

Sustainable development of product service system design based on analytic hierarchy process

Hui Liang, Jun Zhou

College of Mechanical Engineering, Shanghai University of Engineering Science, Shanghai, China

Abstract—In response to the increasingly serious environmental problems, a new design approach called sustainable development of product service system design will be presented to achieve the goal of sustainable development. It combines product-design, service-design and environmental design. Product service system is divided into three categories: product-oriented product service system, apply-oriented product service system and utility-oriented product service system. On this basis, analyzing elements of the three product service system based on Analytic Hierarchy Process and expert evaluation method and comparing their differences to guide the design of the three product service systems. It provides new ideas and design theory for the sustainable development of product service system design as well. By the example of car, the feasibility of the design method and design method is verified.

Index Terms—product service system, sustainable development, environmental design, analytic hierarchy process

I. Introduction

Although in recent years, the rapid development of industrial has brought human highly developed material civilization, but also produced some problems which restrict the development of the human and survival: 1) waste more and more; (2) resource overexploitation and excessive consumption; (3) the environmental pollution and the destruction of the natural ecology^[1]. How to solve these problems to achieve long-term goal of sustainable development has become an important problem in the current. From the perspective of System theory, Product Service System (the Product Service System, PSS) will be linked to tangible products and intangible Service to solve the environmental problems^[2]. PSS has changed the traditional mode of production and consumption, make the society towards a more sustainable development for the great significance to the economic, social and environmental are^[3,4]. However, when facing some complex machinery, only consider the products and services and lack the design of the environmental factors in the design of PSS can not properly solve environmental problems. According to the above problem, this article first introduced environment design in PSS design phase, emphasis on the essence of PSS design is coupling of product design, service design and environmental design, that can satisfy the design of the attribute and environmental attribute of the system at the same time. On the one hand, PSS can meet the needs of customers to the functions and services; On the other hand, PSS can eliminate or reduce the adverse impacts on the environment. Based on Analytic Hierarchy Process and expert judgment method, respectively analysis the importance weights of design factors in the three kinds of product service system design, the three kinds of product service system design are Product-oriented PSS, Apply-oriented PSS and Utility-oriented PSS, analyzed the results of AHP method under three kinds of product service system, guide the design of the three categories of product service system.

II. The sustainable development of PSS design

2.1. Product service system (PSS)

Although PSS put forward more than ten years, however, PSS is not a unified definition^[5]. Roy put forward that the core of PSS is provided to consumers a special function and the result, consumers don't need to buy or own material products^[6]; Tukker thought that PSS is through the business network (or with a product) provided to the customer a special type of value concepts^[7]; Maussang defined PSS: PSS is the product in combination with service to meet user needs^[8]. In addition, there are many scholars have defined PSS. Although these definitions vary, the key features of PSS can be extracted from these definitions:

(1) The first purpose of PSS is to create new value to meet customer demand; The second is to achieve sustainable development.

(2) PSS is integration of tangible product and intangible service. The key is the function of the product and the result, the user can not own or buy material products achieving the features of the product and the result^[9].

According to the Product service system ownership of customer and the degree of service in Product service system, Product service system can be divided into Product oriented PSS, application oriented PSS and Utility oriented PSS^[10], as shown in table 1. Study is based on the three kinds of PSS.

TABLE 1: CLASSIFICATION OF PSS

Name	Level of service	ownership
PPSS	The process of service has began, but the level of service is low.	Customers have products with the rights of possession, use, usufruct and disposition.
APSS	Compared with Product-oriented PSS, the level of service deepens.	Manufacturer reserves the right to possess, dispose of the product, the customer only to purchase the right to use the products of a certain period and earnings.
UPSS	the level of service is the highest in three kind of Product service system.	Customers don't have the product and do not directly use the product, only has the usufruct of product and service.

1.2. The sustainable development of PSS

The sustainable development has intimate relationship with the environment. Sustainable development theory is put forward because "environmental crisis" has become a threat to human survival and restrict the economic development and the direct factors affecting social stability, humans began to think seriously about the relationship between human and environment, to have a clear understanding of economic development^[11]. To realize the sustainable development of PSS design, not only considering the design of the product and service, but also to carry on the design for the environment. According to the ErP (Enter - realted Products) directive, in various stages of the product life cycle to evaluate the main environmental factors as follow^[12]:

- (1) the consumption of resources;
- (2) emissions to air, water and soil;
- (3) the noise pollution, radiation, etc;
- (4) material recycling, recycling of energy.

analyzing From the Angle of the system, the reasonable system design is the result of system optimization, there is a cross coupling relationship between product design, service design and environment design, as shown in figure 1, to make the PSS can achieve optimal design, only taking the overlap of each other, we can achieve the

sustainable development of Product service system.

