Research Article

A Method of Capturing and Transferring Customer Value in Product Service System

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The methods of capturing and transferring the customer value in a product service system (PSS) are studied to capture the customers' intrinsic value requirements, grasp the importance level of requirement, and transform it into design elements to more reasonably allocate resources and develop products more in line with the customers' needs and more competitive at a minimum cost. First, a hierarchical model of the customer value based on the means-end chain theory is constructed to analyze the customer value from the perspective of customer expectations. In the process of determining the importance priority of value elements, the cloud model is used to process the expert evaluation information, and the competitive correction factor and the Kano factor are used to modify the basic importance of the value elements. The customer value in the PSS is then transferred to the product and service performance domain by constructing the parallel house of quality embedded cloud model (PHOQ-ECM). In other words, the cloud model is used to process the group decision-making values with fuzziness and randomness to complete the correlation calculation of the parallel HOQ. The important priority of the performance characteristics is then obtained. Finally, the abovementioned methods are applied to capture and transfer the customer value of a shearer, and the results are compared with other studies. The results show that the hierarchical model of the customer value can more deeply capture the customer value. The cloud model solves the problem of group decision-making with fuzziness and randomness. The competition correction factor and the Kano factor improve the accuracy of the importance priority of the value elements. PHOQ-ECM achieves the transfer and distribution of the customer value to two different objects of product and service and improves the accuracy of the performance characteristics importance priority. The method feasibility and validity are verified through the abovementioned analysis. Consequently, the method can effectively guide the PSS design.

1. Introduction

Made in China 2025 pointed out the acceleration of the coordinated development of manufacturing and service and the promotion of the transformation of production-oriented manufacturing to service-oriented manufacturing [1]. The product service system (PSS) is a production system with a high-degree integration of product and service [2]. The overall solution of "product + service" provided by the PSS can adapt to the strategic transformation from production-oriented manufacturing to service-oriented manufacturing. The conceptual design of the PSS begins with the customer demand information, which is usually vague [3]. Therefore, the methods of capturing and transferring the customer value

in conceptual design must be studied. Customer value refers to the customer's perceptual preference and evaluation of the product attributes, product efficacy, and use results to achieve or hinder their goals and intentions in a certain use situation [4]. The present study captures the customer value from the perspective of customer expectation to help PSS designers obtain customer requirements in depth. The importance priority of the customer requirement is determined by a cloud model and modified by the competitive factor and the Kano factor. Finally, the parallel structure HOQ is constructed to transfer and distribute the customer value to the performance domain to realize a reasonable allocation of resources and develop more competitive products with the lowest cost.

2. Literature Review

2.1. Review of Customer Value Capture. To better capture the customer value and improve customer satisfaction, Sun et al. [5] proposed the Kano model to qualitatively analyze demand information and identify and classify customer demand items. The Kano model provides an effective method for the qualitative analysis of customer demand information but can hardly quantify customer satisfaction. Chen et al. [6] proposed a ladder structured interview technology to build a prototype system of customer demand. Kumar et al. [7] proposed the enlightenment of users to express context dimensions that affect their preferences to achieve demand acquisition by communicating with them. However, the effectiveness of such methods is often strongly related to the ability and active participation of demand engineers and respondents, and the quality of the requirements cannot be guaranteed. Dai et al. [8] formed a multidimensional demand classification system composed of the life cycle, supply chain, and characteristic dimensions through a comprehensive analysis of the demand characteristics, time, and space distribution. Sheng et al. [2] took the PSS of the numerical control machine as the research object and established the customer demand model. Cao et al. [9] constructed the customer preference model to analyze the customer demand. Wang et al. [10] put forward the method of sorting out and screening the customer demand by analyzing the relationship between customer demand in view of the general and lack of systematic characteristics of the acquired customer demand. However, the traditional demand analysis method focuses on the attributes of the products and does not capture the intrinsic value requirements of the products purchased by customers.

