee, sound of music, and even workspace available. On the other hand, negative RSPs in the service may include a monetary cost, transportation to the cafe, and noise.

3.2.3. Flow model

Services are in general delivered through a network. Between a receiver and a provider, many intermediate agents exist. Intermediate agents have double characteristics of a receiver and a provider. We call the sequential chain of agents a "flow model" of a service. This model is needed because designers are supposed in SE to consider how organizations participating in a concerned service could be successful in their business.

For instance, in a service by a cafe, agents such as a cafe runner, a customer, and a coffee machine maker participate (see the upper part of Figure 4).

3.2.4. Scope model

It is necessary to specify a range of a service spanning from an initial provider to a final receiver for effective service design. For the sake of this, a "scope model" was introduced. A scope model includes all the RSPs within the relevant provider and receiver (see Figure 4). Designers of a coffee machine will need scope models both between a coffee machine maker and a cafe runner and between a coffee machine maker and a customer of a cafe for effective

design.

3.2.5. View model

A view model expresses the mutual relationships among RSPs and FPs (CoPs and ChPs). Thus, it helps designers with customizing value and costs in the form of RSPs by changing corresponding realization structures represented in the form of FPs. It should be emphasized that not only products but also services are represented by CoPs and ChPs. In a view model of a cafe service, which is taken from the scope model between a cafe runner and a cafe customer carrying out his/her jobs there with drinking coffee, an RSP of workspace available can be connected to CoPs such as a size of a table and a shape of a chair. Then, those CoPs might be connected to a ChP of evenness of a floor. It should be emphasized that a view model works as a bridge between value/costs represented in the form of RSP and structures of physical products and service activities.

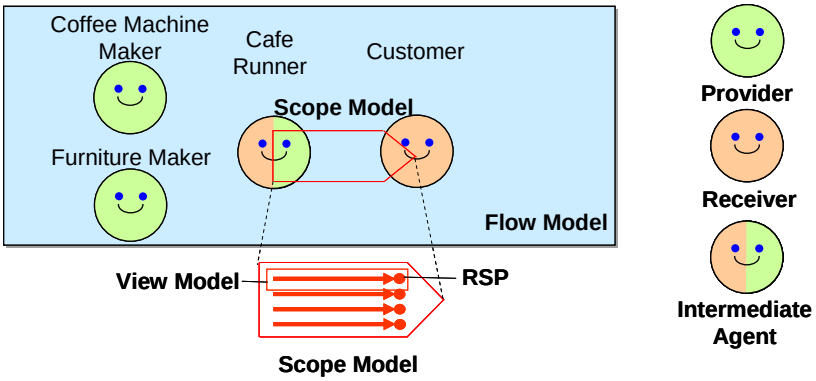


Figure 4: The relation among three sub models; flow model, scope model, and view model

3.2.6. Scenario model

Last but not least, the scenario model is explained. This model represents receivers themselves and their behaviors in receiving the service. This is necessary because the grounds behind RSPs of service receivers should be understood. In other words, the scenario model serves as a direct source for producing a variety of RSP sets depending of customers' properties. Therefore, this will be a key element for understanding customers' needs and wants.

A scenario model represents two kinds of information; one is a behavior of a receiver while the other is a property of the receiver. The former is described as a transition graph whose node represents a state of a receiver and whose arc refers to a transition between two states (either temporal or causal). A state is described as a set of parameters with their values. The parameters are classified into two types; internal ones for the states inside a receiver and external ones for the outside. For instance, in a cafe service, the size of a workplace is a kind of an external parameter, while coziness of the receiver is internal. Furthermore, those parameters have a hierarchical relation among themselves from end to means. By using this transition graph, the receiver's final goals, and their activities can be described. RSPs are a partial set of parameters of a state selected by designers.

The latter is represented by an application of the concept named Persona [18]. Persona is an imaginary target user and is frequently used in practical design of software interfaces. The information to identify Persona is classified into two types; one is demographic data such as age, gender, and professional carrier, while the other is psychological data such as personality and life style. The data for Persona is given by objective information, e.g. statistic data and results from marketing. It is important to determine the properties of Persona concretely and accurately, rather than abstractly and correctly, since it can prevent the target customers from varying from one form to another during the whole design process. Psychological data is necessary because it lets designers recognize a target customer like a real living person.

3.3. Design methodology

The authors have already proposed a generic method for service design [19, 20], which adopts the model of service explained in Paragraph 3.2., and verified it through application to industrial cases (e.g. [21]). Designers are able to design a target service efficiently by following this method. After this already-proposed method, Figure 5 describes the procedures of a newly-proposed design method with more details on some important issues of this paper, namely the part of describing a target receiver (steps 3) and 4)) and identifying the value using a scenario model (steps from 5) to 8)).

a) making a preliminary flow model

First, in the steps from 1) to 2), a flow model is generated with scope models for some of the relations between two agents. Note that the four nodes on the right hand in Figure 5 can be adopted only in case of redesign. A preliminary flow model gives a basic formulation of participants called agents in the whole process of service providing. This is needed, since designers can recognize the relationships between value and cost of an agent and those of another, such as positive and negative relationships.

b) describing the target receiver

To extract RSPs afterwards, a scenario model plays a crucial role, because it is the source to produce what a category of customers need and want.

3) generating a Persona for a receiver

For the target receiver in the target scope model, a Persona is generated and the demographic and psychological data is given according to results of marketing etc. in order to make it more concrete.

4) describing important state parameters for the receiver

Because it is impossible to describe a state of a receiver in a scenario model only by the data given for the Persona in the previous step, described here are important parameters concerned in the target service. These parameters are identified through customer surveys etc. Concrete methods to do this could include Laddering [22]. The parameters in the upper most level in a hierarchy are supposed to be one of the nine parameters in LOV (list of value) [23] shown below as a reference so that parameters of different Personas are comparable.

- sense of belonging
- self-fulfillment
- fun and enjoyment in life
- warm relationships with others
- being well-respected
- excitement
- sense of accomplishment
- security
- self-respect

c) describing the value

It is in the steps from 5) to 8) that designers determine the provided value, which is represented in the form of RSP, for a specific type of receiver in each scope model.

5) setting the final goal of a scenario

The final goal of a target Persona in the service is described. For instance, in case of a laundry service, a final goal might be getting clothes clean.

6) describing a chain of actions of the receiver

Actions needed to fulfill the final goal are described so that designers specify how the service is received. In case of a laundry service, a chain of actions would be from walking to a laundry space at night after his/her work, putting shirts and pants in a washing machine, waiting until finished, and getting the clothes back home, as an example.

7) identifying the goal parameters

The parameters adopted to judge the fulfillment of the goal given in the step 5) are selected from the important parameters described in the step 4). Here, the hierarchy in the parameters is utilized so that a parameter in a higher level is prioritized to be a goal parameter.

8) extracting the RSPs

RSPs, which are the target in designing the service afterwards, are selected from

- the goal parameters (identified in the step 7)) that are external, and
- not the goal parameters but external parameters affecting the goal parameters.

It should be noted that both of the two types above are external because designers can control only external parameters. In addition, RSPs may be complemented here by designers, if needed. A parameter corresponding to a "must-be quality" in Kano model [24] and one proposed from designers or the providing organization can be complemented.

d) generating a realization structure

A realization structure for the target value is determined (step 9) and 10)). The realization structure is classified into that of a physical product and of a service activity. For generating the former one, design process based on an existing scheme for mechanical design (e.g. [25]) can be adopted. After a realization structure is made, designers can go back to the steps for *c) describing the value*. This path is allowed, because designers often hit on an idea for a new

value by being presented with an intermediate solution of a realization structure. This recursive process is among crucial parts for an effective service design.