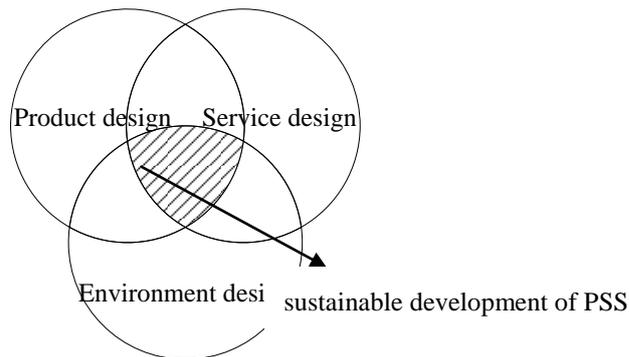


Figure 1: the most optimal design of PSS based on sustainable development

III. Method of Analytic Hierarchy Process (AHP)

The analytic hierarchy process^[13] is a solution to solve the complex problem of multi-objective decision which is the method of qualitative and quantitative. This method combines qualitative analysis with quantitative analysis, using the experience of decision makers to judge the standard of each target can be fulfilled between the relative important degree, and reasonably give each decision a weight, the weight is used to determine the relative importance or identify the pros and cons of each solution sequence.

Sustainable development of PSS based on AHP which basic train of thought is target decomposition, introducing environmental design in the design phase, then, using the AHP method to analyze the weight, the final result is used to guide the design of PSS. Figure 2 is the flow chart of the AHP method.

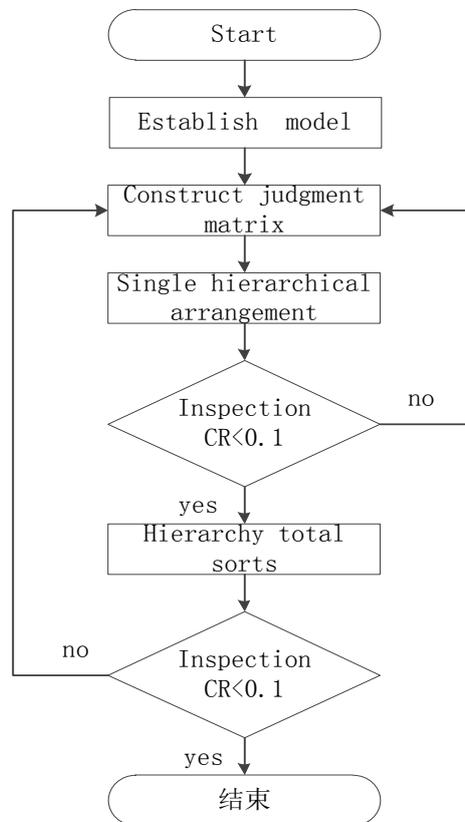


Figure 2: flow chart of Analytic Hierarchy Process

The steps of the AHP method are as follows:

(1) establish hierarchy structure model

According to the relationship between decision objective, decision factors (decision criterion) and decision-making object, we divided the system into top layer, middle layer and the lowest. At the highest level is the purpose of decision making, the problem to be solved; The middle layer is the problem of the consideration and decision criteria; The lowest layer is for decision-making object design.

(2) construct judgment matrix

Judgment matrix shows upperdominatelower thatevery lower relative to the upper level of the importance, It is the same level of pairwise comparison results between the elements. Assuming that A_i and the next layerof B_1, B_2, \dots, B_n which have relationship with A_i in A layer of elements , The structure form of the judgment matrix as shown in table 2.

Table 2:table structure of judgment matrix

A_i	B_1	B_2	...	B_n
B_1	b_{11}	b_{12}	...	b_{1n}
B_2	b_{21}	b_{22}	...	b_{2n}
.
.
.
B_n	b_{n1}	b_{n2}	...	b_{nn}

Among them, the b_{ij} shows in A_i, B_i to B_j relative important degree, usually b_{ij} option 1, 2, 3.... 9, and the reciprocal of them, the meaning of the Numbers as shown in table 3.

Table 3: scale and meaning of judgment matrix

scale	implication
1	Compared to two factors, they have the same importance
3	Compared to two factors, One factor is more important than another factor slightly.
5	Compared to two factors, One factor is more important than another factor obviously
7	Compared to two factors, One factor is more important than another factor strongly
9	Compared to two factors, a factor than another factor is extremely important
2,4,6,8	above two adjacent judgment of values
reciprocal	Factors compared to j is the judgment of the a_{ij} . factor j compared to i, the compare judgment $a_{ji} = 1 / a_{ij}$

(3) the level of single order and consistency check

Hierarchical single sorting refers to calculate a relative important degree of each element in the hierarchy according to the judgment matrix. Hierarchical single sorting is calculating the eigenvalue and eigenvector of judgment matrix B, calculating characteristics of the vector W (normalized eigenvector), W_i is the weight of corresponding elements. To test the consistency of judgment matrix, need to use consistency judgment form:

$$CR = CI / RI < 0.1 \quad CI = (\lambda_{\max} - n)(n - 1)$$

The CI as consistency index, RI as average consistency index. RI values shown in table 4.

