

Full Length Research Paper

Strategy selection for product service systems using case-based reasoning

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A product service system integrates products and services in order to lower environmental impact. It can achieve good eco-efficiency and has received increase in the last decade. This study focuses on strategy selection for product service system design. Case-based reasoning is utilized to provide suggestions for finding an appropriate strategy. To build a case database, successful PSS cases from the literature and websites were collected and formulated. Twelve indices under three categories were analyzed and selected to describe cases. A lot of successful PSS cases and their information were collected. Forty seven cases were used in this study because of the completeness of information. The analytic hierarchic process is used to find the relative weights of the factors that relate to the selection of customers. These weights are used in calculating the similarity in the case-based reasoning process. The successful strategy of the most similar case is extracted and recommended for PSS strategy determination. More than 90% of tested cases obtained an appropriate strategy from the most similar case. Finally, two new products are introduced to find the best strategy for product service system design and development using the proposed case-based reasoning system.

Key words: Product service system, analytical hierarchic process, case-based reasoning.

INTRODUCTION

In the last decade, sustainability issues have attracted increasing attention in business management and product design. An increasingly common idea is that the environmental impact should be prevented in the “cradle” stage instead of solving problems after the damage has been done. Preventive actions are recognized as having higher priority than that of traditional end-of-pipe remediation actions (Kang and Wimmer, 2008). The New version of the well-known environmental management system ISO-14000 includes more detailed suggestions on green product design and life cycle thinking. Product designers have learned how to develop new products with less environmental impact. This trend has been expedited by European directives such as ELV, WEEE, RoHS, and EuP. The ripple effect passing through the global production network has increased the awareness of green product design and manufacturing.

However, in order to achieve higher eco-efficiency, simply modifying or redesigning hardware of products is not enough. Function innovation and system innovation are required to make “Factor 10” a reality. To initiate function and system design, many ideas have been raised in the last decade, such as dematerialization, closed loop, extended producers’ responsibility and product service systems (PSS). The core idea of these terms is that service should be jointly considered with product design so that higher eco-efficiency can be achieved (Goedkoop et al., 1999; Mont, 2002). What type of service should be considered together with products to make a successful PSS is the key question in this study.

Product service system related issues are becoming increasingly popular (Mont, 2004; Tukker, 2004). Journal of Cleaner Production published special issues (Vol 11, Iss 8, 2003, and Vol 14, Iss 17, 2006). On “product service systems and sustainable consumption” and “product service systems: reviewing achievements and refining the research agenda” respectively. Many definitions of PSS have been given in the literature (Goedkoop et al., 1999; Mont, 2004; Tukker, 2004;

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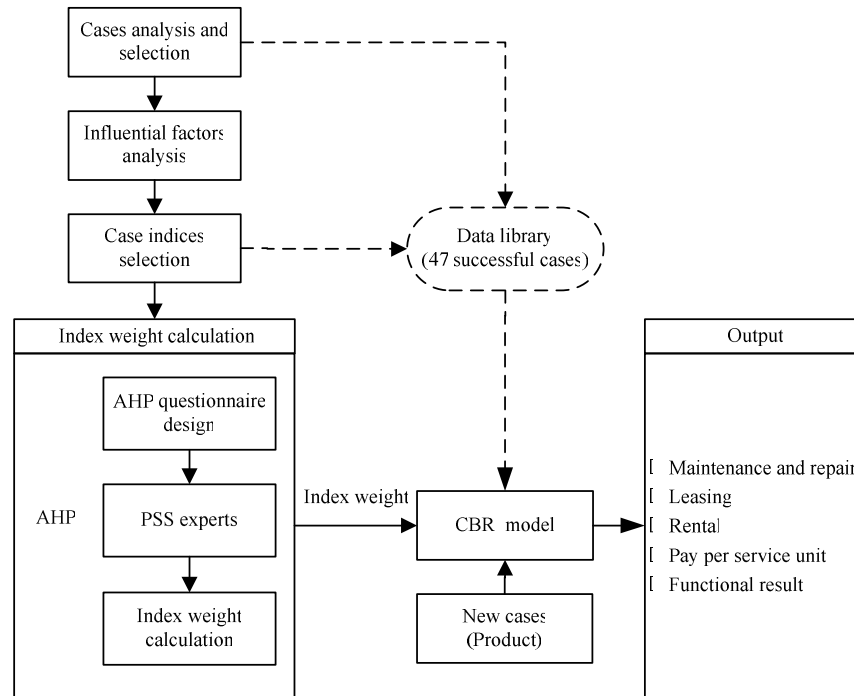


Figure 1. The framework of the proposed CBR approach.