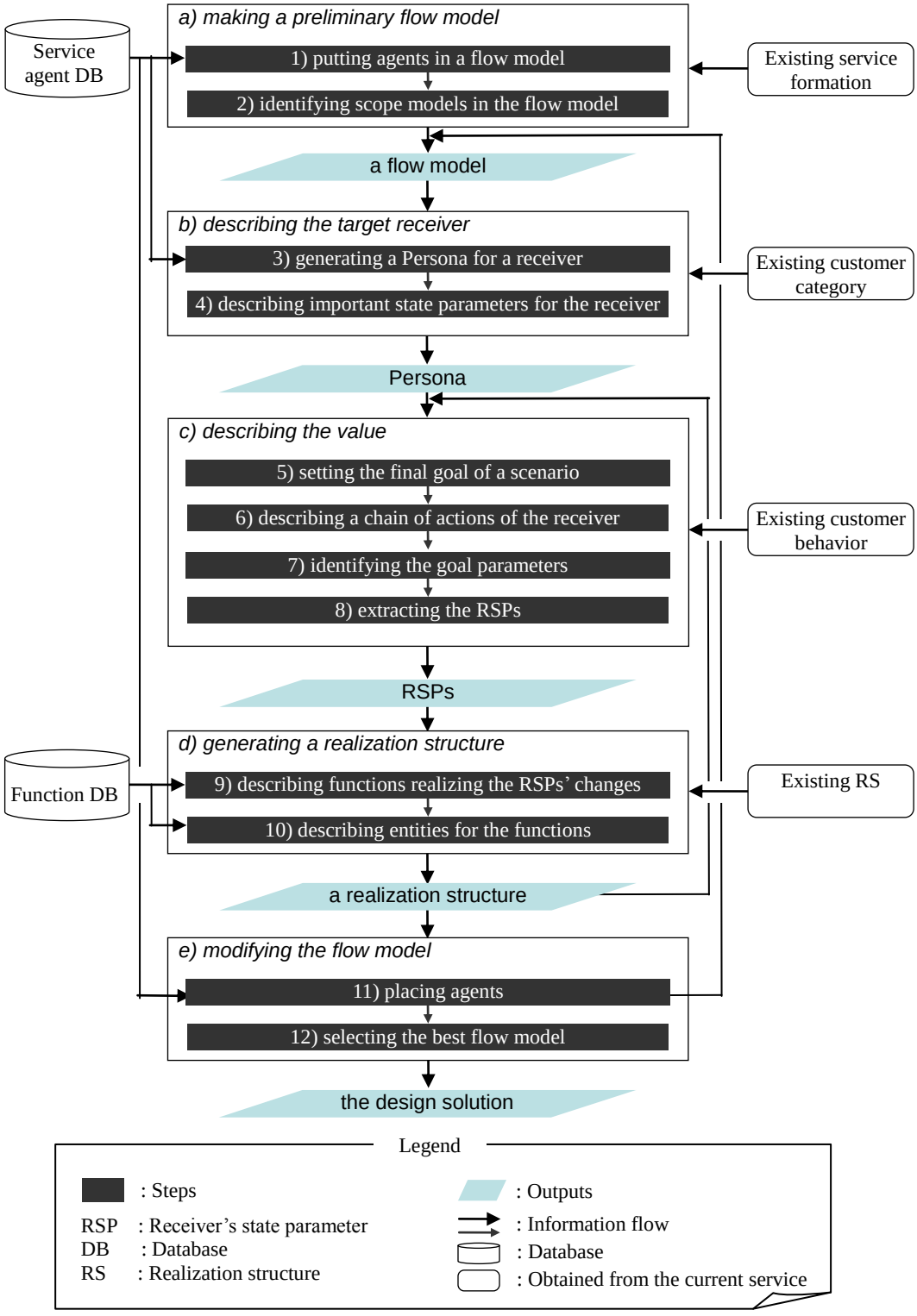


Figure 5: The proposed design process

e) modifying the flow model

Finally, the preliminary flow model is modified to generate the design solution (steps 11) and 12)). If an agent is added in step 11), they must go back to the step 3).

3.4. Design support tool

3.4.1. Overview

A prototype system of a computer-aided design tool for service design, which is called Service Explorer, has been developed [17, 19, 29, 30]. Designers can describe services, and register them in a database, reload them, evaluate them, as well as design services from scratch.

Figure 6 depicts the system configuration of Service Explorer. The current version of Service Explorer was developed using Java (Java2 SDK, Standard Edition 1.4.1) and XML version1.0 in the Microsoft Windows XP Home Edition environment. Data on various types of Persona is stored in "Service Agent DB" in Figure 6.

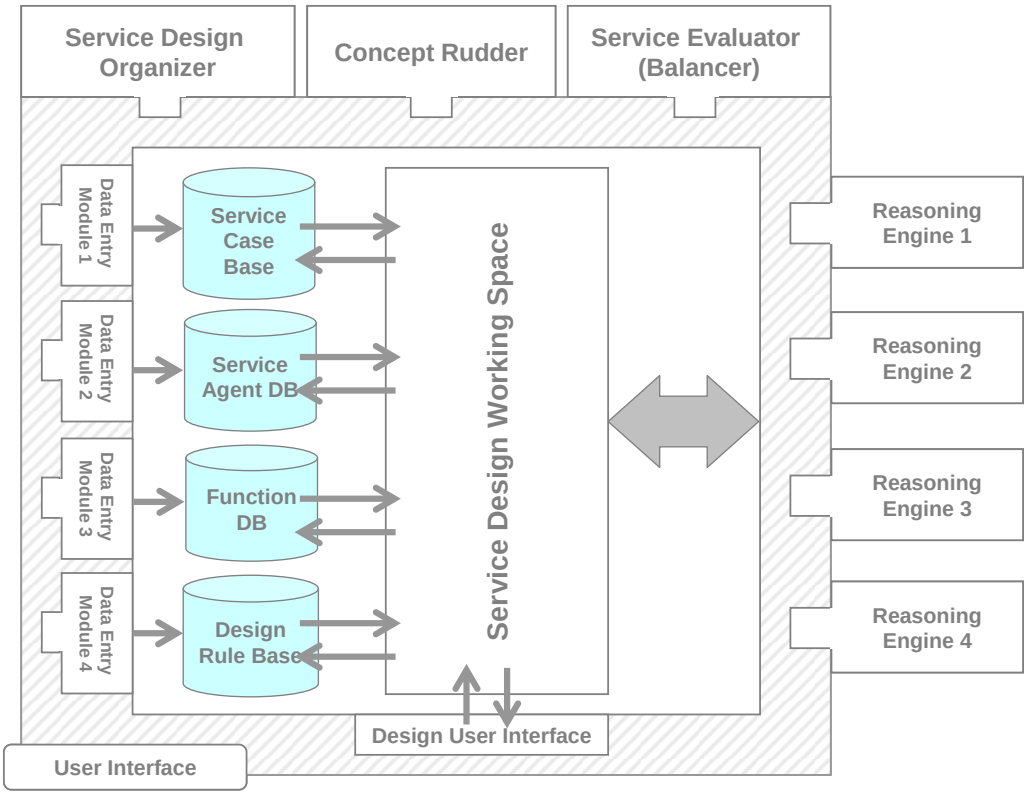


Figure 6: Conceptual structure of Service Explorer

3.4.2. Functionality

This paragraph describes three types of main functionality of Service Explorer.

1) Model building

Designers can model services on Service Explorer based on the methodology explained in Paragraph 3.2. using some databases of Service Explorer. Namely, they can construct flow models, scope models, view models, and scenario models. Examples of concrete operations are:

- Generate nodes like agents, RSPs, and functions.

- Generate arcs among nodes.
- Change attributes of nodes.
- Search suitable service components in a database such as analogous services and partly-related services.

Four screenshots are shown: Figure 8 presents the widest coverage on the models, displaying a flow model with scope models, an action chain of a target receiver, and RSPs in an action. To edit a Persona for a target receiver, a window of Figure 9 is employed. These two screen shots are taken from a case of designing a hotel service. To extract RSPs from an action chain, a window of Figure 7 is adopted. The upper half is for describing a chain of actions, corresponding to the lower middle part of Figure 8, and the lower one visualizes a hierarchy among the parameters. This is taken from a laundry service. To deploy RSPs further to obtain functions on a view model, designers face a screen image like Figure 10 on Service Explorer.