Table 4: value of R_I

order	1	2	3	4	5	6	7	8	9	10
R_I	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

When $C_R < 0.1$, the consistency of judgment matrix is satisfied, otherwise, we need to adjust the judgment matrix, make it has satisfactory consistency.

(4) the level of total sorts and consistency check

After the calculation of relative importance of various elements we can achieve comprehensive importance of each factor relative to the system.

$$CR = C_I / R_I < 0.1$$

Total sorts consistency check:

$$C_I = \sum_{j=1}^n a_j C_{Ij} \quad R_I = \sum_{j=1}^n a_j R_{Ij}$$

When $C_R < 0.1$, the consistency of judgment matrix is satisfied, otherwise, we need to adjust the judgment matrix, make it has satisfactory consistency.

IV. PSS design decisions instance

According to the introduction of the AHP, the AHP is very suitable for constructing multiple targets and multiple attribute of the model to solve the problem. The design of product service system is a process about building the design criteria and design index system, at the same time it is a top design process. For example, the sustainable PSS design of cars is just such a multiple attribute and multiple objective decision making problems. This research establish the PSS designing model about cars as shown in figure 3. The AHP model about cars instruct as follows :

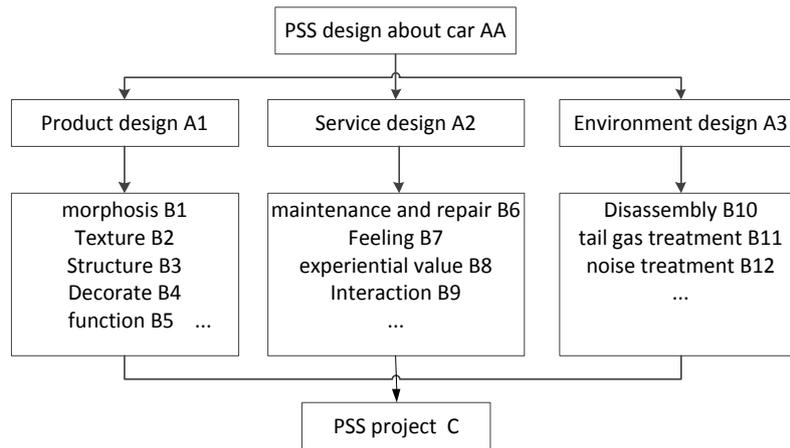


Figure 3: AHP model about the PSS of car

(1) Model is the top-down, divided into four layers: AA layer, A layer, B and C. The AA layer designed for PSS in the car, for example: The A layer is target layer that including product design, service design and environment design; The B layer is further decomposition of indicators aiming at the A layer design elements; The C layer is the undetermined layer of design schemes.

(2) The model of the upper to the lower have the control relationship, forming a model that the upper layer decide the lower layer, and the lower layer influence the upper layer.

(3) From AA layer to A layer, A layer to B layer is aiming at the upper element to build the judging matrix, it is the result that making single hierarchical arrangement. From B to A layer, A layer to AA layer is result of total hierarchical arrangement.

The fusion of different design form the PSS system, the existence of the index layer and criterion layer makes no matter how complex the PSS design becoming possible. This paper respectively for PPSS, APSS and UPSS are studied.

First using the AHP to analyze PPSS: construct judgment matrix: first, in the PPSS, according to the model given by figure 3, judgment matrix is obtained by comparative of each two elements that in the same level. The parameters of the judgment matrix of each layer by the first 20 experts evaluation, and then averaged to determine, last, achieving the judgment matrix AA, A1 - A3.

AA→A:

$$AA = \begin{bmatrix} 1 & 5 & 3 \\ 0.2 & 1 & 0.5 \\ 0.333 & 2 & 1 \end{bmatrix}$$

A1→(B1: B5):

$$A1 = \begin{bmatrix} 1 & 0.25 & 0.5 & 2 & 0.333 \\ 4 & 1 & 3 & 5 & 2 \\ 2 & 0.333 & 1 & 3 & 0.5 \\ 0.5 & 0.2 & 0.333 & 1 & 0.25 \\ 3 & 0.5 & 2 & 4 & 1 \end{bmatrix}$$

