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A Strategy of Providing Upgradable Product Service System for Economic and Environmental Balance

Shuho YAMADA[a,1], Takumi SUGIURA[a], Tetsuo YAMADA[b], Stefan BRACKE[c] and Masato INOUE[a]
[a] *Meiji University, Kanagawa, Japan*
[b] *The University of Electro-Communications, Tokyo, Japan*
[c] *University of Wuppertal, Wuppertal, Germany*

Abstract. For the attainment of sustainable society, not only reducing resource usage, disposal and environmental load but also saving consumer's payment for receiving product and service and yielding high profit for product and service provider are necessary. This paper proposes a planning method for determination of upgrading strategy for upgradable product service system: Up-PSS that is the one of the sustainable developing and consumption business model. The meaning of sustainability in this study is generating larger profit for service provider with cheaper service cost (price) for customers and lower environmental impact for the earth compared with traditional product selling. Hence, this study defines lifecycle cost, profit, and environmental load emission as considerable agendas. At first, this study discusses the occurrence factor of Up-PSS's cost and environmental load in the entire lifecycle of an upgradable product. Second, this paper proposes a decision-making method for particular upgrading way such as send-back upgrade and serviceman upgrade. Third, modeling mothed for lifecycle cost, profit, and environmental load is shown by using aforementioned occurrence factors. Finally, proposed method is applied to a packaged product leasing as a case study. The result of case study attained lower price, higher profit, and lower environmental load in the periodic product lifecycle than conventional product selling by obtaining appropriate profit rate, product using generation, and upgrading amount.

Keywords. Sustainability, Upgradability, PSS, Set-based Design, Product lifecycle

Introduction

Attainment of sustainable society is the recent worldwide concern. Recently, the concepts of Circular Economy [1] and Industry 4.0 [2] are actively discussed as the critical concept for this. In these concepts, increase of productivity based on IoT technology and reuse of not only material but also existing product and idle assets are regarded as the key approaches. Recently, in G7 Bologna Environment Ministers' Meeting, utilizing RRRDR (Remanufacturing, Refurbish, Repair, and Direct Reuse) is highlighted as the effective method for increasing resource efficiency [3]. However, these environmental approaches need to be high yieldable. Because utilizing these

[1] Corresponding Author, Mail: s_yamada@meiji.ac.jp.

approaches brings high cost, nobody intends to utilize. The one of the solutions of this problem is upgradable product service system: Up-PSS [4] which consist of upgradable product and its upgrading service. For designing Up-PSS and maximizing its availability, a designer needs to define appropriate upgrade way, time and frequency. Therefore, this paper proposes planning method for Up-PSS provision. The aim of planning is the obtainment of appropriate upgrade way, cycle and physical lifetime which upgradable product system should have from the economic and environmental perspectives.

1. Up-PSS provide planning method

1.1. Upgradable design and previous study

Upgradable design is the one of the environmental conscious design method. This method aims to design upgradable product for re-increasing its temporally obsoleted value and preventing consumers from product replacement and disposing. Exchanging and/or adding component are the fundamental approaches of this design method. In the process of upgradable design, a designer needs to predict future required functions and performance in advance for providing appropriate upgrading service to service receivers [5]. In previous studies, almost design methods utilize the concept of set-based design [6] for adapting this situation.

Watanabe et al [7], for example, proposed upgrade planning method based on the estimated database of future available components. In this method, a designer needs to collect future available components data and calculate product performance by utilizing their design information. This performance which also means the combination of components is mapped on the temporal chart called VP: valuation parameter roadmap and the performance range of each time are prepared. A designer additionally divides this range into 3 types: high-end, middle-end, low-end user required ranges. From this roadmap, designer understands upgrade time by the observation of that initially selected combination strays form VP roadmap with time. This method enables to obtain upgrade times for each user types and easy to understand necessary components because the plot which shows necessary performance on the roadmap also indicates the necessary component combination.

Second case is the authors' study. Yamada et al [8]. proposed upgradable product design method based on set-based design method. This method consists of 5 steps: (i) target product determination stage, (ii) upgradable function and component definition stage, (iii) adverse effect estimation stage, (iv) user requirement definition stage, and (v) solution obtainment stage. Analytic Hierarchy Process: AHP is utilized for prioritizing candidates of functions which will be upgraded and Quality Functional Deployment: QFD is utilized for detecting component which should be exchanged to improve target function. This upgradable product design method identifies adverse effect caused by exchanging component by marshaling its input-output relationship and adding over-specification to related component. In addition, applying set-based design method for the calculation of ranged design solution attains multi-objective design solution sets which resolve trade-off relations between over-specification and adverse effect and among lifecycle cost, profit, and environmental loads. From these studies, following agendas are emerged.