As regards the ranking of the importance of customer requirements, Tian et al. [11] proposed the analytic hierarchy process (AHP) to obtain the importance of the performance characteristics. Zhang et al. [12] used the AHP to evaluate the importance of various factors in the social vulnerability index system, which has significantly improved the consistency of the expert questionnaire. Wu et al. [13] used the fuzzy analytic hierarchy process (FAHP) to determine the priority of the development of attractive factors. As an improved method of the AHP, the analytic network process (ANP) was used in the decision-making of the most suitable strategy for energy recycle [14]. Yazdani et al. [15] proposed a novel hybrid Decision-Making Trial and Evaluation Laboratory and analytic network process (DEMATEL-ANP) model to stress the importance of the evaluation criteria when selecting alternative renewable energy. Kaya et al. [16] reviewed the multicriteria decision-making techniques for solving energy decision-making problems, such as AHP and ANP. Although the AHP and ANP methods have advantages in solving the evaluation problems of design schemes, with the increase of indicators and schemes, the evaluation process is time consuming, and a large number of evaluation matrices and pairwise comparisons will be generated. The consistency of the pairwise comparisons in the AHP must be controlled at a relatively high level, which requires decision-makers to repeatedly and constantly adjust the evaluation information.

The objectivity of the evaluation may also be undermined. Campisi et al. [17] evaluated the multiplicity of measures regarding energy efficiency in residential building planning and renovation through multicriteria decision-making. Meanwhile, Mohammad K F et al. [18] used the ordered weighted average to determine the optimal areas for solar power installation. The pairwise comparison information given by customers or experts is usually fuzzy; hence, expressing it with accurate numbers is difficult. Therefore, Sousazomer et al. [19] proposed the fuzzy analytic hierarchy process to combine the fuzzy set theory with the AHP and determine the importance of customer requirements. Zaim et al. [20] applied fuzzy numbers and the ANP to Quality Function Deployment (QFD) to analyze the relationship between the customer requirements and the technical characteristics as well as the relative importance of customer requirements. Gitinavard et al. [21–23] applied the fuzzy set theory to multicriteria group decision-making to determine the best scheme. Some researchers applied rough sets to the ranking of the importance of customer requirements [24]. Cheng et al. [25] put forward a customer requirement model for a product family based on conjoint analysis and fuzzy clustering. Although fuzzy sets and rough sets can solve the problem of fuzziness in the evaluation process, they cannot solve the problem of randomness of evaluation information. However, the cloud model can solve the fuzziness and randomness of group decision-making [26]. In addition, it is necessary to adjust the importance of customer demand [27] because the priority calculation of the customer demand does not consider the impact of market competition and the realization of value factors on customer satisfaction. Lai et al. [28] considered not only the comparison between customer requirements, but also the market competition, and put forward a more comprehensive method of determining the importance of customer requirements in a competitive environment. Sun et al. [5] revised the importance of customer requirements by Kano factor, which improved the accuracy of the importance of customer requirements.

2.2. Review of Customer Value Transfer and Distribution. In the design mode of the PSS, QFD is used to transfer customer requirement information because of the insufficient accumulation of related data between customer requirements and solutions. QFD is a systematic and structured tool used to effectively deal with customer requirements. It can transfer and distribute customer requirements in multilevel and multistage and transform them into technical requirements in different stages. Kang et al. [29] used QFD to convert customer requirements into engineering characteristics. The practice showed that the application of QFD can improve product quality, enhance product competitiveness, and improve customer satisfaction to a great extent and ultimately achieve better economic benefits [30]. Sun et al. [5] mapped customer demand information to product attributes by QFD and obtained the importance determining method of personalized product attributes. Pun et al. [31] proposed a typical three-stage service QFD model, including three HOQ, namely, service planning, process configuration, and strategic

FIGURE 1: Hierarchical model of the customer value.

FIGURE 2: Customer value domain model.

configuration. Hwarng et al. [32] proposed a three-stage service model, namely, service planning, factor planning, and business planning. The traditional structure of the HOQ can hardly realize the parallel transfer process from customer requirements to two different objects, product, and service. The structural improvement must be considered to support the transfer and distribution of customer requirements in the conceptual design of the PSS.

3. Customer Value Capture and Importance Analysis

3.1. Customer Value Capture

3.1.1. Hierarchical Model of Customer Value. The main difference between the PSS requirements and the product or service requirements is that it integrates customer goals and expectations. When purchasing products or services, customers not only consider functions, but also expect the results and goals of the functions in a deeper level, thereby forming their own value hierarchy system. Therefore, the analysis of the customer value from the perspective of customer expectations can help designers of products and services gain

in-depth customer needs. In this study, a hierarchical model of the customer value is constructed based on the means-end chain theory [33] (Figure 1).

