TPI-based Idea Generation Method for Eco-business Planning

S. Kondoh, N. Mishima

Advanced Manufacturing Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Namiki 1-2-1, Tsukuba, Ibaraki 305-8564, Japan

Kondou-shinsuke@aist.go.jp

Abstract

Environmental consciousness has gained increasing interest in recent years, and product life cycle design that aims to maximize total value while minimizing environmental load and costs should be implemented. To achieve that, the processes of idea generation and decision-making for eco-business strategies, as well as the design of a target product and its life cycle options, should be systematically supported. This paper proposes a strategic decision-making method for eco-business planning so that a designer can easily find a set of eco-business ideas that effectively improve environmental and economic performance simultaneously. A decision-making procedure based on this method is also illustrated with a simplified example of a laptop computer business.

Keywords

product service system (PSS), eco-business, total performance indicator (TPI), idea-generation method, eco-business rule, eco-business case base.

1 INTRODUCTION

Environmental consciousness has been growing in recent years, and product life cycle design that aims to maximize utility value while minimizing environmental load and cost should be implemented in addition to environmentally conscious design of the product itself. In this context, many life cycle design tools and concepts have been proposed in recent years [for example, 1,2,3,4,5,6]. Among them, Product Service System (PSS) [5,6], which is often defined as "a marketable set of products and services capable of jointly fulfilling a user's needs" [5], is seen as an excellent means for significant reduction of environmental load as well as enhancing competitiveness of the businesses.

However, it is not easy for a designer to derive a practical design solution for the product life cycle (e.g., product specifications and life cycle options for components, etc.) by using them. To solve these problems, we have proposed the Total Performance Design (TPD) method, focusing on the balance of the customer's utility value of a product and its resulting environmental load and cost throughout the entire life cycle [7]. In this method, the Total Performance Indicator (TPI), which represents the environmental and economic performance of the product life cycle, is used as an objective function and a design solution is derived as a set of life cycle options (e.g., reuse, recycling, upgrading, extension of physical lifetime, and upgrading) for each component, specifications for each functional requirement, and product lifetime that maximizes TPI under a given business environment.

Although this tool was shown to be useful through a case study, it is also important to consider eco-business strategies (e.g., three types of PSS: product-oriented services, use-oriented services, result-oriented services) to improve TPI. For example, adequate control and management of operating conditions are effective for products which consume large quantities of energy and materials during their usage stage (classified as a kind of result-oriented services of PSS). In this case, providing products with energy-saving service (e.g., ESCO business [8] and eco-drive training for drivers) is a promising approach. In addition to operating conditions, product lifetime and its physical wear and deterioration are also insufficiently controlled by product design alone. Therefore, the idea generation and decision-making processes for eco-business strategies, as well as the design of the target product and its life cycle options, should be examined.

The objective of this study is to propose a decision-making method for eco-business planning so that a designer can easily find a set of practical business ideas that effectively improve TPI in a systematic manner. Specifically, we take an approach that provides a business designer with general rules extracted from existing eco-businesses in relation with 17 business parameters that describe the applicability of each rule in a given business environment. In other words, we seek to develop a pattern language in the domain of eco-business planning.

2 APPROACH

2.1 Definition of eco-business and objective function

We here define eco-businesses as businesses that provide greater user value at lower environmental load and cost than existing ones. By using the Total Performance Indicator (TPI) [7], which simultaneously represents the efficiency of utility value production from environmental and economic viewpoints, eco-businesses are considered to be those that achieve higher TPI than existing ones. TPI, which is used as an objective function in this study, is defined as the balance of customer utility value (UV) and its resulting environmental load and cost as follows:

$$TPI = \frac{UV}{\sqrt{LCE \times LCC}} \tag{1}$$

where LCE and LCC denote environmental load and cost throughout the entire life cycle, respectively. We selected equation 1, above, because (i) the evaluation of environmental and economic performance is viewed as having the same level of importance and (ii) arithmetic average of LCE and LCC is not suitable due to difficulties in converting LCE and LCC into the same unit.