- Upgrade time is obtained from only functional perspective.
- The length of lifetime that upgradable product should have is not considered.
- Upgrade service providing way is ill-argued.

Therefore, this study focuses on above three agendas and proposes planning method that can obtain upgrade cycle, necessary lifetime, and upgrade service providing ways based on economic and environmental perspectives.

1.2. Up-PSS service design method

This paper proposes a planning method for upgrade service providing. This method is a part of Up-PSS design method. In this study, Up-PSS design method consists of 6 steps. At first, designer determines target service receivers and investigates their lifestyles for obtaining their needs and dissatisfactions. Second, designer gets an idea regarding providing service from this investigation result. In addition, generated service idea is detailed into service components which include tangible and intangible factors. In the case that the service needs to adapt to rapid technical progress or provision of the new value and lifestyle, replacement of parts of the product might not attain future required performance and function. Therefore, a designer needs to consider the availability of product itself replacement and its recycling scheme. Third, these service components are modularized from the perspective of supply chain management. Because upgrading is conducted at future time, uncertainty-robust supply chain is essential for providing tangible service component certainly. Forth, modularized tangible service components are evaluated their appropriate lifecycle options which are reuse, remanufacturing (maintenance), and upgrade by using adaptability indicators [10]. Fifth, designer determines upgrade service provide plan that includes upgrade time, upgrade way, and so on. And finally, a designer designs and produces service component (product) and maintains its service. From first to forth steps are able to be implemented by existing methods of upgradable design. Hence, this study especially focuses on fifth step and proposes decision support method for upgrade time and ways.

2. Upgrade service provide design

2.1. Planning procedure

Proposing planning method for upgrade service start after the determination of upgrade target service component. At first, designer determine upgrade way of each upgrade target. This paper assumes 4 upgrade ways and proposes determine matrix.

Second, designer prepares service component's lifecycle and understands the generation source of cost and environmental loads. Because the amount of cost and environmental loads of transportation stage especially depends on upgrade way, designer has to pay attention to transport way, length, and weight.

Third, designer defines comparison criteria for the definition of requirement and obtainment of design solution. The ultimate purpose of Up-PSS is concurrent attainment of higher yieldability, lower service price, and lower environmental loads compared with existing business models. Therefore, selecting business model which is to be compared is the essential. In the case of the target service, for example, has already deployed as leasing widely, this upgrade service should be designed to have an advantage over leasing in aforementioned purpose.

In final step, designer applies requirements and design variables to multi-objective optimization method for the obtainment of provide plan. Multi-objective optimization method is used for solving trade-off relations between evaluation criteria (e.g. profit and price).

2.2. Determination of upgrade provide ways

Upgrade ways are following 4 types: (i) send-back upgrade, (ii) user-s upgrade, (iii) user-b upgrade, and (iv) serviceman upgrade. Figure 1 shows the schematic of these upgrade ways. Send-back upgrade means that when upgrade time comes, service provider collects product from receiver and upgrades this product by provider or related agent itself. After the upgrading, upgraded product is backed to receiver and put onto next generation usage stage. The characteristics of this upgrade way is product quality is easy to attain uniformly high because all upgrading processes are conducted by professionals belong to provider. However, it brings higher cost compare with user upgrade due to the necessary of transport of not only component but also entire product.

User-s upgrade and user-b upgrade mean that upgrade action is executed by user himself. In this case, provider only has to send upgradable component to receivers and needs not to prepare upgrade work line. In addition, cost and environmental loads caused by transportation are possible to reduce compared with the other upgrade ways because only upgradable component is transported. The difference between user-s and user-b upgrades is waste (exchanged component) disposal. In the case of the user-s upgrade, waste is disposed by service receiver himself like general household garbage. On the other hand, in the case of the user-b upgrade, service receiver sends exchanged component to provider and provider disposes it responsibly. Therefore, these upgrade ways are applied depending on reusability of waste and difficulty and legal requirement of disposal. For example, when electronic component is upgrade target, exchanged component should be collected and disposed by its provider in accordance with WEEE directive.