A2→(B6: B9):

$$A2 = \begin{bmatrix} 1 & 3 & 2 & 4 \\ 0.333 & 1 & 0.5 & 0.333 \\ 0.5 & 2 & 1 & 3 \\ 0.25 & 3 & 0.333 & 1 \end{bmatrix}$$

A3 → (B10: B12) :

$$A3 = \begin{bmatrix} 1 & 3 & 5 \\ 0.333 & 1 & 3 \\ 0.2 & 0.333 & 1 \end{bmatrix}$$

According to the AHP method to calculate, the weight of each factor are as follows:

$$\lambda = [0.064, 0.270, 0.104, 0.040, 0.170, 0.055, 0.013, 0.033, 0.02, 0.146, 0.06, 0.025]$$

Then calculated importance weights of each design element in the design of APSS and UPSS.

In the design of APSS:

$$AA = \begin{bmatrix} 1 & 1.5 & 2 \\ 0.667 & 1 & 1.5 \\ 0.5 & 0.667 & 1 \end{bmatrix}$$

In the design of UPSS:

$$AA = \begin{bmatrix} 1 & 0.5 & 0.667 \\ 2 & 1 & 1.5 \\ 1.5 & 0.667 & 1 \end{bmatrix}$$

Results are as follows:

Design of APSS:

$$\lambda = [0.046, 0.191, 0.072, 0.03, 0.121, 0.145, 0.035, 0.086, 0.053, 0.140, 0.057, 0.024]$$

Design of UPSS:

$$\lambda = [0.022, 0.092, 0.036, 0.014, 0.057, 0.209, 0.051, 0.125, 0.075, 0.202, 0.083, 0.034]$$

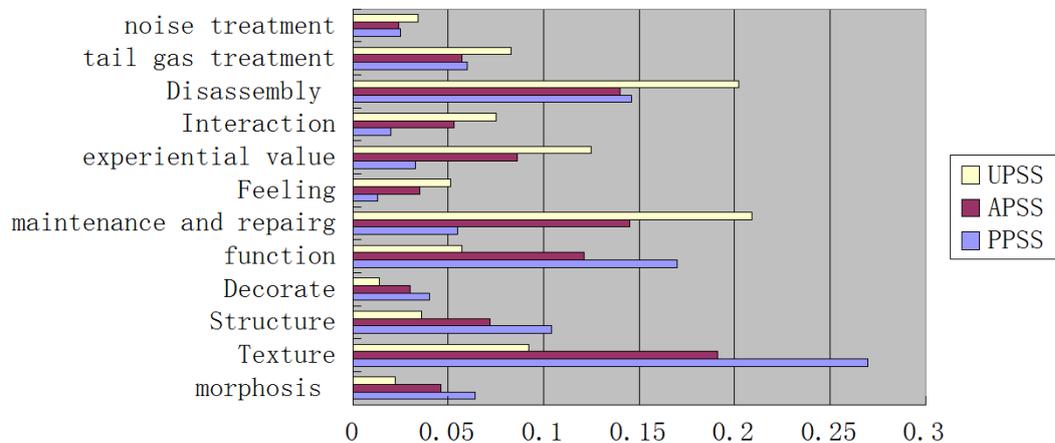


Figure 4: weight of factors in three kinds of car PSS design

As figure 4 shown, in three kinds PSS design of cars, the importance weight of each element

is different, different PSS have different requirements:

(a) The product design weight is 0.648 in the PPSS design, apparently, when the design main consideration should be the product design, such as structure design and function design. For the environment and the service is designed to realize the function of the product.

(b) In the weight of service design in the design of APSS begin to increase, such as the weight of vehicle maintenance increase from 0.055 to 0.145. At this stage, under the premise of considering the product structure, the function design of cars also need to consider.

(c) The environmental design and service design is a main position the design of UPSS, in the system of green

design should not only consider the product design, but also focus on the elements of service and the environment, such as emotional elements, exhaust gas treatment, remove and recycle of the vehicles and so on. Therefore, using the AHP method to research on design of PSS, the appearance of method is simple and intuitive, logical relationship clear advantages; When designing different PSS, need to grasp the important degree of each element, and then to carry on the design.

V. Summary and outlook

PSS design based on the sustainable development can more effectively protect the environment, saving resources and realize sustainable development, in accordance with the nature and purpose of product service system. In this paper, using the AHP method and the ideas of sustainable development to design PSS, solved the problems of product service system design as following:

- (1) introduce design of environmental design in PSS;
- (2) determine the importance degree of each index in the PSS design;
- (3) three types of product service system design index have different important degree, so we should design for the corresponding PSS system design.

Judgment matrix in AHP is used to determine the weight of all index in PSS design, designer can find out the emphasis of PSS design quickly and accurately, save a lot of time and costs for the design and provide a good guide for the sustainable development of PSS design.

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