2.2 Strategic decision-making method for eco-business planning

In order to help a designer to find eco-business ideas that effectively improve TPI, we provide a business designer with a set of eco-business rules and conditions for applying them.

First, we identify 17 business parameters, from which UV, LCE and LCC are constructed. A set of key (influential) parameters in a given business environment is identified by sensitivity analysis of TPI and it gives a pattern of a given business environment.

Second, for each eco-business rule, we analyze its effect on these 17 parameters in 70 eco-business examples in Japan. Summarizing a general tendency of each rule, the applicability of each rule is given by a rules-parameters matrix. By using this matrix and consulting business case base, a business designer can easily find a set of business rules that effectively improve TPI in a given business environment.

The procedure of the method is summarized as follows.

Step 1: Identification of business environment

First, the business designer identifies customers' functional requirements and calculates the values for 17 parameters in a given business environment.

Step 2: Sensitivity analysis of TPI

The business designer executes sensitivity analysis of TPI to find a set of influential parameters.

Step 3: Idea generation for eco-business

Using predefined eco-business rules that were derived by analyzing existing eco-businesses, the business designer selects a set of rules that improves the key parameters derived in Step 2, and generates eco-business ideas by consulting the eco-business case base, which describes how each rule improves these parameters in each existing eco-business case.

Step 4: Evaluation of the eco-business ideas by TPI

Based on the eco-business ideas generated in Step 3, TPI of a product (service) is recalculated. If the business designer is not satisfied with the improvement in TPI, then the designer returns to Step 2.

The remainder of this paper is organized as follows. Section 3 presents the 17 business parameters that construct the objective function TPI. Section 4 describes the rules we used in this study. Section 5 illustrates a procedure of this method through a case study of a laptop computer business. Section 6 concludes the paper.

3 FORMULATION OF UV, LCE AND LCC

3.1 Formulation of UV

UV as time integral of product value.

The UV of a product rises as the product's functional performance increases and the longer it is used. Thus, UV is defined as the time integral of product value, assuming that the product value is strongly correlated with its functional performance.

$$UV = \int_0^{lt} V(t)dt \tag{2}$$

where *lt* and *V(t)* denote the lifetime and product value at time *t*, respectively.

Estimation of UV by multi-attribute utility theory

From the viewpoint of the multi-attribute utility theory [9], product value at time *t* can be allocated to its dominant functional requirements (FR) given as follows:

$$V(t) = \sum_i V_i(t) \tag{3}$$

$$V_i(t) = w_i(t) FR_i(t) \tag{4}$$

where *i*, $V_i(t)$, $w_i(t)$ and $FR_i(t)$ denote the index of FRs, product value allocated to FR_i, weighted factor for FR_i, and functional performance of FR_i at time *t*, respectively. The weighted factor for each FR represents its consumer importance. Those with high importance have great potential for improving product value. In this study, we assume that product value is measured by market price. Therefore, the importance of each FR can be estimated by conjoint analysis of various products with different specifications.

Time variation of UV.

Since UV is defined as the time integral of product value, the time variation of product value should be estimated. Product value deteriorates for the following reasons: *(i) physical causes* and *(ii) value causes* [10]. Physical causes include product failure and degradation due to aging and wear. Value causes include obsolescence of product FRs (including aesthetic quality). The value of products such as computers or mobile phones deteriorates too fast due to very rapid technological innovations, and so both types of causes should be estimated at the same time. Since the value of a product is given as the weighed sum of its functional performance, value deterioration over time is given by decreases in functional performance and importance.

(i) Deterioration due to physical causes

Here, deterioration due to physical causes is represented as a decrease in functional performance $FR_i(t)$. $FR_i(t)$ is estimated using empirical data on the deterioration of similar products at their usage stage by applying reliability theory. For the sake of simplicity, deterioration of $FR_i(t)$ is expressed by the following linear equation:

$$FR_i(t) = c_i t + d_i \tag{5}$$

where c_i and d_i denote deterioration rate and initial performance of FR_i, respectively.