Baines et al., 2007). This study adopts the following definition: “A system of products, services, network partners, and supporting infrastructure that is economically feasible, competitive, and satisfies customer needs. It offers dematerialized solutions that minimize the environmental impact of consumption (Baines et al., 2007). How to combine a service with a product is essential for making a successful PSS.

In designing and promoting a product service system, the best type of PSS for a given kind of product must be determined. This study collects successful PSS cases and builds a case-based reasoning (CBR) system to help service selection. PSS cases were stored in a case library with well-defined indices.

The types of service for the successful cases were also categorized. Suggestions for suitable service types for a new product can be obtained using the proposed system. The research scheme is shown in Figure 1, where index selection and evaluation is on the left and the types of service suggestion are on the right. The Weight of each index is evaluated using Analytic hierarchic process (AHP) and the suitable service type of a new case is evaluated using CBR. Each of the 47 cases is used to test the suitability of the chosen factors and the corresponding weights.

STRATEGY SELECTION FOR PSS

Tukker (2004) categorized several PSS classifications into 8 types by orientation as follows.

(A) Product oriented: The business model is based on product ownership transaction, although services are provided to improve the functionality of the product.

1. Maintenance or convenient access during the use phase of the product.
2. Advice and consultancy.

(B) Use oriented: The product is held by the provider or shared by a group of users.

3. Leasing.
4. Renting or sharing.
5. Product pooling.

(C) Result oriented: The focus is on the result. Products are considered as a tool to achieve the desired results.

6. Activity management (such as outsourcing activities).
7. Pay per service unit.
8. Functional result.

This study focuses on five types of service strategy: (1) maintenance and repair, (2) leasing, (3) rental, (4) pay per service, and (5) functional results. Consultancy, product pooling, and outsourcing are excluded from the case library since the number of related cases is comparatively small.

Case-based reasoning is a branch of artificial intelligence. It includes case retrieval, reuse, revision, review, and retention. CBR has been widely used in unstructured and vague problem solving (Aha, 1998). Experience from past cases is extracted for new problems. Similarity between existing cases and a new case can be calculated using a weighted sum of differences of case indices (Watson, 1998). The Weights of the indices can be determined using methods like genetic algorithm, neural network,

and AHP. This study uses AHP to determine the weights of indices in calculating similarity.

Analytic hierarchic process is used in several sitting problems (Larichev and Olson, 2001; Rachdawong and Apawootichai, 2003; Chen, 2006). The strength of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structured yet relatively simple solution to decision-making problems (Saaty, 1982, 1990; Saaty and Thomas, 2000). The idea behind using AHP that it allows a comprehensive, logical, and structured framework for providing a solution to a particular problem. It can make use of subjective judgments, which is a particularly important feature for decisions that are made on a poor information base. An overview of various AHP methods and their applications can be found in previous studies (Zahedi, 1986; Vargas, 1990; Roper-Lowe and Sharp, 1990; Al-Subhi and Al-Harbi, 2001; Forman and Gass, 2001; Vaidya and Kumar, 2006).

Case-based reasoning is widely used in new product development (Belecheanu et al., 2003; Wu et al., 2006, 2008; Ho, 2008; Choy et al., 2009; Jung et al., 2009). The present study uses CBR to determine the strategy for selecting the service type to cope with the product to obtain a successful PSS.

Case-based reasoning and index construction

To find a proper service strategy, similar cases or experiences are searched for in the case library. Kolodner and Simpson (1993) suggested a method to calculate similarity that uses the weighted summation of all indices, as shown in Equations (1) and (2).

$$Total\ similarity = \frac{\sum_{i=1}^n w_i * sim(f_i^T, f_i^S)}{\sum_{i=1}^n w_i} \tag{1}$$

Where

$$sim(f_i^T, f_i^S) = 1 - \frac{|f_i^T - f_i^S|}{d_i} \tag{2}$$

and w_i is the weight of the i th index.