The hierarchical model of the customer value includes three levels, namely, the target, result, and attribute levels. Looking down from the model, the customer determines the importance of the product or service result in a usage scenario according to their own purposes. The importance of the result then leads the customer to judge the importance of the product or service attribute.

3.1.2. Value Domain Model Based on the Hierarchical Model of the Customer Value. The hierarchical model of the customer value shows that the result obtained by purchasing products is a way to realize the customers' most fundamental intention, and product attributes are often only a means to realize a higher level of customer value (i.e., the result and target layers). Therefore, we propose herein a customer value domain model, including the result and attribute layers based on the hierarchical theory of the customer value (Figure 2). The result layer is the system task expected by customers. The attribute layer denotes the attributes of the system task of customer expectation expressed by the value

FIGURE 3: Process of determining the comprehensive importance of value elements.

elements of customer expectation. Concurrent, enabling, and independent relationships exist among the system tasks of customer expectation.

3.2. Analysis of the Importance of Value Elements. A cloud model was used to process the group decision value to calculate the basic importance of the customer value elements. The competitive revision factor and the Kano factor were used to modify the basic importance, and the comprehensive importance of the customer value elements was obtained. Figure 3 shows the concrete calculation process.

3.2.1. Calculation of the Basic Importance of the Customer Value Elements Based on the Cloud Model

Definition 1 (cloud model). The cloud model is an uncertain transformation model dealing with the relationship between randomness and fuzziness for qualitative concepts and quantitative values [34]. The model consists of many cloud droplets. Each cloud droplet represents a mapping point from qualitative to quantitative concepts, that is, a quantization process. The cloud model uses the digital features of cloud, expecting Ex , Entropy En , and Super Entropy He to represent the mathematical properties of linguistic values in the form of (Ex, En, He) (Figure 4). Ex represents the expectation of cloud droplets in the spatial distribution of the domain and is the most typical sample that can represent the quantification of qualitative concepts. En is a measure of the uncertainty of qualitative concepts. On the one hand, it represents the acceptable range of cloud droplets in the number domain space (i.e., fuzziness). On the other hand, it reflects the probability that cloud droplets in the universe can represent the qualitative concept (i.e., randomness). He is the entropy of

FIGURE 4: Cloud model and its digital characteristics.

En representing the uncertainty of En , which is determined by the randomness and fuzziness of the entropy En . The bigger the span of the cloud image, the greater the fuzziness of the values in the number field. The bigger the thickness, the greater the randomness of the values in the number field.

Definition 2 (backward cloud generator). The backward cloud generator is a transformation model from the quantitative value to the qualitative concept. It can convert a certain amount of exact data into qualitative concepts represented by digital features (Ex, En, He) . According to the backward cloud algorithm without certainty degree [35], the following steps of backward cloud generator are obtained:

TABLE 1: Corresponding table between the evaluation grade and the evaluation interval.

Importance of the value elements	Relationship between the value elements and the performance characteristics	Competitive grade	Evaluation interval
Totally unimportant	Totally irrelevant	Very bad	[1, 3)
Unimportant	Irrelevant	Bad	[3, 5)
General	General	General	[5, 7)
Important	Relevant	Good	[7, 9)
Very important	Totally relevant	Very good	[9, 10]

- (1) Input the quantitative values of the N evaluation indexes: $x_i (i = 1, 2 \dots N)$.
- (2) Calculate the mean of the sample: $\bar{X} = (1/N) \sum_{i=1}^N x_i$.
- (3) Let $Ex = \bar{X}$.
- (4) Calculate the entropy $En = \sqrt{\pi/2} \times (1/N) \sum_{i=1}^N |x_i - Ex|$.
- (5) Calculate the sample variance $S^2 = (1/(N - 1)) \sum_{i=1}^N (x_i - Ex)^2$.
- (6) Calculate the excess entropy: $He = \sqrt{[S^2 - En^2]}$.