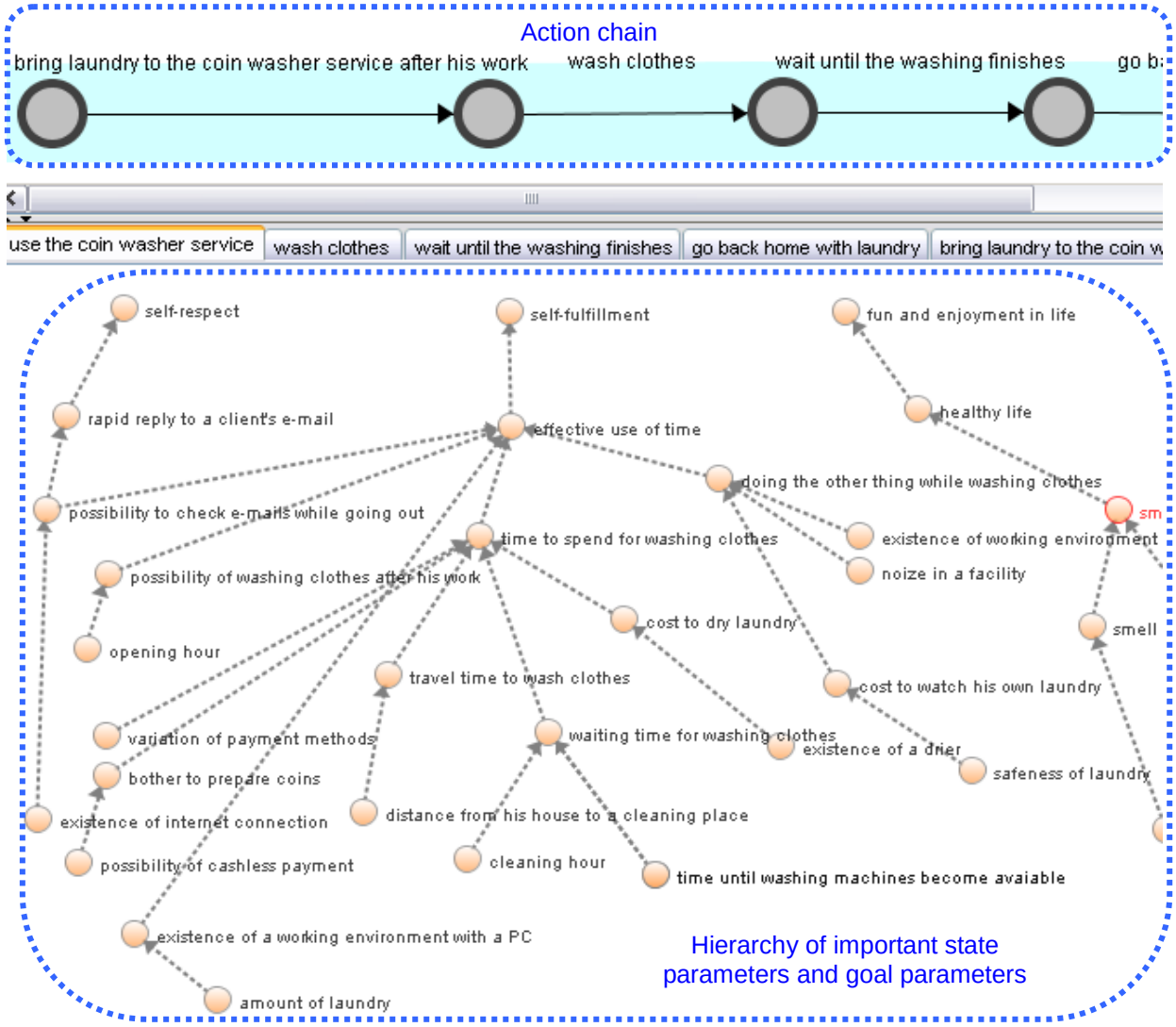


Figure 7: A screenshot of extracting RSPs for a Persona

2) Design guidance

Service Explorer can guide designers based on the design methodology explained in Paragraph 3.3. This guiding functionality itself is implemented as a sub module named “Service Design Organizer” in Service Explorer (Figure 6). “Service Evaluator” is employed in the evaluation in the step 12) in Paragraph 3.3.

3) Reasoning

Several types of reasoning engines will be stored as shown in the right hand side of Figure 6. This functionality is critical from the viewpoint of information system, because designers can take good advantage of a computing facility. One of the promising engines reasons by way of abduction [31, 32]. The authors’ research group has already constructed a generic computer system employing abduction named Universal Abduction Studio (UAS) [33]. By this reasoning module plugged, Service Explorer will be able to help designers with creative design using knowledge in different business fields.

4. Applications

4.1. Accommodation service

4.1.1. The target design of service

As a target of service design with the methods and tools presented in Section 3, redesigning an accommodation service in Abruzzo region, Italy was selected. This hotel has three-star certification, and is characterized by various efforts to reduce environmental impacts. The hotel management regards the environmental consciousness as a sales point to the guests, wants to reduce the environmental impact and develop a new attractive service for the guests [34].

4.1.2. Investigation of the current service

For the sake of redesign of the hotel service, the authors carried out an on-site customer survey about guests’ requirements, namely value and costs on the guests, through delivering questionnaires to them from 15th April to 19th May, 2004. The collected information includes the importance of some forty (40) requirements prepared by the authors, which correspond to the weighting of RSP. During the above-mentioned time span, 1,233 questionnaires were delivered to guests, and 116 filled-in questionnaires were collected (corresponding to a 9.4 % coverage ratio). In addition, the authors investigated the actual hotel service by interviewing the employees and the hotel owner [34, 35].

The results include classification of customers into twelve (12) categories according to their trip purposes (business or others), ages (younger, middle, or elder), and genders (female or male). For each customer category, an average weighting for each RSP was calculated. Among them, Table 1 shows partially the average weightings for eleven (11) RSPs for five categories. Each RSP has its own ID from 1 to 11, and each weighting is denoted as L (low), M (middle), or H (high) depending on its numerical size. It should be noted that the thresholds for the spaces for the age and RSP are manually given. An RSP with italic characters refers to environmentally related issues, though this information was not given to the guests.

Table 1: Customer categories' weightings on RSPs in the hotel service [35]

ID	RSP Content	Category ID	a	b	c	d	e
		Trip purpose	B	B	B	B	B
		Age	L	H	L	M	H
		Gender	F	F	M	M	M
1	Adequate heating and/or air-conditioning		H	H	H	H	L
2	*Reduced release of pollutants into the environment*		H	M	L	L	L
3	*Reduced waste generation*		H	H	L	L	L
4	*Use of materials from renewable resources*		H	H	L	L	L
5	*Water saving*		M	H	M	M	L
6	*Energy saving*		M	H	M	H	L
7	Good lighting (both natural and artificial)		H	H	L	L	L
8	Freshness of towels and bed linen		H	H	H	H	H
9	Comfortable bathrooms provided with various amenities		L	H	H	L	H
10	Well-furnished and attractive rooms		L	H	M	M	L
11	Comfortable and spacious rooms		H	H	M	M	L

Trip purpose: B(business) / O(others)
Age: L(younger) / M(middle) / H(elder)
Gender: F(female) / M(male)
Weighting: L(low) / M(middle) / H(high)

4.1.3. Redesigning the service

By applying the methods and tools of SE, the designers generated three redesign options to improve the current service. The processes following the proposed design methodology explained in Paragraph 3.3 and the generated solutions are described below. Note that only a part will be explained for Options 2 and 3.

It should be noted that designers generated these options as they put a considerable weighting on RSPs of the environment such as energy consumption and released pollutants due to the hotel's consciousness of the environment as described in Paragraph 4.1.1. In addition, the feasibility of a possible option was taken into consideration.