Serviceman upgrade means serviceman brings upgradable component and exchanges it. This upgrade way is recommended to apply to large-scale apparatus such as machine tool which is difficult to transport once installed because upgrade action is conducted by professional serviceman that comes at receiver with necessary component.

A designer needs to decide appropriate upgrade way that is to be applied to each component from these 4 types. This study proposes upgrade way decision matrix: Up-WDM to support designer's decision making. Table 1 shows this matrix. In this matrix, 9 consideration criteria are located on left line. The other lines show recommended condition of every criterion for evaluating aforementioned 4 upgrade ways. A designer rates every criterion of each upgrade target service component on a 3-point scale: -1, 0, and 1 by reference to Up-WDM. In addition, these scores are summated with respect to each upgrade way and the upgrade way which has the highest score is determined as to be applied. Figure 2 illustrates this scoring process. In Figure 2, at first, target component's characteristics is prepared and translated to scores by reference to Up-WDM. Next, score of each upgrade way is summated individually and the highest (send-back upgrade) is emerged.

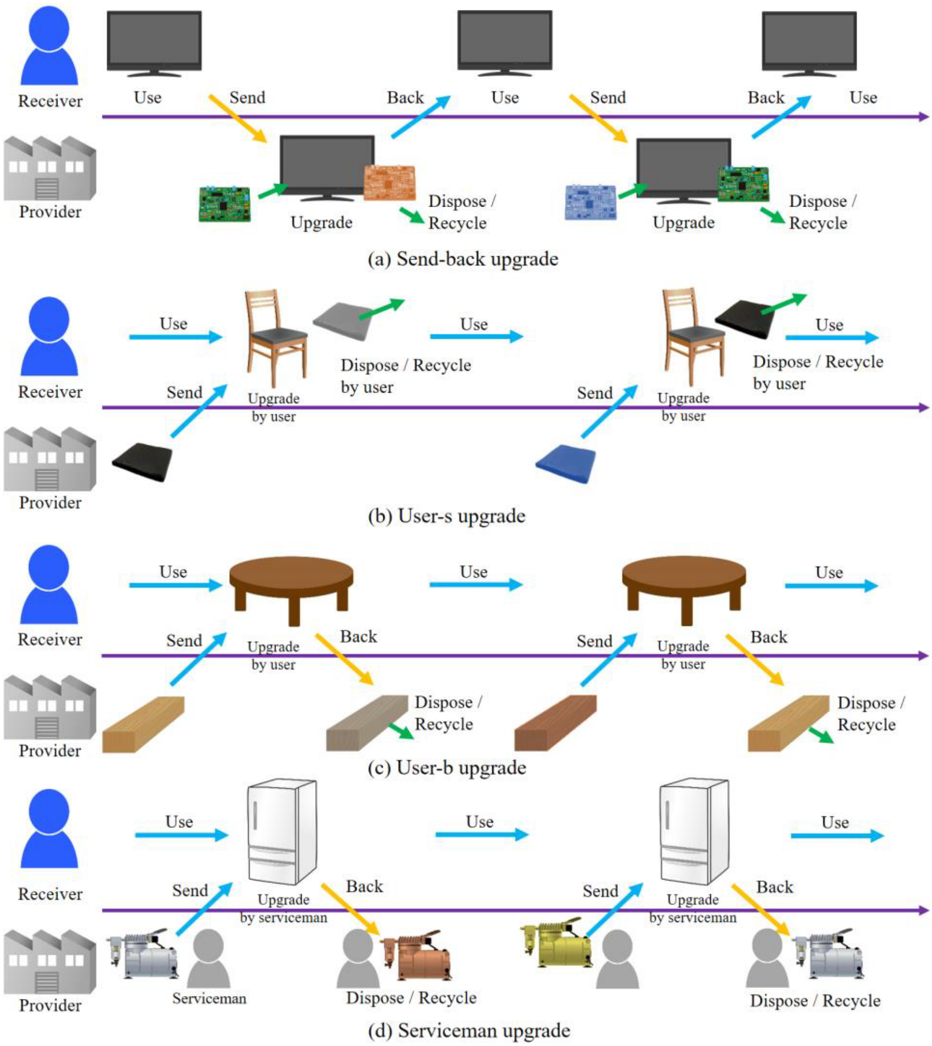


Figure 1. Product and component flow in each upgrade way.