The weight w_i varies among (0, 1) and summation of all w_i is equal to 1. i is the subscript for i th index.

sim is the function of similarity of the index between test case and source case, it ranges between (0, 1).

f_i^T is the value of index i of the test case.

f_i^S is the value of index i of the source case.

d_i is the range of $\{f_i\}$, that is $(\max(f_i) - \min(f_i))$.

n is the number of indices.

PSS cases were collected from the literature (Goedkoop et al., 1999) and company websites. To provide a proper strategy for selecting a service type, a case description must be extracted from successful cases. For confirming the practicability of cases, they are adopted when fulfill at least two of the following conditions: (1)

have existed in the market for more than five years, (2) significantly reduce environmental impact, (3) have more than five service providers in a region, and (4) show strong evidence of profitability. In the proposed system, more than 47 successful PSS cases and their descriptions were collected (Table 1).

Many factors make a PSS case successful. The factors may be due to the product itself, consumer preferences, use patterns, and the market social-economical background (Kotler, 2001). In this study, successful PSS cases were collected with their supporting conditions and influential factors.

These conditions and factors were translated into cases indices and stored in the case library. Various influential factors that may positively support the success of PSS were compared and selected. Twelve factors that fall into three categories (Table 2) were selected as indices for case description:

(A) Consumer behavior and usage patterns of the product, such as place and frequency of product use. These indices show how, when, and where the product is used, and therefore facilitate the selection of a service type.

(B) Characteristics of the product itself, such as weight, volume, price, lifetime, subsequent expenditure, and product life cycle. Physical and other characteristics of the product are also presented as quantitative indices.

(C) Background and environment factors of the target market, including GDP per capita of the targeted market, population density, area of territory, and temperature range. These indices represent the social, economic, and geographical background of the target market for the PSS.

Analytic hierarchic process is used to find the relative weights of the indices. These weights are also used in calculating the similarity in a CBR process. Four domains experts were surveyed on the weights via a paired comparison questionnaire of AHP. The resulting weights for similarity calculation are presented in Table 3.

For AHP, the consistency ratio (CR) was used to determine and justify the inconsistency in the pair-wise comparison made by the respondents. Garcia-Cascales and Lamata (2009) presented a detailed calculation of CR. The CR value in this study is 0.082 that is lower then the acceptable value 0.1.

SYSTEM TESTING WITH CASES

Each of the 47 cases was used as a new case to test and validate the system. Table 4 shows the results, where the top three cases with the highest similarity are presented for each case. If the suggested service type from the top three cases matches the original service type of the case, a correct mark is presented on the right-hand side. For example, the number one case is “washing machine” and the top three cases for it are “repair of refrigerator”, “computer”, and “water heater”. The CBR system recommends “maintenance” as the best strategy for PSS development. It matches the original service type of “washing machine”, therefore a correct mark appears on the right of row one.

A question mark “?” is used for the case 23 (“video game”) because the similarity score of the most similar case is 79.7%, a little lower than those in other cases. However, the strategy-rental provided by the most similar cases match the original case strategy. Similarity scores of the other 46 cases are above 93%, as shown in Table 4.

Table 1. Successful PSS cases selected from literature.

PSS strategies	Cases
Maintenance and repair	(1) washing machine repair, (2) refrigerator repair, (3) computer repair, (4) laser printer repair, (5) LCD monitor repair, (6) water heater repair, (7) handbag maintenance and repair, (8) jewelry maintenance and repair, (9) watch maintenance and repair
Leasing	(10) treadmill rental, (11) washing machine rental, (12) LCD TV rental, (13) sofa rental, (14) dryer rental, (15) platform bed rental, (16) refrigerator rental, (17) credenzas rental, (18) dish washer rental
Rental	(19) luggage box rental, (20) video CD/DVD rental, (21) evening dress rental, (22) entertainment book rental, (23) video game rental, (24) jewelry rental, (25) handbag rental, (26) GPS rental, (27) DV rental
Pay per service unit	(28) fax service, (29) printing service, (30) copying service, (31) scanning service, (32) laminating service, (33) clothes washing service, (34) cleaning service, (35) shoes cleaning service, (36) eyeglass cleaning service, (37) photographic service
Functional result	(38) online music, (39) online magazine, (40) online KTV, (41) music download, (42) multimedia on demand, (43) digital map, (44) online newspaper, (45) online dictionary, (46) digital calendar, (47) book (audio book) download

Note: literatures include Goedkoop et al. (1999) and Tukker, 2004.