Option 1: Window shielding films

a) making a preliminary flow model

First, as step 1) *putting agents in a flow model*, several service agents which participate in the current hotel service were described on Service Explorer; the hotel, the hotel guests, a bed linen rental company, a power supplier, and the environment (see the upper right part of Figure 8). The agent "environment" is a virtual agent to incorporate the environmental impact caused by each agent's activity. As step *2) identifying scope models in the flow model*, scope models were identified, for instance, between the hotel and the hotel guest as shown the upper right part of Figure 8. This scope will be the main target of this redesign.

b) describing the target receiver

As step *3) generating a Persona for a receiver*, the customer category b of the hotel guest, namely elder women on business, was selected as a target type of the customers. As Table 1 shows that their weightings on the RSPs from ID 2 to 6 are generally higher than almost all the other categories, they are relatively environmentally conscious. The demographic and

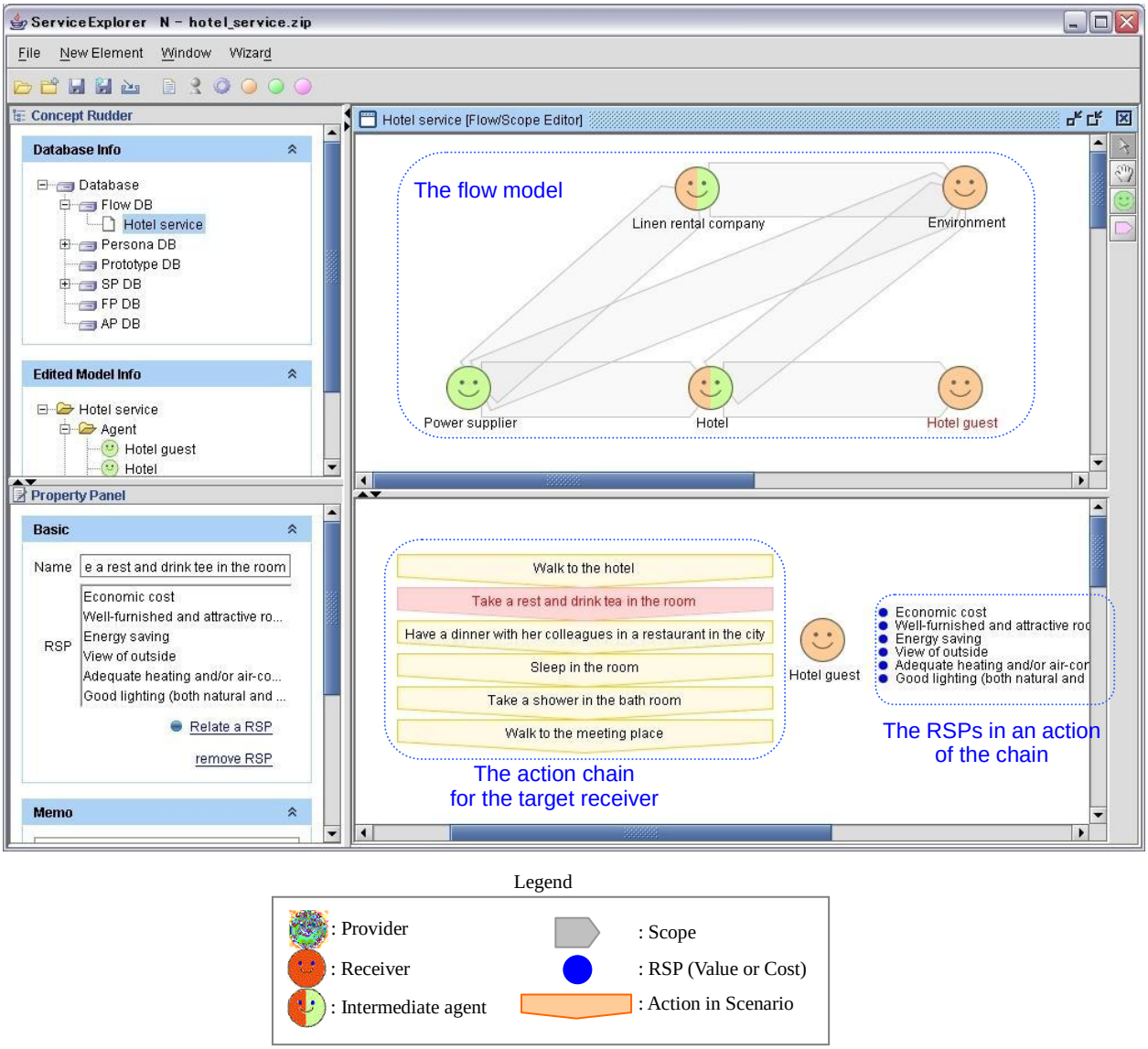


Figure 8: The screen shot displaying the RSPs of a hotel guest in the category b on Service Explorer

psychological data of this Persona was described on Service Explorer as shown in Figure 9. In addition, the Persona was described to consider a great deal of some items of the LOV such as sense of security as step *4) describing important state parameters for a receiver*.

c) describing the value

The final goal of the target Persona was set to be getting prepared for her forthcoming business meeting as step *5) setting the final goal of a scenario*. Her chain of actions were described as shown in the lower part of Figure 8, beginning with "walk to the hotel" and ending with "walk to the meeting place" as step *6) describing a chain of actions of a receiver*. As step *7) identifying the goal parameters*, relaxation was identified here to be the goal parameter, after the second action in the chain, "take a rest and drink tea in the room" was focused. Because the goal parameter, relaxation, is an internal one of the Persona, external parameters affecting this

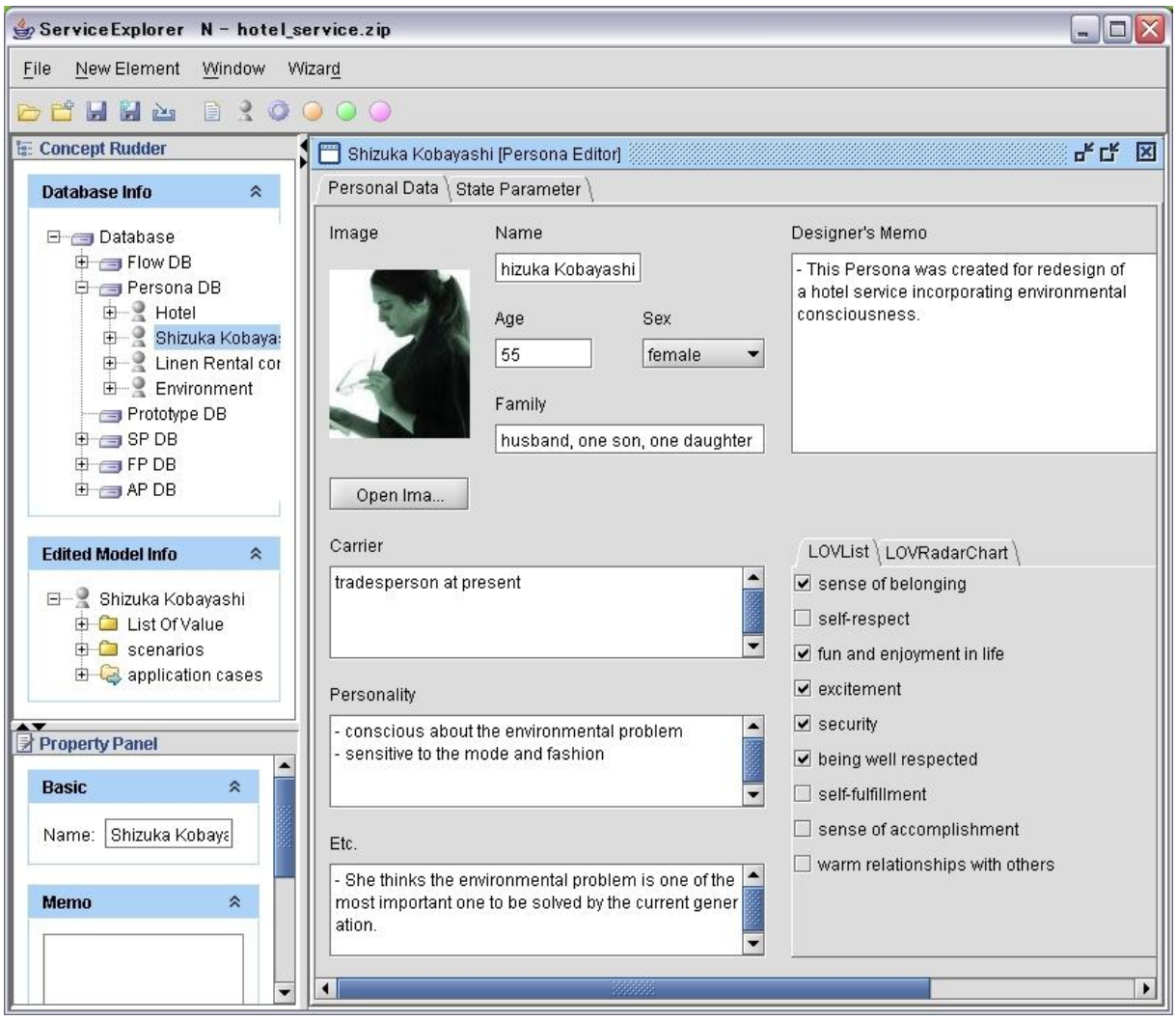


Figure 9: The screen shot for editing the Persona for the category b on Service Explorer

goal parameter were selected as RSPs; “adequate heating and/or air-conditioning” (ID 1), “good lighting” (ID 7), “energy saving” (ID 6), “well-furnished and attractive room” (ID 10), and “economic cost” (step 8)). The first three RSPs in the summer are rephrased as cool and light with less energy.

d) generating a realization structure

Here, the current realization structure of the service was referred. The existing hotel building has a shutter on the outside of a window to prevent the sunlight and heat from coming into the room. When it is in use, it gets cooler due to its performance to prevent the heat transfer. However, natural light does not come into the room, either. It was found in the function database that there exist special films attached on the window to shield a specific range of radiation frequency (e.g. [36]). Installing these films on the window of the rooms contribute to decrease the energy usage by air conditioners for the rooms. This redesign option will achieve the change

of all the three RSPs mentioned above (cool and light with less energy).