Definition 3. If the importance cloud model of the value elements $CV_i (1 \leq i \leq m)$ is $A_i(Ex_i, En_i, He_i)$, the mean $\bar{A}(Ex, En, He)$ of M cloud models can be calculated as shown in Formula (1).

$$\begin{aligned} \bar{A} &= \frac{1}{m} (A_1 + A_2 + \dots + A_m) \\ &= \left(\frac{1}{m} \sum_{i=1}^m Ex_i, \frac{1}{\sqrt{m}} \sqrt{\sum_{i=1}^m Ex_i^2}, \frac{1}{\sqrt{m}} \sqrt{\sum_{i=1}^m He_i^2} \right) \end{aligned} \quad (1)$$

When calculating the basic importance of the customer value, designers use value domain models to obtain the customer value elements in the PSS through customer interviews and surveys. The value elements are recorded as $CV_i (1 \leq i \leq m)$. Experts then use the evaluation rules in Table 1 to evaluate the importance of the value elements.

Next, the evaluation results are processed by the backward cloud generator in Definition 2 because of the fuzziness and the randomness of the evaluation results of the group decision-making of the experts mentioned earlier. The importance value of the value elements CV_i evaluated by expert $P^k (1 \leq k \leq q)$ is expressed as $S_i^k (1 \leq i \leq m)$. S_i^k is then translated into a cloud model by a backward cloud generator recorded as $A_i(Ex_i, En_i, He_i)$.

The cloud model is not an exact value; hence, it cannot be used to complete the subsequent calculation. Therefore, according to the relative preference relation of the triangular fuzzy number [36], the cloud model is converted to the exact value by calculating the relative preference relation between each cloud model and the mean value. The specific process is shown below.

If $A_1, A_2, \dots, A_m (A_i(Ex_i, En_i, He_i))$ is a group of cloud models with an average value of $\bar{A}(Ex, En, He)$, then the relative preference relationship between A_i and $\bar{A}$ is expressed as $RP(A_i, \bar{A})$:

$$\begin{aligned} RP(A_i, \bar{A}) &= \frac{1}{2} \\ &\times \left(\frac{(Ex_{il} - Ex_r) + 2(Ex_i - Ex) + (Ex_{ir} - Ex_l)}{2 \|T\|} \right. \\ &\left. + 1 \right) \end{aligned} \quad (2)$$

where $Ex_{il} = Ex_i - 3En_i$, $Ex_{ir} = Ex_i + 3En_i$, $Ex_l = Ex - 3En$, $Ex_r = Ex + 3En$

$\|T\|$

$$\begin{aligned} &= \begin{cases} \frac{(t_l^+ - t_r^-) + 2(t^+ - t^-) + (t_r^+ - t_l^-)}{2} & t_l^+ - t_r^- \geq 0 \\ \frac{(t_l^+ - t_r^-) + 2(t^+ - t^-) + (t_r^+ - t_l^-)}{2} + 2(t_r^- - t_l^+) & t_l^+ - t_r^- < 0 \end{cases} \\ t_l^+ &= \max \{Ex_{il}\}, \\ t_r^+ &= \max \{Ex_{ir}\}, \\ t_r^- &= \max \{Ex_{ir}\}, \\ t_l^- &= \min \{Ex_{il}\}, \\ t^- &= \min \{Ex_i\}, \\ t_r^- &= \min \{Ex_{ir}\} \end{aligned} \quad (3)$$

Finally, the importance $RP(A_i, \bar{A})$ of the value elements CV_i is calculated using Formula (2). The basic relative importance BIR_i of the value elements is obtained as follows after normalization:

$$BIR_i = \frac{RP(A_i, \bar{A})}{\sum_{i=1}^m RP(A_i, \bar{A})} \quad (4)$$

3.2.2. Competitive Analysis of the Customer Value. The calculation of basic importance does not consider the influence of market competition; therefore, the influence of market competition must be used to correct it.

(1) The set of enterprises is $\{G_1, G_2, \dots, G_j, \dots, G_t\}$, $(1 \leq j \leq t)$, where G_1 means the enterprise, and $G_2 - G_t$ denote $(t -$

1) competitive enterprises. Experts p^k use the 1–10 evaluation rules in Table 1 to evaluate the competitive grade of the value elements CV_i of the enterprise G_j , which is recorded as Q_{ij}^k .