Table 1. Upgrade way decision matrix: Up-WDM.

Criterion \ Upgrade way	Send-back	User-s	User-b	Serviceman
Necessary technique	High	Low	Low	Middle
Influence on receiver's life or work by upgrade-operation time	Low	Middle	Middle	High
Weight of entire product	Light	Heavy	Heavy	Middle
Weight of target component	Middle	Light	Light	Heavy
Size of entire product	Small	Large	Large	Large
Size of target component	Large	Small	Small	Middle
Reusability of exchanged component	High	Low	High	High
Disposal cost occurrence of exchanged component	Yes	No	Yes	Yes
Inclusion of hazardous substance in exchanged component	Yes	No	No	Yes

Criterion	Characteristics
Necessary technique	High
Influence on receiver's life or work by upgrade-operation time	Low
Weight of entire product	Middle
Weight of target component	Light
Size of entire product	Small
Size of target component	Middle
Reusability of exchanged component	High
Disposal cost occurrence of exchanged component	Yes
Inclusion of hazardous substance in exchanged component	No

Scoring

	Send-back	User-s	User-b	Serviceman
Score	1	-1	-1	0
	1	0	0	-1
	0	0	0	1
	1	0	0	0
	1	-1	-1	-1
	0	0	0	1
	1	-1	1	1
	1	-1	1	1
	-1	1	1	-1
Result	5	-3	1	1

Recommended upgrade way

Figure 2. Scoring by Up-WDM and decision process of upgrade way.

2.3. Estimation of upgrading scenario and collecting related data

After the determination of upgrade way, a designer estimates lifecycle scenario of component as shown in Figure 1 for understanding the flow of material and money. The amounts of lifecycle cost and environmental load consist of the cost and environmental loads in production, transportation, upgrade (operation), and disposal phases. Especially, costs of transportation and upgrade phases strongly depend on upgrade way. Therefore, a designer needs to discuss about information regarding transportation way and distance between stakeholders carefully. In addition, it is necessary that the value of the generation sources of cost and environmental load are prepared as ranged value that covers possibility of occurrence. Finally, a designer formulates service cost (price), profit, and environmental load emission as the summation of generation sources.

2.4. Definition of requirement and evaluation criteria

For the obtainment of sustainable design solution, definition of appropriate comparison criteria is essential. Because Up-PSS's ultimate purpose is attainment of PSS model that can provide high level service continually with high yieldability, low service price, and low environmental load, service cost and environmental load should be lower than existing business model and profit should be higher. Hence, a designer investigates information about existing deploy models of the service component and defines required value ranges of cost, profit, and environmental load of Up-PSS.

2.5. Obtainment and consideration of design solution

In this step, designer applies requirement, formula, and value ranges of design variables that include the aforementioned generation source, profit rate, providing years or generations, and the rate of upgradable amount to Preference Set-based Design: PSD system [9] which is the one of the multi-objective optimization method. Figure 3 illustrates the schematic of obtainment process of ranged design solution. In the obtained range, the range of evaluation variable means expected range by providing upgradable service and design variable's means necessary value range for the attainment of these situation. Designer decides providing strategy by reference to the solution ranges of design variables because these variables include information with regard to upgrade cycle, provide term and so on. After the determination of providing strategy, necessary physical lifetime becomes clear and this information is to be used in the later Up-PSS design step.

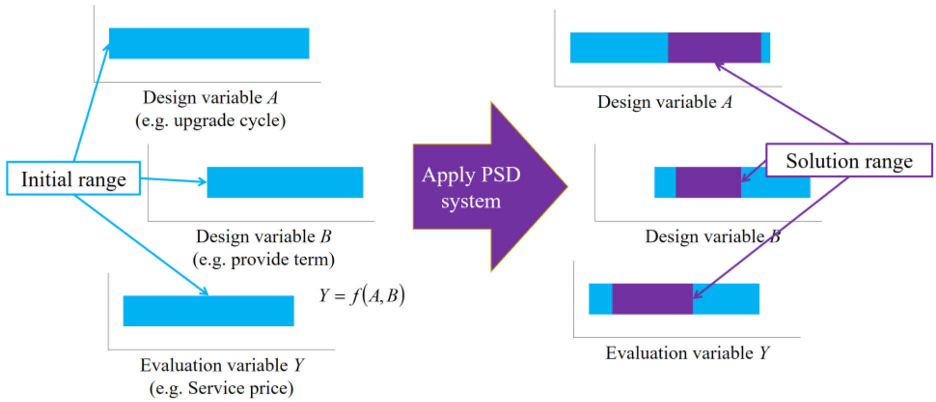


Figure 3. Schematic of ranged design solution obtainment.