The function structures for RSPs were developed and then the entities for those functions were described on Service Explorer (steps 9) and 10)). Figure 10 shows just a small part of the developed view model of the service, corresponding to an RSP "adequate heating and/or air-conditioning". The RSP is connected to CoPs of "comfortability of the temperature in the room" and "comfortability of the humidity in the room". The first CoP is linked to a ChP of "capability to shield heat of the films". One can understand the service structure also by looking at functions and entities in the view model. Namely, the RSP is influenced by functions like "control the temperature in the room", which are deployed further to lower functions including "attach window shielding films". The last function is realized by an entity of "window film".

After following the feedback route in Figure 5 and returning to the steps of *c) describing the value*, an RSP named "view of outside" was newly recognized.

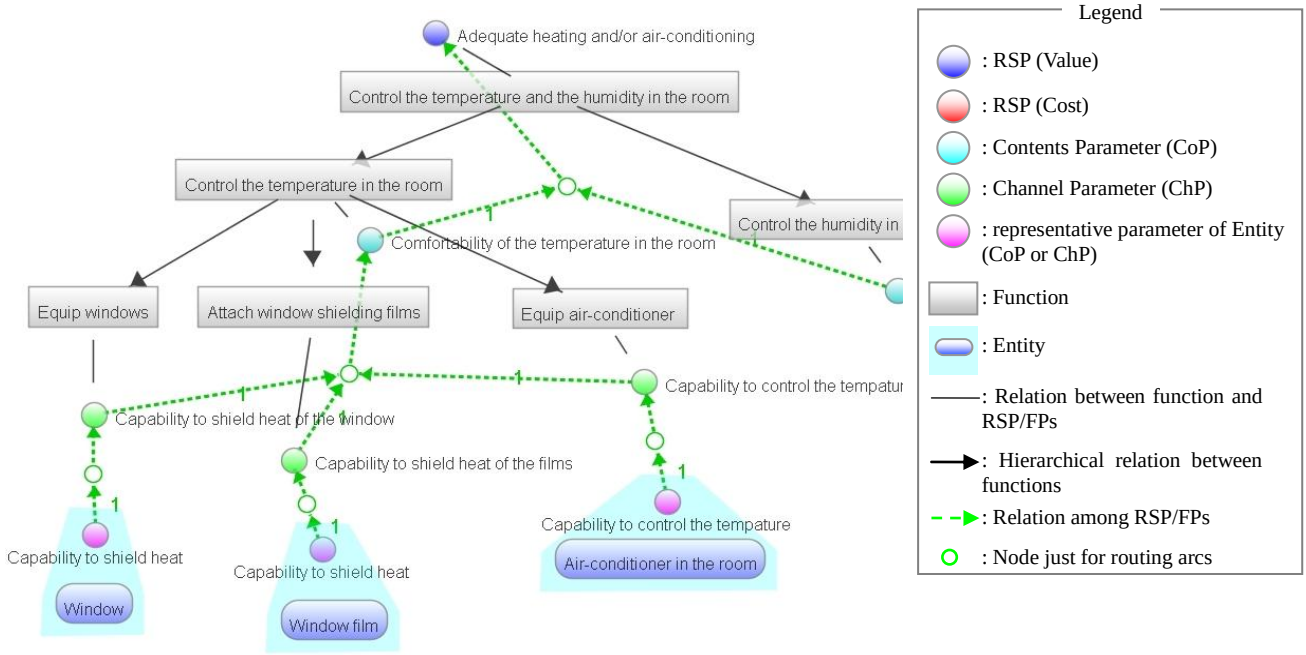


Figure 10: The screen shot for a partial view model for an RSP with its realization structures

e) modifying the flow model

In this case, no modification of the flow model was achieved.

Option 2: A Sunlighting System

After the processes same in those steps from 1) to 8) in Option 1, a lighting system was focused for the redesign target. Artificial lighting by use of electricity is employed for the whole area of the current hotel building. By considering that the RSPs for the Persona include "good lighting" and "energy saving", a new lighting system called a sunlighting system (e.g. [37] was proposed in the steps 9) and 10). This system gathers sunlight outside the shelter and canalizes the light to a destination inside the building. It can decrease the energy consumption by lighting

in the hotel while keeping the level of lighting. It should be mentioned that a new RSP “feeling nature” was found in the second round of step 8).

This improvement is beneficial not only for the target Persona but also for all the others. However, “feeling nature” may be beneficial especially for the target Persona, who is more concerned about the environmental issues.

Option 3: “Cash-back per non-wash” system

From Table 1, one more characteristic Persona than that used for Options 1 and 2 was generated as steps 3) and 4). This is for elder males on business, who put lower weightings on environmental RSPs than the other categories. It was also confirmed in the step 8) that both of those Personas put a high weighting on the RSP, “freshness of towels and bed linen” (ID 8).

Now, in the steps 9) and 10), the current realization structure for these RSPs is referred: At present, the hotel give choices for the guests to decide whether to wash the towels used in the bath rooms or not. This system could give a higher satisfaction level to several environmental RSPs such as “reduced release of pollutants into the environment” (ID 2). In addition, this will be beneficial for the more environmentally consciousness Persona. However, this service structure does not work for the second Persona, who is less environmentally conscious, since they would use fresh towels every time rather than use unwashed towels.

The newly-proposed service system named “Cash-back per non-wash” would allow guests not only to decide whether they have towels washed or not, but it would also give some form of discount to guests per a non-cleaned towel. This option would additionally decrease the economic cost of stay. As all the hotel guests apparently have a high weighting on the monetary cost, this improvement option must be beneficial for all the Personas. Hence, this type of charging system would bring benefits also to the less environmentally conscious Persona.

It should be emphasized that this option is different from the two options mentioned above in the point that different realization structures are provided to customers. As a result, the value provided to a customer category is different from that to another: Economic cost reduction to the customer without a high environmental consciousness, and the less environmental burden to the customer with a high environmental consciousness.

4.1.4. Feedbacks

Feedbacks on the options above were obtained from the hotel company as follows. All the proposed improvement options were new to them. Actually, they started to investigate the feasibility of the light shielding window films (Option 1) and “cash-back per non-wash” system (Option 3). They also began to collect the detailed product information of the sunlighting system (Option 2).

According to the outputs from the application and the feedbacks to them, the methods and tools of SE are suggested to be effective for designing services increasing the level of customer satisfaction.

4.1.5. Verification

The methods and tools presented in Section 3 are verified here whether the defects pointed out in Section 2 were overcome, by reviewing the processes and the solutions explained in Paragraph 4.1.3. First, the processes and the solution for Option 1 (window shielding films) proved that the presented methods and tools facilitate designers adding new value ("view of outside" in this case) on a service (corresponding to Transformation 3 in Figure 1). Designers following typical product eco-design procedures would not generate this type of newly added value since the task is lowering the environmental burden while fulfilling the requested function. Another newly added value, "feeling nature", in Option 2 is the case, too. This is a benefit mainly from the model representing value and cost explained in Paragraph 3.2. In addition, designs toward Transformation 2 in Figure 1 are proved to be supported. As an example, Option 2 (a sunlighting system) allows not only the cost (environmental burden) to be lowered by decreasing the energy for the lighting but also the value (economic value of the hotel) to be increased simultaneously. Furthermore, the consumer model was proved to work effective to identify value, as shown in all the options.

Second, the presented methods and tools were proved to deal with both products and services (corresponding to Operation 3 in Figure 2) as demonstrated in Option 3 ("Cash-back per non-wash" system). This is a benefit from the *soft* modeling scheme and design process which allow designers to handle products and services in a flexible way. Designing services and products in parallel is also possible, for example, by following the feedback route in Figure 5.