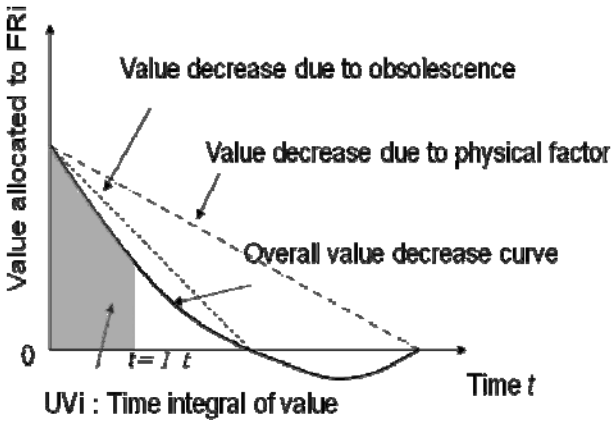

Figure 1: Time variation of value and UV

(ii) Deterioration due to value causes

Another cause of product value deterioration is obsolescence of FRs. Assuming that a set of dominant product FRs does not change, the obsolescence of each FR is expressed by the decrease in importance of each FR given as follows:

$$w_i(t) = a_i t + b_i \tag{6}$$

where a_i and b_i denote the obsolescence rate and initial importance of FR_i, respectively. These values can be

estimated by regression analysis on $w_i(t)$ at various times t.

Figure 1 depicts the time variation of value allocated to each FR. The horizontal axis and vertical axis denote product use time, and value allocated to FR_i, respectively.

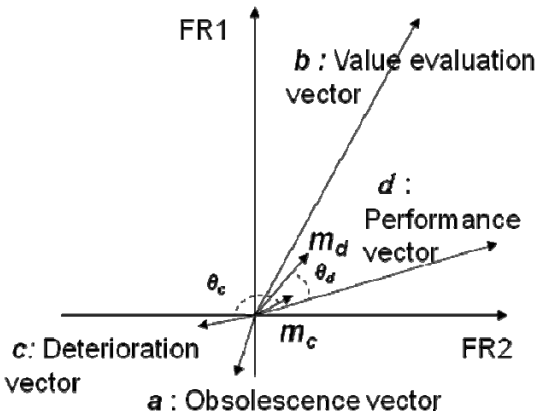

Figure 2: Relationship among obsolescence, value evaluation, deterioration and performance vectors

Vector representation of UV.

Let assume that a target product contains n FRs. The UV of a product is formulated as follows:

$$UV = lt^2(\frac{1}{3}lt\vec{a} + \frac{1}{2}\vec{b}) \cdot \vec{c} + lt(\frac{1}{2}lt\vec{a} + \vec{b}) \cdot \vec{d} \tag{7}$$

where ***a***, ***b***, ***c***, and ***d*** denote obsolescence vector, value evaluation vector, deterioration vector, and performance vector, respectively.

In general, ***a*** and ***b***, which represent user preference for a product and its time variation respectively, are given by the market environment and cannot be controlled by a business designer, whereas ***c*** and ***d***, which represent product performance and its time variation respectively, can be controlled by a business designer. Thus, a designer should select adequate values for ***c*** and ***d*** for given ***a*** and ***b***.

Introducing $\boldsymbol{m_c}$ and $\boldsymbol{m_d}$, which are resultant vectors of ***a*** and ***b***, equation 7 can be transformed as follows by using scholar values: norms of $\boldsymbol{m_c}$, $\boldsymbol{m_d}$, ***c*** and ***d*** and the angles between them.

$$UV = lt^2\|\vec{m}_c\|\|\vec{c}\|\cos(\theta_c) + lt\|\vec{m}_d\|\|\vec{d}\|\cos(\theta_d) \tag{8}$$

$$\vec{m}_c = \frac{1}{3}lt\vec{a} + \frac{1}{2}\vec{b} \tag{9}$$

$$\vec{m}_d = \frac{1}{2}lt\vec{a} + \vec{b} \tag{10}$$

where ||c||, and ||d|| represent physical deterioration speed, and overall performance of a target product, respectively.