3. Case study: Home appliance and furniture packaged leasing

3.1. Design condition

This paper applies proposed planning method to upgradable household appliance and furniture packaged leasing design. This study assumes that designing leasing service consists of periodic upgrade, transport, and installation services. Upgrade target household appliance and furniture are defined as shown in Table 2. Table 2 shows upgrade targets, their specifications, Up-WDM score, and applied upgrade way. Upgrade way of target is determined based on the Up-WDM result which is conducted according to the specification. The purpose of this service is defined as continually providing higher class household appliance and furniture with lower price and high profit for provider compared with purchasing low price goods. Therefore, this study defines design variables as shown in Table 3. Table 3 shows the initial value ranges of upgradable case and assumed value of conventional sellout case. These values are defined by reference to existing product and IR reports. The aim of this case study is attainment of aforementioned purpose by obtaining appropriate value range of profit rate, use generation. This study defines service provide time as 8 years because 70% of rented accommodation users in Japan change their address within 4 years. And, upgrade cycle (i.e. use time per generation) which is used for the calculation and comparison of lifecycle cost, profit, and environmental load during service providing is defined as every 4 years. Hence, in case that use generation range is obtained from 5 to 6, upgradable household appliance and furniture is to be used from 20 to 24 years and they need to have enough physical lifetime.

In this case study, evaluation criteria for the obtainment of upgrade generation: *UGN*, rate of the upgradable amount: *UAR* which means usable amount of cost and material, and profit rates: *UpPRfu*, *UpPRha*, and *UpPRtv* are following 3 performance variables: environmental load by service provision per generation: *SELpG*, price of service provision per generation: *SPpG*, and profit by service provision per generation: *SRpG*. Equation 1 to 3 shows the relation between performance variables and design variables.

Table 2. Design information of upgrade target household appliance and furniture.

Upgrade target	Size (W, D, H) [mm]	Weight [kg]	Up-WDM sore				Determined upgrade way
			Send-back	User-s	User-b	Serviceman	
Dining chair	460, 460, 800	4.0	1	3	2	-3	User-s
Dining table	1800, 900, 700	42.5	-1	-1	0	3	Serviceman
Low table	1000, 750, 350	24.0	0	2	3	-2	User-b
Cabinets	890, 590, 1870	77.0	-1	-3	-2	3	Serviceman
Work desk	1000, 550, 730	71.9	1	-5	-4	3	Serviceman
Television	900, 190, 570	11.0	6	-2	3	2	Send-back
Air conditioner	800, 150, 250	8.0	5	-7	-2	7	Serviceman
Refrigerator	600, 700, 1820	79.0	3	-7	-2	7	Serviceman
Washing machine	600, 610, 1000	40.0	4	-6	-1	6	Serviceman

Table 3. Initial value ranges of upgradable service and conventional sellout case.

Constant		Upgradable	Conventional
TEL	Environmental load of transportation phase [kg-CO_2]	300	190
REL	Environmental load of recycling phase [kg-CO_2]	7.0	32
TC	Transportation cost [Yen]	60000	55000
RC	Recycling cost [Yen]	6300	16000
WC	Working cost [Yen]	38000	38000
Constraint of design variable			
PELfu	Environmental load of furniture production phase [kg-CO_2]	[36.2, 39.8]	36.2
PELha	Environmental load of household appliance production phase [kg-CO_2]	[522.7, 575.0]	522.7
PELtv	Environmental load of television production phase [kg-CO_2]	[50.0, 55,0]	50.0
PCfu	Production cost of furniture production phase [Yen]	[96000, 225000]	9600
PCha	Production cost of household appliance production phase [Yen]	[161500, 209000]	161500
PCtv	Production cost of television production phase [Yen]	[45000, 63000]	45000
Design variable			
UpPRfu	Profit rate of furniture	[0.4, 0.6]	0.20
UpPRha	Profit rate of household appliance	[0.05, 0.1]	0.05
UpPRtv	Profit rate of television	[0.1, 0.15]	0.10
UAR	Rate of upgradable amount	[0.35, 0.50]	-
UGN	Upgrade generation	[2, 6]	-
Evaluation variable			
SELpG	Environmental load emission by service provision per generation [kg-CO_2]	[360, 719]	719
SPpG	Price of service provision per generation [Yen]	[220000, 449000]	449000
SRpG	Profit by service provision per generation [Yen]	[337500, 75000]	37500

These equations consist of the amount by generation that means the sum of the amounts in first production and every upgrading phases divided by the number of provision generation. In the case of *SPpG* and *SELpG*, the amounts of transportation, working, and recycling phases are added to aforementioned amount.