4.2. Renting home appliances

4.2.1. The target service

In order to demonstrate that the presented methods and tools are also applicable to services depending on physical products more strongly, application to a renting service of home appliances is described in Paragraph 4.2. Why this service is selected is that the service is a good instance for a dematerialized service employing a product that is normally at present provided in a product-sales, namely materialistic, form of service. Note that only a part will be explained as Options 2 and 3 in Paragraph 4.1.

The provider rents a set of home appliances, i.e. a TV set, a refrigerator, a vacuum cleaner, and a microwave to end users for a contracted period of one or two years. This service is expected to contribute to decrease the environmental impact because it can accelerate product reuse resulting in producing a smaller number of physical products.

4.2.2. Designing the service

b) describing the target receiver

Let us here target a business person who lives alone away from his/her family for a short period. The steps of 3) and 4) explained in Paragraph 3.3 in this case are as follows. In this case, the Persona was described as shown in Table 2.

A part of describing the important state parameters based on the data of the target Persona is as follows. It is natural that he hates to watch a TV set with a small sized display, because it

makes the target receiver, who considers self-fulfillment is valuable, feel misery (see Figure 11). The important state parameters ranged from a size of a related physical product to the sense of values of a Persona.

Table 2: Data for the target Persona

Name	Tadashi Nagano
Age	45
Gender	Male
Family members	4 (currently living alone)
Professional life	He is as a director in a subsidiary in Osaka of a company in Tokyo, where he used to work. His mission is boosting the revenue of the subsidiary in two years. His position is quite stressful between his own colleagues in Osaka and his boss in Tokyo, but he works hard proudly.
Private life	He lives alone in a rented apartment in Osaka. His wife and two daughters (high school students) stay in his own house in Tokyo. He wants to get relaxed alone in his apartment at night.
LOV	sense of accomplishment, being well respected, self-fulfillment

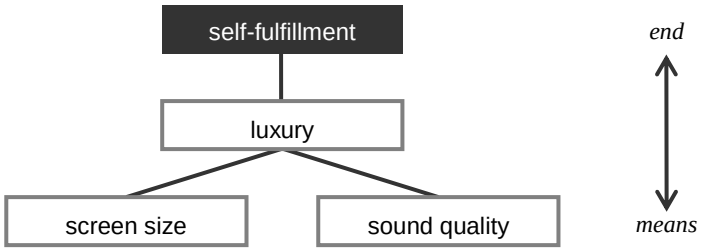


Figure 11: A part of important parameters of the target Persona for watching TV

c) describing the value

In the steps from 5) to 8), the final goal of the target Persona was defined to be "getting relaxed in his apartment at night after work on week days". The chain of actions in this case starts with sitting on a sofa after coming home, goes through watching TV with drinking whisky, and ends in going to bed. The goal parameters include the size of the display.

In addition, functionality newly introduced to the market were not described in this service, because the target receiver is not interested in them as he puts no weight on "fun and enjoyment in life" and "excitement" from LOV. Furthermore, since the target Persona is so busy that he does not want to spend time struggling with installing or fixing the machine. Hence, the time for handling the machine was included, too.

d) generating a realization structure

To realize the RSPs obtained in the previous steps, the size of the display was determined large. To realize the reduction of risks, maintenance, installment, and take-back after the contract activities were put as a service structure.

4.2.3. Verification

This application suggested that the modeling scheme and the design methods of SE are helpful especially for guiding designers to describe the target customer using the concept of Persona in a scenario model. In addition, this application explains that producers may have to

change their way of product design if they widen the design space. It can be recalled that producers have paid an enormous amount of resource to add newly introduced functionality on physical products to gain profit from activities of selling physical products in the mass production paradigm. It is quite reasonable that brand new functionality is among the greatest factors to motivate consumers to buy products.

In fact, this example service was recently commercialized by a giant producer of home appliances in Japan [38]. They advertise toward customers including a business person who lives alone away from his/her family for a short period, a university student staying away from his/her parents' home, and a family with a possibility to move to a different city in the near future. Furthermore, they appeal simplicity of using the machines and a restricted selection of often used functionality as well as relatively brand new functionality such as drying clothes of chemical materials by wind blow in washing machines. According to this, it can be suggested that the modeling scheme and the design method of SE has power to support service designers effectively.

5. Discussions

5.1. Verification of Service Engineering

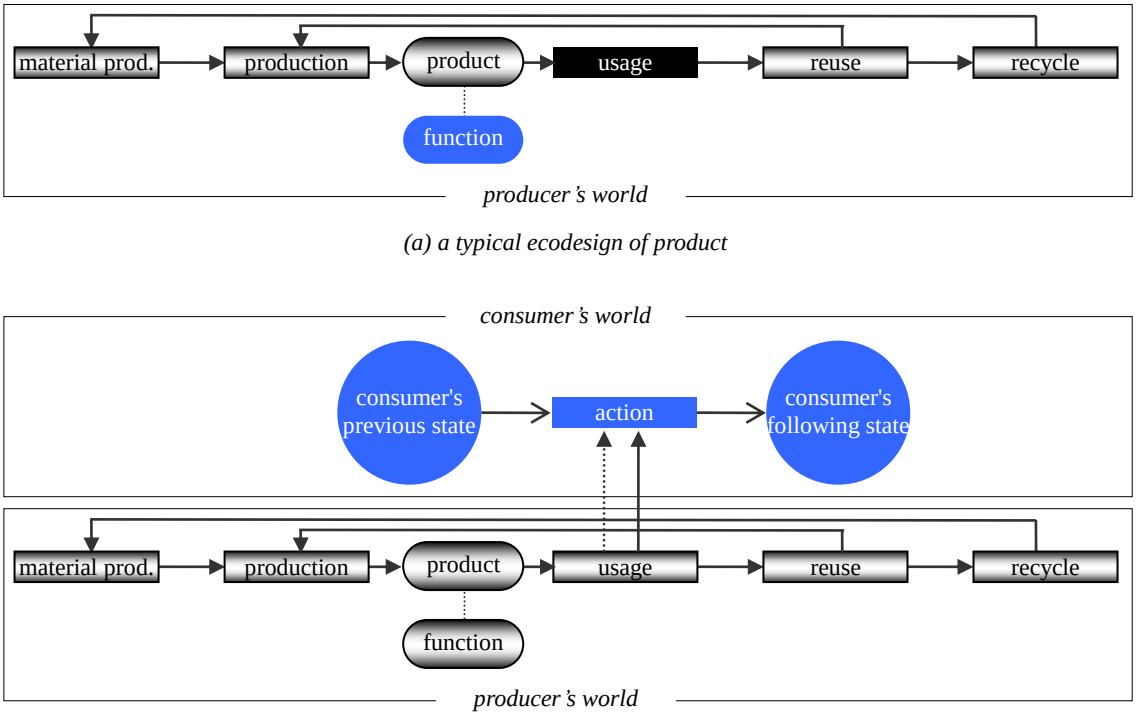
Through application to two examples of environmental conscious design in Section 4, the methods and tool of SE explained in Section 3 were proved to support designers with realizing value effectively for environmentally conscious service. It should be emphasized firstly the scheme to model positive changes of consumers as value and the design procedure to identify the value with realization structures are provided. Environmental consciousness is here represented as an RSP of an agent of either consumers or environment, so that it can be incorporated indirectly or directly. More importantly, the other types of value such as product functionality and economic value are also modelled as the same concept. Thus, adding or removing instances of the other value, and comparing them with environmental consciousness is possible, whether they are related or not to environmental consciousness.

Secondly, the model to describe a target consumer is provided for grounding the identified value. In fact, it was demonstrated that the methods and tool facilitate designers identifying new instances of value to raise the total benefit for a target consumer.

Thirdly, SE argues designing services in parallel with products, neither designing only products nor designing services after products. Hence, the methods and tool have potential to better design a physical product to achieve environmentally conscious service. Actually, they were suggested to produce a physical product different from what would be designed if how the service employs the physical product were neglected.

Figure 12 compares the presented service design with a typical eco-design of product. A typical eco-design of product has so far targeted the environmental burden while fulfilling a requested function of a physical product without changing the provider's process during the usage phase. The consumers' behaviours are obviously neglected. On the contrary, the presented design targets the state changes of a consumer while the functions of physical products and provider's activities are media. It should be noted that provider's activities like maintenance

services are included in the usage process. The evaluation by consumers has a premium, although the decrease of the environmental burden itself is also taken into account by RSP of the agent of the environment.