Table 2. Indices for case description.

Categories	Index	Definition	Index value
User behavior	Place of usage	The place where the product is often used	1 = indoor, 2 = both, 3 = outdoor
	Frequency of usage	The frequency that the product is often used	1 = 1 time / month, 2 = 2 times / month, 3 = 4 times / month, 4 = 8 times / month, 5 = 1 time / day, 6 = more than 1 time / day, 7 = anytime
Product	Product fashion cycle	The period of the product existing in the market (The four stages are product introduction, growth, maturity and decline)	1 = less than 3 months, 2 = 3~6 months, 3 = 6~9 months, 4 = 9~12 months, 5 = more than 12 months
	Volume	Volume of the product	1 = about 1,000 cm ³ , 2 = about 5,000 cm ³ , 3 = about 50,000 cm ³ , 4 = about 100,000 cm ³ , 5 = more than 200,000 cm ³
	Weight	Weight of the product	1 = about 4 kg, 2 = about 8 kg, 3 = about 12 kg, 4 = about 20 kg, 5 = more than 30 kg
	Useful life	It is the length of time that any manufactured item can be expected to be 'serviceable' or supported by its originating manufacturer.	1~100 years
External environment	Price	Expenditure of the product purchasing	1 = less than 30 US dollars, 2 = 31 ~ 300 US dollars, 3 = 301 ~ 900 US dollars, 4 = 901 ~ 1500 US dollars, 5 = more than 1500 US dollars
	Subsequent expenditure	The total expenditure of the product after you bought it.	1 = less than 30%, 2 = 30~60%, 3 = more than 60%
	GDP per capita	Gross Domestic Product per capita of target market	1 = less than 10,000 US dollars, 2 = 10,000 ~ 20,000 US dollars, 3 = 20,001 ~ 30,000 US dollars, 4 = 30,001 ~ 40,000 US dollars, 5 = more than 40,000 US dollars

Table 2. Cont.

Population density	Number of people per km ² of the target market	1 = less than 50 persons / km ² , 2 = 51 ~ 100 persons / km ² , 3 = 101 ~ 150 persons / km ² , 4 = 151 ~ 200 persons / km ² , 5 = more than , 200 persons / km ²
Area of territory	Total area of target market	1 = less than 5 km ² , 2 = 5 ~ 37 km ² , 3 = 38 ~ 69 km ² , 4 = 70 ~100 km ² , 5 = more than , 100 km ²
Temperature range	The difference between minimum and maximum monthly mean temperature in target market	1 = less than 5 °C, 2 = 5 ~ 10 °C, 3 = 10.1 ~ 15 °C, 4 = 15.1 ~20 °C, 5 = more than 20 °C

Table 3. Relative weights of the indices.

Categories	Weights	Indices	Weights
User behavior	0.348	Place of usage	0.116
		Frequency of Usage	0.232
Product	0.343	Product fashion cycle	0.042
		Volume	0.036
		Weight	0.034
		Useful life	0.064
		Price	0.082
		Subsequent expenditure	0.085
External environment	0.309	GDP per capita	0.119
		Population density	0.079
		Area of territory	0.052
		Temperature range	0.059

One of the reasons for this outlier is that case 23 was retrieved from the USA, whereas the top three cases are from Taiwan. Hence, the difference of indices of environment and background lowers the similarity score. However the system still found an appropriate strategy-rental in this case. The system performance is quite satisfactory based on results for the forty seven cases.