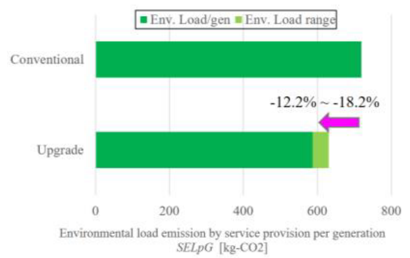
$$SELpG = \{1 + UAR(UGN - 1)\} \times \frac{(PELtv + PELfu + PELha)}{UGN} + REL + TEL \quad (1)$$

$$SPpG = \frac{1 + UAR(UGN-1)}{UGN}\left(\frac{PCtv}{1-UpPRtv} + \frac{PCfu}{1-UpPRfu} + \frac{PCha}{1-UpPRha}\right) + WC + RC + TC \quad (2)$$

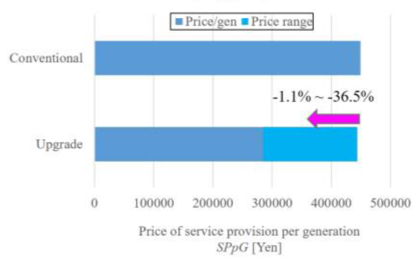
$$SRpG = \frac{1 + UAR(UGN-1)}{UGN}\left(\frac{PCtv \cdot UpPRtv}{1-UpPRtv} + \frac{PCfu \cdot UpPRfu}{1-UpPRfu} + \frac{PCha \cdot UpPRha}{1-UpPRha}\right) \quad (3)$$

3.2. Result and discussion

Figure 4 illustrates obtained solution ranges and comparison of the design and evaluation variables. The ranged solution shows that high yieldable, low price and low environmental load product service system is possible to be attained as long as the designer develops the upgradable household appliance and furniture that can be used from 5.5 to 6 generations (from 22 to 24 years) by upgrading 35% to 36.9% of themselves. In particular, following availability is indicated that this solution attains from -1.1% to -36.5% reduction effect in service price, from 7.5% to 165.9% increase in profit, and from -12.2% to -18.2% reduction effect in environmental load emission compared with conventional purchase case.



	Design variable	Solution range
UpPRfu	:Profit rate of furniture	[0.425, 0.45]
UpPRha	:Profit rate of household appliance	[0.0625, 0.0688]
UpPRtv	:Profit rate of television	[0.1, 0.106]
UAR	:Rate of upgradable amount	[0.35, 0.369]
UGN	:Upgrade generation	[5.5 , 6]



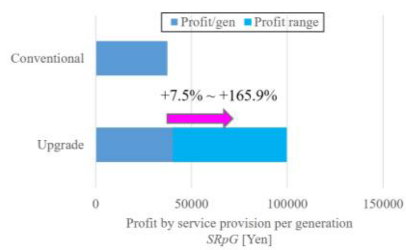


Figure 4. Solution ranges of design and evaluation variables.

4. Summary

This paper proposed planning method for Up-PSS design from the economic and environmental perspectives. In our proposal, the authors especially focused on the upgrade service provision way that is the ill-argued topic in the previous studies of design for upgradability [5,7,8] and proposed Up-WDM for supporting designer's decision making with regard to selecting appropriate upgrading way by reference to specification (i.e. upgrade working, transportation, and environmental perspectives) of the upgrade target product. In addition, this paper showed the necessary design variables (e.g. upgrade generation) and interpretation of obtained ranged design solution. Proposed planning method is applied to household appliance and furniture packaged leasing design and its result shows the capability of the attainment of high yieldable, low price, and low environmental load service system.

The future works of this study are modeling service receiver's satisfaction and applying it to proposed method. This satisfaction model needs to cover receiver's diversity and temporal change of their needs because upgrade service is provided longer time compared with conventional sellout business model.

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