θ_c and θ_d ,which are called *deterioration fitness* and *performance fitness* in this study, denote angles between ***c*** and $\boldsymbol{m_c}$ and ***d*** and $\boldsymbol{m_d}$, respectively. The former and the latter represent adequateness of product deterioration and initial performance in a given market environment ($\boldsymbol{m_c}$ and $\boldsymbol{m_d}$), respectively. Relationships among these vectors for n = 2 are depicted in Figure 2. Note that ***c*** and $\boldsymbol{m_c}$ belong to different quadrants while ***d*** and $\boldsymbol{m_d}$ belong to the same quadrant. Thus, the first term of the left side of equation 8 is a negative quantity and the second term is positive quantity.

Interpretation of UV parameters.

Equation 8 shows that enhancement of overall performance (||d||) is quite effective when *lt* is small and on the contrary, improvement of deterioration speed (||c||) is quite effective when *lt* is large.

In addition to norms of ***c*** and ***d***, the angles between ***c*** and $\boldsymbol{m_c}$ (θ_c) and ***d*** and $\boldsymbol{m_d}$ (θ_d) also affect UV. As shown in equation 8 and Figure 2, UV becomes large as θ_d approaches 0 degree and θ_c approaches 90 degree. This means that preferential improvements of c_i and d_i, which effectively improve θ_c and θ_d are also quite promising.

3.2 Formulation of LCE and LCC

Focusing on energy-using products, the longer a product is used, the higher its LCE and LCC become. Thus, the simplest representation of LCE and LCC of a product is given as follows:

$$LCE = e_{use}\ lt + e_{prod} + e_{dist} + e_{col} + e_{eol} \tag{11}$$

$$LCC = f_{use}\ lt + f_{prod} + f_{dist} + f_{col} + f_{eol} \tag{12}$$

where e_{use} and f_{use} denote environmental load and cost during the product usage stage per unit time, respectively. e_{prod}, e_{dist}, e_{col}, and e_{eol} denote environmental load at the production, distribution, collection and end of life (EOL) treatment stages, respectively. f_{prod}, f_{dist}, f_{col}, and f_{eol} denote the cost at production, distribution, collection and EOL treatment stages, respectively.

LCE and LCC of a product can be calculated by conventional life cycle assessment (LCA) and life cycle costing (LCC) tools, respectively.

3.3 Sensitivity analysis

As given in equations 8, 11 and 12, TPI is constructed from 17 parameters, namely, $\|\boldsymbol{m_c}\|$, $\|\boldsymbol{m_d}\|$, $\|\boldsymbol{c}\|$, $\|\boldsymbol{d}\|$, θ_c, θ_d, e_{use}, e_{prod}, e_{dist}, e_{col}, e_{eol}, f_{use}, f_{prod}, f_{dist}, f_{col}, f_{eol} and *lt*. Note that due to interdependency among these parameters, each parameter cannot be controlled independently from the others. Therefore, preferential improvement of the parameters with the greatest influence is an effective approach. In order to find influential parameters among them, sensitivity analysis of TPI should be executed. However, interdependency among the parameters which construct UV and those which construct LCE and LCC is generally unknown in mathematical forms. Thus, we separately conducted sensitivity analysis on the numerator and the denominator of TPI. A set of key parameters is selected by calculating sensitivity vector s as follows:

$$s = (\|c\|\frac{\partial UV}{\partial\|c\|}, \|d\|\frac{\partial UV}{\partial\|d\|}, \theta_c\frac{\partial UV}{\partial\theta_c}, \theta_d\frac{\partial UV}{\partial\theta_d}, e_{use}\frac{\partial TL}{\partial e_{use}}, e_{prod}\frac{\partial TL}{\partial e_{prod}}, e_{dist}\frac{\partial TL}{\partial e_{dist}}, e_{col}\frac{\partial TL}{\partial e_{col}}, e_{eol}\frac{\partial TL}{\partial e_{eol}}, f_{use}\frac{\partial TL}{\partial f_{use}}, f_{prod}\frac{\partial TL}{\partial f_{prod}}, f_{dist}\frac{\partial TL}{\partial f_{dist}}, f_{col}\frac{\partial TL}{\partial f_{col}}, f_{eol}\frac{\partial TL}{\partial f_{eol}}, lt\frac{\partial TPI}{\partial lt}) \tag{13}$$

where *TL* denotes the geometrical average of LCE and LCC.