(2) The expert evaluation value Q_{ij}^k is converted into a cloud model using a backward cloud generator denoted as $D_{ij}(Ex_{ij}, En_{ij}, He_{ij})$. The technical competitiveness evaluation matrix M composed of D_{ij} can then be obtained as follows:

$$M = \begin{bmatrix} D_{11} & D_{12} & \cdots & D_{1t} \\ D_{21} & D_{22} & \cdots & D_{2t} \\ \vdots & \vdots & & \vdots \\ D_{m1} & D_{m2} & \cdots & D_{mt} \end{bmatrix} \quad (5)$$

(3) Cloud models are not exact values and they are represented by three numerical features. The cloud relative preference relation analysis is used to convert D_{ij} into an exact value. The technical competitiveness evaluation matrix M_1 based on the cloud relative preference relation analysis is obtained as follows:

$$M_1 = \begin{bmatrix} RP(D_{11}, \overline{D}_1) & RP(D_{12}, \overline{D}_1) & \cdots & RP(D_{1t}, \overline{D}_1) \\ RP(D_{21}, \overline{D}_2) & RP(D_{22}, \overline{D}_2) & \cdots & RP(D_{2t}, \overline{D}_2) \\ \vdots & \vdots & & \vdots \\ RP(D_{m1}, \overline{D}_m) & RP(D_{m2}, \overline{D}_m) & \cdots & RP(D_{mt}, \overline{D}_m) \end{bmatrix} \quad (6)$$

(4) Calculating the correction factor of competitive importance: two situations may arise if the difference of the value element CV_i between enterprises is relatively small. One is that it is difficult to improve the value element when it encounters bottlenecks. The other is that the value element is at the general level of the industry, and the impact of improving the value element on improving customer satisfaction is small. Therefore, when the difference of the value elements between enterprises is small, this value does not have a high priority for improvement. Meanwhile, a large difference of the customer value among enterprises indicates that the improvement of the value element greatly influences the enhancement of the competitiveness and customer satisfaction. At this time, the importance of the value elements should be appropriately increased.

The mean square deviation can reflect the degree of difference in statistics. When a set of data is centralized, the mean square deviation is relatively small; otherwise the mean square deviation is relatively large. Therefore, the mean square deviation maximization model can be constructed to reflect the revision factor of competitive importance. The revision factor of competitive importance of the value

elements CV_i is recorded as CIR_i . The specific process of the model is shown in the following formula:

$$\begin{aligned} \max F(CIR) \\ &= \sum_{i=1}^m CIR_i \\ &\quad \cdot \sqrt{\frac{1}{t} \sum_{j=1}^t \left(d \left(RP(D_{ij}, \overline{D}_i), \frac{1}{t} \sum_{j=1}^t RP(D_{ij}, \overline{D}_i) \right) \right)^2} \quad (7) \\ \sum_{i=1}^m (CIR_i)^2 &= 1 \\ 0 &\leq CIR_i \leq 1 \end{aligned}$$

The Lagrange function is constructed to solve the above model:

$$\begin{aligned} L(CIR_i, \lambda) \\ &= \sum_{i=1}^m CIR_i \\ &\quad \cdot \sqrt{\frac{1}{t} \sum_{j=1}^t \left(d \left(RP(D_{ij}, \overline{D}_i), \frac{1}{t} \sum_{j=1}^t RP(D_{ij}, \overline{D}_i) \right) \right)^2} \quad (8) \\ &\quad + \frac{1}{2} \lambda \left[\sum_{i=1}^m (CIR_i)^2 - 1 \right] \end{aligned}$$

Calculating the partial derivatives of CIR_i and λ in Formula (8) results in the following formula:

$$\begin{aligned} \frac{\partial L}{\partial (CIR)} \\ &= \sqrt{\frac{1}{t} \sum_{j=1}^t \left(d \left(RP(D_{ij}, \overline{D}_i), \frac{1}{t} \sum_{j=1}^t RP(D_{ij}, \overline{D}_i) \right) \right)^2} \quad (9) \\ &\quad + \lambda \cdot CIR_i = 0 \end{aligned}$$

$$\frac{\partial L}{\partial \lambda} = \frac{1}{2} \left[\sum_{i=1}^m (CIR_i)^2 - 1 \right] = 0$$