APPLICATION TO NEW CASES

Two hypothetical cases were used to test the application potential for the CBR system. First case is books for qualification examination for government employees in Taiwan. These books are usually revised every three years. Prices range from 10 - 30 US dollars and users do not keep them once they pass the exam. The top three

similar cases are (1) entertainment book rental (similarity: 97%), (2) scanning service (94%), and (3) video CD/DVD rental (92%). The first and the third cases suggest short-term rental while the second suggests pay per service. These two strategies can be applied to books for exam preparation.

The second hypothetical case is milk bottle sterilizers for parents with babies. A sterilizer is about 30 to 40 US dollars and its lifetime is about 5 years. After using the proposed CBR system, the three most similar cases are (1) eyeglass cleaning service (similarity 99%), (2) scanning service (similarity 95%), and (3) clothes washing service (92%). All three cases fall into the category of pay per service. In fact, there is a Swedish that company provides this kind of service. The sterilizer has an electronic counter that keeps track of the number of uses of the product. The company charges consumers

Table 4. Results of system testing.

Testing products (original PSS strategy)	Top three cases with highest similarity			Rationality
	1st case (similarity score) (%)	2nd case (similarity score) (%)	3rd case (similarity score) (%)	
(1) Washing machine (maintenance and repair)	Refrigerator repair (93.99)	Computer repair (91.59)	Water heater repair (90.19)	V
(2) Refrigerator (maintenance and repair)	Water heater repair (96.20)	Washing machine repair (93.99)	Computer repair (93.31)	V
(3) Computer (maintenance and repair)	LCD monitor repair (95.67)	Refrigerator repair (93.61)	Water heater repair (93.01)	V
(4) Laser printer (maintenance and repair)	Washing machine repair (90.14)	Printing service (88.4)	Computer repair (85.23)	V
(5) LCD monitor (maintenance and repair)	Computer repair (95.67)	Water heater repair (95.64)	Refrigerator repair (91.84)	V
(6) Water heater (maintenance and repair)	Refrigerator repair (96.20)	LCD monitor repair (95.64)	Computer repair (93.01)	V
(7) Handbag (maintenance and repair)	Jewelry maintenance and repair (95.00)	Watch maintenance and repair (93.18)	Treadmill rental (74.44)	V
(8) Jewelry (maintenance and repair)	Handbag maintenance and repair (95.00)	Watch maintenance and repair (94.08)	Jewelry rental (80.67)	V
(9) Watch (maintenance and repair)	Jewelry maintenance and repair (94.08)	Handbag maintenance and repair (93.18)	Refrigerator rental (75.94)	V
(10) Treadmill (leasing)	Washing machine rental (94.86)	LCD TV rental (90.33)	Dryer rental (89.69)	V
(11) Washing machine (leasing)	Treadmill rental (94.86)	Dryer rental (94.83)	LCD TV rental (93.67)	V
(12) LCD TV (leasing)	Washing machine rental (93.69)	Treadmill rental (90.33)	Refrigerator rental (89.09)	V
(13) Sofa (leasing)	Platform bed rental (93.29)	Credenzas rental (86.77)	Refrigerator rental (86.67)	V
(14) Dryer (leasing)	Washing machine rental (94.83)	Treadmill rental (89.69)	LCD TV rental (88.50)	V
(15) Platform bed (leasing)	Credenzas rental (93.48)	Sofa rental (93.29)	Dish washer rental (86.23)	V
(16) Refrigerator (leasing)	LCD TV rental (89.09)	Sofa rental (86.68)	Washing machine rental (86.26)	V
(17) Credenzas (leasing)	Platform bed rental (93.48)	Sofa rental (86.77)	Refrigerator rental (82.47)	V
(18) Dish washer (leasing)	LCD TV rental (88.62)	Platform bed rental (88.22)	Washing machine rental (85.42)	V
(19) Luggage box (rental)	GPS rental (94.86)	Scanning service (87.44)	Cleaning service (85.21)	V
(20) Video CD/DVD (rental)	Entertainment book rental (94.70)	Fax service (93.24)	Multimedia on demand (92.27)	V
(21) Evening dress (rental)	handbag rental (85.67)	jewelry rental (84.78)	Video game rental (75.48)	V
(22) Entertainment book (rental)	Video CD/DVD rental (94.70)	Scanning service (90.61)	Online magazine (88.40)	V
(23) Video game (rental)	Entertainment book rental (79.66)	jewelry rental (77.46)	Video CD/DVD rental (77.22)	V

Table 4. Cont.