$$TL = \sqrt{LCE \cdot LCC} \tag{14}$$

4 RULES FOR ECO-BUSINESS PLANNING

Now we can choose a couple of influential parameters. The next issue is how to improve these key parameters without considerable impact on other factors. To do that, we provide a business designer with a set of eco-business rules and conditions for applying them in relation to the 17 business parameters.

In this study, we use 12 eco-business rules that are extracted and modified from our previous work [11]. In our previous work, we identified four kinds of customer benefits (cost reduction, avoidance of risks, improvement

Rules/parameters	UV				LCE					LCC					lifetime
	Deterioration speed $\|\|c\|\|$	Deterioration fitness θ_c	Overall performance $\|\|d\|\|$	Performance fitness θ_d	Use e_{use}	Production e_{prod}	Distribution e_{dist}	Collection e_{col}	EOL e_{eol}	Use f_{use}	Production f_{prod}	Distribution f_{dist}	Collection f_{col}	EOL f_{eol}	
(A) Management of life cycles	*		*		*	*	*	*	*	*	*	*	*	*	*
(B) Expansion of the business scale				○		○	○	○	○		○	○	○	○	
(C) Reutilization of wastes /Use one more time						○	○	○	○			○	○	○	
(D) Utilization of knowledge and information	○	○		○	○					○					○
(E) Linkage and cooperation among various industries			○	○				○	○		○	○	○	○	
(F) Combining various business values	○	○	○	○	○					○					○
(G) Technological innovation	○	○	○	○	○	○	○		○	○	○	○		○	
(H) Outsourcing / Contracting for environmental loads						○			○		○			○	
(I) Servicizing					○	○	○	○	○	○	○	○	○	○	
(J) Timesharing	×		○		×					×					×
(K) Management of hidden bottlenecks	○	○			○					○					○
(L) Application of cleaner methods to satisfy customer needs					○	○			○	○	○			○	

Table 1: Rules-parameters matrix

of service quality, and improvement of customer's image from a societal viewpoint) and derived 8 rules for improving these benefits and 8 rules for decreasing operation cost through an analysis of 130 eco-business cases in Japan, considering the material and monetary flows among all the stakeholders involved. As the description of each rule only contains its meaning and typical examples in our previous work, we formulated their applicable conditions by analyzing the effect of each rule on the 17 business parameters in 70 typical eco-business cases in Japan. Although the effect of each rule on each business parameter differs from case to case, the general tendency of its effect is summarized as follows:

(A) Management of life cycles

Proper management and control of product life cycle (especially, after they are sold) can reduce both environmental loads and costs. Closed-loop manufacturing of a one-time-use camera is an example of this rule. This rule is interpreted as changing a set of control parameters by taking responsibility for the life cycle stages other than the production stage.

(B) Expansion of the business scale

As in traditional businesses, expansion of business scale reduces LCE and LCC at the production, distribution, collection, and EOL treatment stages (e_{prod}, e_{dist}, e_{col}, e_{eol}, f_{prod}, f_{dist}, f_{col} and f_{eol}). Examples include sharing of the logistic system (including reverse logistic system) among multiple firms. In addition, this rule sometimes helps improve performance fitness θ_d because the larger the scale of business, the easier it becomes to collect a wide variety of users.

(C) Reutilization of wastes / Use one more time

Reusable or recyclable goods and energy are sometimes thrown away because, for instance, the amount is too small for them to be reused or recycled. If they are used one more time, LCE and LCC at both the EOL treatment and the production stages (e_{prod}, e_{eol}, f_{prod}, and f_{eol}) are reduced. Utilization of waste plastics as reductant in blast furnaces is an example of this rule.