Therefore, the competitive correction factor is obtained as shown in the following formula:

$$\begin{aligned} CIR_i \\ &= \frac{\sqrt{\frac{1}{t} \sum_{j=1}^t \left(d \left(RP(D_{ij}, \overline{D}_i), \frac{1}{t} \sum_{j=1}^t RP(D_{ij}, \overline{D}_i) \right) \right)^2}}{\sqrt{\sum_{i=1}^m \left(\frac{1}{t} \sum_{j=1}^t \left(d \left(RP(D_{ij}, \overline{D}_i), \frac{1}{t} \sum_{j=1}^t RP(D_{ij}, \overline{D}_i) \right) \right)^2 \right)}} \quad (10) \end{aligned}$$

3.2.3. Correction Analysis of Customer Value by Using Kano Factor. When the value elements belong to different Kano

TABLE 2: Kano assessment form.

		Value elements are realized				
		Like	Must-be	Neutral	live with	Dislike
Value elements have not been realized	Like	Q	A	A	A	O
	Must-be	R	I	I	I	M
	Neutral	R	I	I	I	M
	live with	R	I	I	I	M
	Dislike	R	R	R	R	Q

A: Attractive, O: One-dimensional, M: Must-be, I: Indifferent, R: Reverse, and Q: Questionable.

classifications, the realization of the value elements has different effects on customer satisfaction; hence, the Kano model must be used to revise the basic importance of the value elements. The customer value elements can be divided into the following according to Kano's model [37, 38]: Attractive (A), One-dimensional (O), Must-be (M), Indifferent (I), and Reverse (R). Among them, A indicates that the value element belongs to the innovation point, which can greatly improve the customer satisfaction. O indicates that the value element causes the difference and can greatly improve the customer satisfaction. M means that these value elements must be satisfied, which is taken for granted. I indicates whether or not the realization of the value element would affect customer satisfaction. R indicates that customers do not want the value element in the product.

First, the influence of the customer value realization on the customer satisfaction and the Kano category of the value elements are analyzed according to the Kano questionnaire. We can then determine the Kano factor of the value elements and modify the value elements through the Kano factor following these specific steps:

(1) Questionnaire survey: the Kano questionnaire designed two opposite questions for each value element. Each question has five answers to choose, expressing the user's attitude when the value elements are realized or not. The Kano classification for this user is then determined by the Kano assessment table (Table 2).

(2) Calculating the customer satisfaction coefficient: the type of customer requirements is determined by the "satisfaction degree" of all users when the value elements are realized and the "dissatisfaction degree" of all users when the value elements have not been realized. These two indicators can be reflected by introducing the two-factor coefficient SI_i and DI_i of customer satisfaction.

$$SI_i = \frac{N_A + N_O}{N_A + N_O + N_M + N_I} \quad (11)$$

$$DI_i = \frac{N_M + N_O}{N_A + N_O + N_M + N_I} \quad (12)$$

Among them, SI_i indicates the increasing rate of customer satisfaction when the value elements have been realized. DI_i indicates the decreasing rate of customer satisfaction when the value elements have not been realized. N_A, N_O, N_M, N_I represent the number of Kano classifications selected.

(3) Determining the Kano classification of the customer value: the Kano classification of the value elements CV_i can

FIGURE 5: Relationship between the satisfaction coefficient and Kano classification.

be determined according to the coordinate position of the midpoint (SI_i, DI_i) in Figure 5.

(4) Determining the Kano factor of the value element: the calculation of the Kano factor AJ_i of value element CV_i is shown in the following formula:

$$AJ_i = (1 + \max(SI_i, DI_i))^{k_i} \quad (13)$$

where k_i is the Kano classification coefficient. The k_i values are 1.5, 1.0, 0.5, and 0 when the customer value elements are A, O, M, and I, respectively.

3.2.4. Calculation of Comprehensive Importance. The competitive correction factor and the Kano factor are used to modify the basic importance of the value elements. The comprehensive importance of the value elements is then obtained. The calculation method is shown in the following formula:

$$FIR_i = BIR_i \cdot CIR_i \cdot AJ_i \quad (i = 1, 2, \dots, m) \quad (14)$$

4. Transfer Analysis of Customer Value

4.1. Performance Domain Model. After establishing the value domain model, the designer can now establish the performance domain model and convert the customer value into a PSS performance through HOQ.