(a) a typical ecodesign of product

(b) the presented ecodesign of service

Figure 12: Differences between the two types of design

On the other hand, SE has a limitation to the scope of effective applicability. Designing a product which is difficult to be bound with service activities, whose value has a tight one-to-one relation to its property, and whose value is independent of receiver categories would not be a promising target. Designing salt may be such an example. The effective target of application is a service whose value is developed more than in product-sales form. With regards to Service Explorer, the functionality of model building, evaluation and design guidance is fully implemented; however, the usability of the software remains to be improved. In addition, reasoning engines are currently under implementation as noted in Paragraph 3.4.2.

5.2. Innovativeness

5.2.1. Computer aided design tool

The most remarkable point is that a computer aided design tool is provided. This implies that the presented model and the design process, which are implemented to form a part of the software, are proved to be rigorously logical. Having implemented a computer tool has brought two benefits; one is the ability to manage various types of information efficiently. The other comes from taking advantage of the power of computing. For instance, a reasoning engine for abduction would be able to discover a good analogy in a different field to let designers notice some clues towards innovative ideas in the concerned field.

Quite a few methods or tools to support environmentally conscious design of services or product-service systems (PSS) have been developed. For instance, Zwan et al. [39] proposed a methodology of design whose target is to meet the customer needs, not the means, with more space than traditional design of products. In addition, Stevels [40] presented a method to carry out brainstorming in product creation process after categorizing consumers from the viewpoint of their environmental consciousness. Furthermore, a systematic engineering method for developing PSS [41], a technical service design method in a product life cycle context [42], and a sustainable innovation design method with a brainstorming tool [43] are included. However, none of them is implemented as a computer tool as demonstrated in this paper.

5.2.2. Comprehensive coverage of design process

A large number of tools for eco-design are available, some of which are so sophisticated as to be commercialized. Figure 13 distinguishes Service Explorer with other existing eco-design tools from the viewpoints of their applied stages in a flow of designing service. It should be noted that the main target of service design here includes designing products employed in the service. The flow of service design in Figure 13 is aggregated by combining the two flows of traditional service design [44] and traditional product design [45].

Most of existing eco-design tools correspond to a specific phase. A tool by Finster et al. [46] supports to identify the provided value in eco-design using the Kano technique [24] is applied to the first phase. QFD (Quality Function Deployment) [27] based tools [47-50], which is effective in eco-design for translating requirements from customers and the environment into product functions and attributes etc., is applied to the second phase. So Environmental Effect Analysis [51] is, too. Assessment tools like Life Cycle Assessment [52] and DfX (Design for X) tools dealing with specific environmental aspects such as Design for disassembly [53] have a specific phase for application.

On the contrary, Service Explorer covers more phases of design starting with analyzing customers and ending with detailed design, although implementing integration with modules for the stage of embodiment design and, further, detailed design is prospected as explained in Paragraph 3.3.

5.2.3. Integration of multiple disciplines

As explained in Section 3 and demonstrated in Section 4, SE has a possibility to become a

novel discipline. The methods and tools are constructed based on the engineering discipline while taking advantage of the marketing discipline. For instance, as the example in Paragraph 4.1. shows, customer categorization, which is a typical marketing method, is employed. However, SE does not provide a new method within the marketing field. Thus, SE will be characterized as a novel discipline coupling marketing and engineering activities [20]. They provide environment for design activities seamless from analysing customers up to constructing physical structures. This is innovative from the viewpoint of academic disciplines.

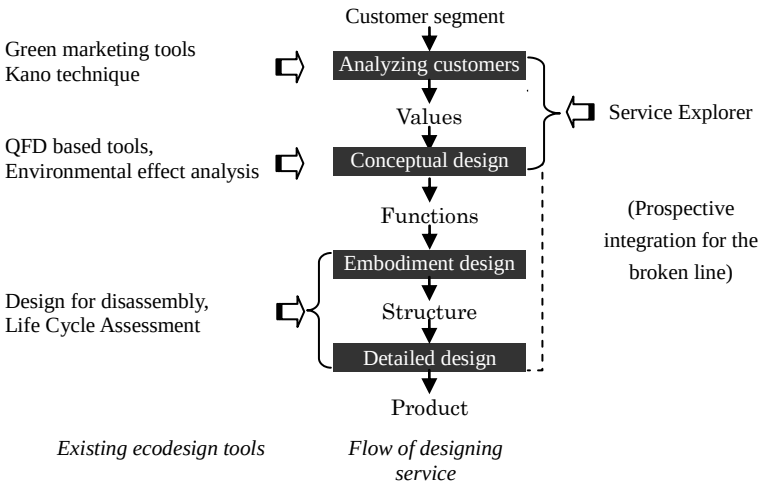


Figure 13: Differences of applied design phases among tools

5.3. Model for balancing value and costs

Paragraph 5.1 explained one of the remarkable features of the presented methods and tools of SE. Yet, missing is another piece of technology; a way of balancing the value and cost provided by a service. This is critical because a service with a higher value but a more cost might not be accepted. In addition, balancing among multiple agents (e.g. environment) is crucial, since producers must somehow treat with the environment even without consumers' environmental consciousness. For the sake of this, the authors have begun to develop a model named MVC (Model for Balancing Value and Costs) [54], which is a fundamental model to design services with an appropriate balance. In MVC, a flow model with RSPs serves as a basis. It should be noted that how to quantify value and cost is needed within the balancing method.

6. Conclusions

This paper proposed a novel discipline, SE (Service Engineering), in order for producers to achieve sustainable production which contribute to sustainable consumption. To do so, the presented methodologies and tools of SE were verified through application to design of actual design of an environmental conscious service in industry and an existing environmentally conscious service. This discipline is innovative in the point that the target design parameter is value and the value is grounded on consumers. Furthermore, this takes advantage of design spaces widened for both products and services. This is different from most of the existing techniques for product eco-design.

Future works include constructing a model for balancing value and costs explained in Paragraph 5.3. and how to deal with multiple Personas for a single receiver. The latter will lead to how to realize customization of services for multiple consumer categories.

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Notation list

AHP: Analytical Hierarchy Process
CAD: Computer Aided Design
ChP: Channel Parameter
CoP: Content Parameter
DB: Database
DfX: Design for X
FI: Function Influence
FN: Function Name
FP: Function Parameter
LOV: List of Value
MVC: Model for Balancing Value and Costs
PSS: Product-Service-System
QFD: Quality Function Deployment
RS: Realization Structure
RSP: Receiver State Parameter
SE: Service Engineering
UAS: Universal Abduction Studio

References

[1] United Nations General Assembly. Agenda 21. Rio de Jainero: United Nations Division for Sustainable Development. (www.un.org/esa/sustdev/agenda21text.htm); 1992.
[2] Norwegian Minister of Environment. Oslo Roundtable on Sustainable Production and Consumption, Elements for an International Work Programme on Sustainable Production and Consumption http://www.iisd.ca/linkages/consume/oslo000.html