(D) Utilization of knowledge and information

Utilization of knowledge and information about usage conditions can effectively reduce LCE and LCC at the product usage stage (e_{use} and f_{use}) by increasing the efficiency of energy and material usage. In addition, this rule also improves product lifetime (*lt*) and durability ($||\mathbf{c}||$ an θ_c) by providing adequate maintenance or consultancy services on product use. Eco-drive training service for a driver provided by auto manufacturer is an example of this rule.

(E) Linkage and cooperation among various industries

Related to the rule *Expansion of the business scale*, cooperation among various industrial sectors sometimes contributes to reduction in LCE and LCC at the production, distribution, collection, and EOL treatment stages (e_{prod}, e_{dist}, e_{col}, e_{eol}, f_{prod}, f_{dist}, f_{col} and f_{eol}). The zero emission concept, which aims at reutilizing wastes from a factory as resources for another factory by organizing industrial clusters, is an example of this rule. In addition, this rule sometimes improves utility value ($||\mathbf{d}||$ and θ_d) by creating a new combination of services (related to the rule *Combining various business values*).

(F) Combining various business values

Providing multiple products/services bundled into a package sometimes improves the customer benefit ($||\mathbf{c}||$, $||\mathbf{d}||$, θ_c, and θ_d). In addition, product lifetime and LCE and LCC at the usage stage (*lt*, e_{use} and f_{use}) can be improved by providing products with maintenance and consultancy services.

(G) Technological innovation

Technological innovation is sometimes indispensable for implementing a business idea described as a combination of other business rules. The overall performance and durability of a product, and LCE and LCC at the production, distribution, product-use, and EOL treatment stages (||***d***||, ||***c***||, θ_c, θ_d, e_{prod}, e_{dist}, e_{eol}, $f_{pro}d$, *fdist*, and *feol*) were improved by various technological innovations in many cases.

(H) Outsourcing/Contracting for environmental load

As eco-businesses often cover multiple life cycle stages (from cradle to grave), firms cannot execute the entire tasks by themselves. Therefore, making the right outsourcing decision is important for reducing LCE and LCC. Furthermore, undertakers of the outsourcing can reduce their costs by applying the rule *Expansion of the business scale*.

(I) Servicizing

Servicizing [2] refers to selling a service or functionality rather than a product. While the product is still owned by an eco-business provider, customers pay for use or maintenance. E-learning and videoconference substituting for transportation are examples of servicizing. This rule sometimes significantly reduces LCE and LCC (e_{use}, e_{prod}, e_{dist}, e_{col}, e_{eol}, f_{use}, f_{prod}, f_{dist}, f_{col} and f_{eol}).

(J) Timesharing

The capacity of products such as personal automobiles and industrial equipment is sometimes under-utilized. By encouraging users to abandon individual ownership, more intensive utilization of products can be realized (i.e., a kind of use-oriented services of PSS). This can reduce users' procurement costs and risks for disposal of products. Leasing and rental schemes are examples of this rule. Assuming that *m* users with the same preference for a product (***a*** and ***b***) use the same product in a lease and rental scheme under the same operating conditions, ||***d***||, ||***c***||, e_{use}, and f_{use} become $m \times \|d\|$, $m \times \|c\|$, $m \times e_{use}$, and $m \times f_{use}$, respectively.

(K) Management of hidden bottlenecks

Identification and proper management of hidden environmental bottlenecks of a user's activities often reduce the user's costs and environmental risks. An example of application of this rule is the ESCO business [6], where ESCO comprehensively manages the use of electricity by its user to save electricity. This rule can improve the overall deterioration speed, deterioration fitness, LCE and LCC at the product-use and EOL treatment stages (||***c***||, θ_c, e_{use}, e_{eol}, f_{use}, and f_{eol}).