(24) Jewelry (rental)	handbag rental (99.10)	Evening dress rental (84.78)	Jewelry maintenance and repair (80.67)	V
(25) Handbag (rental)	jewelry rental (99.10)	Evening dress rental (84.78)	Jewelry maintenance and repair (80.67)	V
(26) GPS (rental)	Luggage box rental (94.86)	Cleaning service (88.55)	Eyeglass cleaning service (88.34)	V
(27) DV (rental)	Photographic service (95.90)	Cleaning service (89.01)	GPS rental (87.00)	V
(28) Fax modem (pay per service unit)	Video CD/DVD rental (93.24)	Scanning service (93.23)	Online dictionary (89.67)	V
(29) Printer (pay per service unit)	Clothes washing service (94.01)	Laminating service (92.33)	Copying service (91.96)	V
(30) Photostat (pay per service unit)	Clothes washing service (97.95)	Printing service (91.96)	Shoes cleaning service (90.22)	V
(31) Scanner (pay per service unit)	Eyeglass cleaning service (95.76)	Fax service (93.23)	Laminating service (91.52)	V
(32) Laminator (pay per service unit)	Eyeglass cleaning service (95.76)	Printing service (92.33)	Scanning service (91.52)	V
(33) Washing machine (pay per service unit)	Copying service (97.95)	Printing service (94.01)	Eyeglass cleaning service (90.58)	V
(34) Cleaning product (pay per service unit)	Clothes washing service (90.37)	DV rental (89.01)	GPS rental (88.55)	V
(35) Shoes cleaning product (pay per service unit)	Copying service (90.22)	Clothes washing service (88.17)	Eyeglass cleaning service (86.48)	V
(36) Eyeglass cleaning machine (pay per service unit)	Scanning service (95.76)	Laminating service (90.58)	Clothes washing service (88.99)	V
(37) Advanced DV (pay per service unit)	DV rental (95.90)	Cleaning service (84.91)	GPS rental (82.90)	V
(38) Music CD (functional result)	Online newspaper (97.14)	Multimedia on demand (96.130)	Online magazine (94.70)	V
(39) Magazine (functional result)	Multimedia on demand (98.57)	Online music (94.70)	Online newspaper (94.41)	V
(40) Karaoke Machines (functional result)	Multimedia on demand (91.96)	Online magazine (90.53)	Online music (88.09)	V
(41) Music CD (functional result)	Book (audio book) download (98.70)	Platform bed rental (81.72)	Credenzas rental (81.10)	V
(42) Video CD/DVD (functional result)	Online magazine (98.57)	Online music (96.13)	Online dictionary (95.84)	V
(43) Map (functional result)	Online magazine (86.26)	Multimedia on demand (84.83)	Online dictionary (84.83)	V
(44) Newspaper (functional result)	Online music (97.14)	Online magazine (94.70)	Multimedia on demand (93.28)	V
(45) Dictionary (functional result)	Multimedia on demand (95.84)	Online magazine (94.42)	Online music (91.97)	V
(46) Calendar (functional result)	Online newspaper (89.15)	LCD monitor repair (86.45)	Online music (86.29)	V
(47) Book (audio book) (functional result)	Music downloads (98.70)	Platform bed rental (80.42)	Credenzas rental (79.80)	V
Rate of successful reasoning			46/47 = 97.87%	

per use and provides full cleaning and maintenance services.

Conclusion

A PSS that combines services with products to increase customer satisfaction and that reduces environmental impact has attracted increasing attention. How to select an appropriate service strategy is thus an important issue. This study proposed a CBR method to provide suggestions for a service strategy for a given product to make a successful PSS. Successful PSS cases were analyzed and collected into a case library. Twelve indices under three categories are selected to quantitatively describe the cases. Weights of the indices for calculating similarity were determined using the AHP method. Forty seven cases were tested for validation and very good results in service selection were obtained. Strategy selection for two new products was demonstrated to show the application potential of the proposed system.

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