[3] OECD. Sustainable Consumption and Production. Paris, 1997.
[4] OECD. Towards Sustainable Household Consumption? Trends and Policies in OECD Countries. Paris, 2002.
[5] Bartolomeo M, dal Maso D, de Jong P, Eder P, Groenewegen P, Hopkinson P, James P, Nijhuis L, Orninge M, Scholl G, Slob A, Zaring O. Eco-efficient producer services—what are they, how do they benefit customers and the environment and how likely are they to develop and be extensively utilised? J Cleaner Production 2003; 11: 829-37.
[6] Special Issue on Integrating greener product development perspectives. J Cleaner Production 2002; 10: 403-518.
[7] Fiksel J. Design for Environment. Mc Graw Hill, 1996.
[8] Wimmer W, Züst R. ECODESIGN PILOT, Product-Investigation, Learning- and Optimization-Tool for Sustainable Product Development. Kluwer Academics Publisher B.V., Netherlands, 2003.
[9] Abele E, Anderl R, Birkhofer H (Eds.). Environmentally Friendly Product Development, Methods and Tools. Springer, London, 2005.
[10] Hora M, Tischner U. Successful design and marketing of Eco- and Sustainable Goods. 9th European Roundtable on Sustainable Consumption and Production, 2004.
[11] Michaelis L. The role of business in sustainable consumption. J Cleaner Production 2003; 11: 915-21.
[12] Special Issue on Product Service Systems and Sustainable Consumption. J Cleaner Production 2003; 11: 815-933.
[13] Japanese Ministry of Public Management, Home Affairs, Posts and Telecommunications. Annual Report on the Family Income and Expenditure Survey. Japan Statistical Association, 2002.
[14] Tomiyama T. Service Engineering to Intensify Service Contents in Product Life Cycles. Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing (EcoDesign 2001). IEEE Computer Society, 2001. p. 613-8.
[15] Shimomura Y, Tomiyama T. Service Modeling for Service Engineering. In Proceedings of The 5th International Conference on Design of Information Infrastructure Systems for Manufacturing 2002 -DIISM2002-, Osaka University, Japan, 2002. p. 309-16.
[16] Miles L. Techniques of Value Analysis and Engineering. McGraw-Hill, 1971.
[17] Arai T, Shimomura Y. Proposal of Service CAD System -A Tool for Service Engineering-. Annals of the CIRP, 2004; 53-1: 397-400.
[18] Cooper A. The Inmates Are Running the Asylum. Sams, 1999.
[19] Sakao T, Shimomura Y. A Method and a Computerized Tool for Service Design. International Design Conference (DESIGN 2004), 2004. p. 497-502.
[20] Shimomura Y, Sakao T, Raggi A, Petti L. Proposal of a Service Design Process Model based on Service Engineering. Proceeding of the 6th International Symposium on Tools and Methods of Competitive Engineering (TMCE 2006), Ljubljana, Slovenia, 2006. in print.
[21] Sakao T, Shimomura Y, Lindahl M, Sundin E. Applications of service engineering methods and tool to industries. Innovation in Life Cycle Engineering and Sustainable Development, edited by Brissaud D, Tichkiewitch S, Zwolinski P. Springer, 2006. p. 65-86.~~Lindahl M, Sundin E, Shimomura Y, Sakao T. Verification of a Service Design Tool at a Global Warehouse Provider. Proceedings of the 15th International Conference on Engineering Design -ICED05-, Melbourne, Australia, 2005. CD-ROM.~~
[22] Reynolds J, Jonathan G. Laddering Theory, Method, Analysis, and Interpretation. J Advertising Research 1988; 28 (February/March): 11-31.
[23] Kahle R, Beatty E, Homer P. Alternative Measurement Approaches to Consumer Values, The List of Values (LOV) and Values and Life Style (VALS), J Consumer Research 1986; 13: 405-9.
[24] Kano N, Seraku N, Takahashi F, Tsuji S. Attractive quality and must-be quality. The best on quality, edited by Hromi J. Quality Press, Milwaukee, WI, 1996.
[25] Umeda Y, Ishii M, Yoshioka M, Shimomura Y, Tomiyama T. Supporting Conceptual Design based on the Function-Behaviour-State Modeler. Artificial Intelligence for Engineering Design, Analysis and Manufacturing 1996; 10/4:275-88.
[26] Sakao T, Watanabe K, Shimomura Y. A Method to Support Environmentally Conscious Service Design Using Quality Function Deployment (QFD). Proceeding of the Third International Symposium on Environmentally Conscious Design and Inverse Manufacturing (EcoDesign 2003), IEEE Computer Society, 2003. p.567-74.
[27] Akao Y, Quality Function Deployment. Productivity Press, 1990.

[28] Saaty L. The Analytic Hierarchy Process, McGraw-Hill, 1980.
[29] Arai T, Shimomura Y. Service CAD System - Evaluation and Quantification. Annals of the CIRP, 2005; 54-1: 463-6.
[30] Shimomura Y, Sakao T, Hara T, Arai T, Tomiyama T. Service Explorer - A Tool for Service Design -. In Arai E and Arai T (Eds), Mechatronics for Safety, Security and dependability in a New Era, Elsevier, 2006, in print.
[31] Coyne R. Logic Models of Design. Pitman, London, 1998.
[32] Roozenburg M, Eekels J. Product Design: Fundamentals and Methods. John Wiley & Sons, Chichester, MA. 1995.
[33] Takeda H, Sakai H, Nomaguchi Y, Yoshioka M, Shimomura Y, Tomiyama T. Universal Abduction Studio -Proposal of A Design Support Environment For Creative Thinking in Design-. Proceedings of the 14th International Conference on Engineering Design -ICED03-, 2003. CD-ROM.
[34] Watanabe K, Shimomura Y, Sakao T, Raggi A, Petti L. Application of a Service Modeling Tool to Hotel Industry, The Sixth International Conference on EcoBalance, 2004, p. 495-8.
[35] Sakao T, Shimomura Y, Simboli A, Petti L, Raggi A. Applying Service CAD System to Value Customization~~Service Explorer: A Service CAD System for Value Customization~~. Mass Customization and Information Systems in Business, Blecker T and Friedrich G, editors, Idea Group Publishing, Hershey – London, 2006, in review.
[36] Correa G, Almanza R. Copper based thin films to improve glazing for energy-savings in buildings, Solar Energy, 2004; 76: 111–5.
[37] Jenkins D Muneer T. Modelling light-pipe performances - a natural daylighting solution, Building and Environment, 2003; 38: 965 – 72.
[38] http://www.toshiba.co.jp/tcn/pack/kaden/index_j.htm
[39] van der Zwan F, Bhamra T. Alternative function fulfilment: incorporating environmental considerations into increased design space. J Cleaner Production 2003; 11: 897-903.
[40] Stevels A. Green Marketing of Consumer Electronics. Joint International Congress and Exhibition Electronics Goes Green 2000+, 2000. p. 539-44.
[41] Weber C, Steinbach M, Botta C, Deubel T. Modeling of product-service systems (PSS) based on the PDD approach. Proceedings of International Design Conference – DESIGN 2004, 2004. p. 547-54.
[42] Aurich C, Fuchs C, DeVries, F. An Approach to Life Cycle Oriented Technical Service Design, Annals of the CIRP, 2004; 53-1: 151-4.
[43] Hallenga-Brink C, Brezet C. The sustainable innovation design diamond for micro-sized enterprises in tourism. J Cleaner Production 2005; 13: 141–9.
[44] Ramaswamy R. Design and Management of Service Processes, Addison-Wesley, Reading, MA, 1996.
[45] Pahl G, Beitz W. Engineering Design: A Systematic Approach, Springer-Verlag, 1988.
[46] Finster M, Eagan P, Hussey D. Linking Industrial Ecology with Business Strategy -Creating Value for Green Product Design-. J Industrial Ecology 2001; 5(3): 107-25.
[47] Zhang Y, Wang P, Zhang C. Product Concept Evaluation Using GQFD-II and AHP. Intl J Environmentally Conscious Design & Manufacturing 1998; 7(3): 1-15.
[48] Masui K, Sakao T, Kobayashi M, Inaba A. Applying Quality Function Deployment to Environmentally Conscious Design. Intl J Quality and Reliability Management 2003; 20(1): 90-106.
[49] Ernzer M, Sakao T, Mattheiß C. Effectiveness and Efficiency Application to Eco-QFD. Proceedings of International Design Conference – (DESIGN 2004), Dubrovnik, 2004. p. 1521-6.
[50] Fargnoli M, Sakao T, Notarnicola S. A Procedure to Identify Effective Redesign Options in Ecodesign. In Proceedings of the 15th International Conference on Engineering Design -ICED05-, Melbourne, Australia, 2005. CD-ROM.
[51] Lindahl M. Environmental Effect Analysis -How Does the Method Stand in relation to Lessons Learned from the Use of Other Design for Environment Methods. Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2001. p. 864-9.
[52] ISO. ISO 14040, Environmental management - Life cycle assessment - Principles and framework, 1997.
[53] Rapoza B, Harjula T, Knight A, Boothroyd G. Product Design for Disassembly and Environment, Annals of CIRP 1996: 109-12.
[54] Sakao T, Shimomura Y. MVC (Model for Balancing Value and Costs): A Fundamental Model to Design Environmentally Conscious Services, Proceedings of the Fourth International Symposium on

Environmentally Conscious Design and Inverse Manufacturing (EcoDesign 2005), 2005. CD-ROM ~~in print~~.