(L) Application of cleaner methods to satisfy customer needs

Applying cleaner products or services to satisfy customer needs can improve the environmental performance of products/services directly. Examples of this rule include introduction of green electricity such as photovoltaic power generation. This rule improves LCE and LCC at the use and production stages (e_{use}, e_{prod}, f_{use}, and f_{prod}).

Table 1 summarizes the result of analyzing 70 eco-business examples in Japan. The effect of each rule on each parameter is represented by the symbols ○, × and * in each cell of the table. Improved and deteriorated parameters after applying each rule are represented by ○ and ×, respectively. * denotes the possible control parameters when a business designer applies the rule *(A) Management of life cycles*.

5 EXAMPLE

In order to illustrate the procedure of idea generation and decision-making for PSS business strategies, a case study of a laptop computer is described in this section.

5.1 Identification of business environment

The first step is to identify dominant functional requirements to be provided and calculate the obsolescence, value evaluation, deterioration, and performance vectors of a target product (or service), as well as its resulting LCE and LCC in a given business environment. In this example, first we assume that the business sells its laptop computers to the customers.

Table 2: FRs of a laptop computer

FRs		a_i	b_i	c_i	d_i
FR1	Computing speed	−0.78	100.06	−0.004	1
FR2	Compute large-capacity data	−0.48	29.19	−0.004	1
FR3	Storage capacity	−2.00	107.64	−0.010	1
FR4	Portability	−0.10	27.70	−0.004	1
FR5	Easily viewable	−0.41	114.68	−0.001	1
FR6	Handle multiple recording media	−1.21	88.05	−0.010	1

Table 2 summarizes the dominant FRs of a laptop computer. In the table, all the elements of ***d*** are normalized to 1. ***a*** and ***b***, which consist of obsolescence rate a_i and initial importance b_i for each FR, respectively, are calculated by conjoint analysis for two different years (2002 and 2006). For example, we calculated that the weighted factor for FR1: Computing speed was 58.65 [kJPY/GHz] in 2002 (i.e., the performance of FR1: computing speed (1 GHz) was worth 58,650 yen) and it decreased to 36.95 [kJPY/GHz] in 2006 due to technological innovation. Thus, the obsolescence rate of FR1 (a_1) is calculated as -0.45638 by substituting these two values into Equation 6. For the initial importance (weighted factor) of each FR (b_i), the importance value in 2002 is used. ***c***, which consists of deterioration rate for six FRs, was assumed by referring to the physical lifetime of the constituent components of similar products in the market.

LCE and LCC are also calculated by using the conventional LCA and LCC methods. Product lifetime *lt* is assumed to be 48 months in this example. TPI was calculated as 85.4.

5.2 Sensitivity analysis of TPI

As a result of sensitivity analysis, ||***d***||, e_{prod}, and f_{prod} were selected as key parameters in this example.

5.3 Idea generation for eco-business

Referring to Table 1, the designer selected those rules that improve the key parameters determined in section 5.2. ||***d***|| can be improved by *(J) Timesharing*, *(E) Linkage and cooperation among various industrial sectors*, *(F) Combining various business values*, and *(G) Technological innovation*; e_{prod} can be improved by *(B) Expansion of business scale*, *(C) Reutilization of waste / Use one more time*, *(G) Technological innovation*, *(H) Outsourcing*, *(I) Servicizing*, *(K) Management of hidden bottlenecks*, and *(L) Application of cleaner methods to satisfy customer needs*; and f_{prod} can be improved by *(B) Expansion of business scale*, *(E) Linkage and cooperation among various industrial sectors*, *(G) Technological innovation*, *(H) Outsourcing*, *(I) Servicizing*, and *(L) Application of cleaner methods to satisfy customer needs*. Referring to the eco-business case base associated with these rules, the designer generated a business idea as follows:

The business provides a user with a laptop computer in a lease/rental scheme (improve ||***d***|| by *Timesharing*). At the same time, the business also gets revenue from

advertising on the rental laptop computer for another user (improve ||***d***|| by *Combining various business values*). In addition, laptop computers are recycled or reused at the end of their lives to reduce LCE and LCC at the EOL treatment and production stages (improve e_{prod} and f_{prod} by *Reutilization of waste/ Use one more time*).

5.4 Evaluation of the eco-business ideas by TPI

Assuming that key parameters change as shown in Table 3, TPI was improved to 274. Thus, an approximately three-fold improvement was achieved in this example.

Table 3: Estimation of improvement

Influential parameters	Applied rules	Estimation of improvement
Overall performance $\|\|d\|\|$	(J) Timesharing	$\|\|d\|\|$, $\|\|c\|\|$, e_{use}, f_{use} will double by intensive use of a laptop computer.
	(F) Combining various business values	$\|\|d\|\|$ will increase by 48 [thousand Yen × months].
Environmental load at EOL treatment stage e_{prod}	(C) Reutilization of wastes /Use one more time	e_{prod} will reduce to 54%.
Cost at production stage f_{prod}	(C) Reutilization of wastes /Use one more time	f_{prod} will reduce to 62%.

6 CONCLUSION

This paper proposed a strategic decision-making method for eco-business planning so that a designer can easily find a set of eco-business ideas that effectively improve TPI in a systematic manner. To this end, we identified 17 business parameters, from which TPI is constructed, and formulated 12 eco-business rules in relation with these parameters. Through a case study of a laptop computer business, an idea generation procedure was illustrated, and the validity and effectiveness of the method were demonstrated.

Future work includes the following topics:

Modification of eco-business rules and collection of eco-business cases:

Collection and formulation of existing eco-business cases in relation with 12 rules can help a designer to generate new eco-business ideas. In addition to the 12 rules used in this study, other rules and guidelines for eco-businesses [for example, 4] and PSS reasoning methods can also be used by formulating their applicable conditions in relation with the 17 parameters.

Consideration of interdependency among UV, LCE, and LCC:

In general, there exist interdependencies among the parameters that form UV and those that form LCE and LCC. Therefore, such interdependencies should be considered in a future work.

7 REFERENCES

[1] Hauschild MZ, Wenzel H, Alting L (1999) Life Cycle Design. A Route to the Sustainable Industrial Culture? Annals of the CIRP 48(1):93.96.

[2] White, Allen L., Stoughton, M. and Feng, L., 1999, Servicizing: The quiet Transition to Extended Product Responsibility, Tellus Institute.

[3] Lindahl, M. and Olundh, G., The Meaning of Functional Sales, 2001, Proc. of the 8th CIRP Int. Seminar on Life Cycle Engineering, 211-220.

[4] UNEP, 1997, ECODESIGN: a promising approach to sustainable product and consumption, UNITED NATIONS PUBLICATION

[5] Goedkoop, M. J., van Halen, Cees J.G., te Riele, Harry R.M., and Rommens, Peter J.M., 1999, Product service systems, ecological and economic basis, PricewaterCoopers.

[6] Morelli, N., 2006, "Developing new product service systems (PSS): methodologies and operational tools", Journal of Cleaner Production, Vol. 14, pp.1495-1501.

[7] Kondoh, S. et al., 2008, "Robust design method for product life cycle considering the future uncertainties", Proceedings of DESIGN 2008, pp. 439-448, 2008.

[8] Association for ESCO Business Introduction in Japan, 1998, Committee report for ESCO business introduction in Japan, Energy Conservation Centre Japan.

[9] Winterfeld, D. V and Edwards, W., 1986, Decision Analysis and Behavioral Research, Cambridge University Press, Cambridge, England.

[10] Daimon, T. et al., 2004, "Proposal of Decision Support Method for Life Cycle Strategy by Estimating Value and Physical Lifetimes", Proc. of the 11th International CIRP Life Cycle Engineering Seminar.

[11] Kondoh, S. et al., 2006, "Analysis of Key Success Factors for Eco-Business through Case Studies in Japan", Proceedings of 13th CIRP International conference on Life Cycle Engineering, pp. 275-280, 2006