The performance domain model of the PSS is a tree-like decomposition structure, which describes the goal of system realization from the design point of view (i.e., the performance domain model is the technical expression of

FIGURE 6: Performance domain model.

the PSS solutions for the engineering tasks from the perspective of function and quality for the system tasks of customer expectation in the value domain model). Performance includes product and service performance, while product performance is the result of the interaction between the functional and quality modules more inclined to describe the desired results. Quality is defined as the degree to which a function is implemented and the degree to which the function is maintained, including the quantitative or qualitative performance requirements of the PSS for product economy, complexity, stability, user experience, etc. The input and output streams of the product performance black box include matter, information, and energy, while the service function black box involves matter, information, and personnel. The connection between peers has three modes, namely, concurrent, enabling, and independent. Figure 6 presents the performance domain model.

4.2. Transfer and Distribution of Customer Value Based on PHOQ-ECM. Not all performance characteristics related to customer value are considered because of the limitations of development time, capital, and technology. Therefore, after acquiring the customer value and its importance, it should be transformed into the performance characteristics of products and services. According to the relative importance of the performance characteristics, the design team makes a trade-off in the selection of the performance characteristics to maximize customer satisfaction under the existing constraints.

HOQ is a tool for product and service planning, which can transform user requirements into design language and realize the transformation of user requirements to technical requirements at different stages. HOQ begins with the customer value and then transforms the importance of the customer value into the importance of the product and service performance characteristics. However, the traditional HOQ cannot be directly applied to the PSS design because it cannot be applied to the transfer and distribution of the customer value to two different types of products and services. Therefore, we constructed PHOQ-ECM to realize the abovementioned process. PHOQ-ECM improves the HOQ into a parallel structure and embeds the cloud model into the HOQ to process the group decision information. The corresponding relationship matrix was divided into two parts: product and service. Figure 7 shows the PHOQ-ECM structure.

4.2.1. Calculation of Correlation between Value Elements and Performance Characteristics. The correlation score between the value elements CV_i and the performance characteristic E_j evaluated by expert P^k ($1 \leq k \leq q$) is expressed as T_{ij} ($1 \leq i \leq m$, $1 \leq j \leq n$). Taking T_{ij} as the input, an evaluation cloud model of the relationship between the value elements and the performance characteristics was generated by using a backward cloud generator and recorded as $B_{ij}(Ex_{ij}, En_{ij}, He_{ij})$.

FIGURE 7: Transfer of the customer value based on PHOQ-ECM.

Therefore, the relational matrix R_1 consisting of B_{ij} can be constructed.

$$R_1 = \begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1n} \\ B_{21} & B_{22} & \cdots & B_{2n} \\ \vdots & \vdots & & \vdots \\ B_{m1} & B_{m2} & \cdots & B_{mn} \end{bmatrix} \quad (15)$$

4.2.2. Calculation of the Importance of the Performance Characteristics. From the calculation of the QFD, the importance $W(E)_j$ of the performance feature E_j can be obtained by multiplying the comprehensive importance of the value elements with R_1 . Formula (16) shows the calculation process:

$$W(E)_j = \sum_{i=1}^m BIR_i B_{ij} \quad (16)$$

Similarly, the mean $\bar{W}(E)(Ex', En', He')$ of the cloud model $W(E)_j(Ex_j, En_j, He_j)(1 \leq j \leq n)$ of the performance characteristics is first calculated. Next, the relative preference relation between the cloud model and the mean is calculated using Formula (2). The importance of the performance characteristics is obtained and denoted as $RP(W(E)_j, \bar{W}(E))$.

5. Case Study

5.1. Construction of Shearer's Value Domain Model. The conceptual design of the PSS of a shearer was taken herein as an

engineering example to verify the feasibility and effectiveness of the proposed methods. The shearer is a machine that adapts to the geological changes of the coal seam at the longwall mining face to break down the coal from the coal body by the working mechanism and load it into the conveyor. First, according to the progressive process of the expectation goal–expectation result–expectation attribute and the value domain model shown in Figure 2, the customer information was analyzed, and the value domain model of the shearer was established (Figure 8). Customers needed five system tasks and 15 value elements (Table 3). Among them, the value elements CV_1 – CV_8 were together completed by products and services, called the functional value elements. Value elements CV_9 – CV_{15} were mainly completed by the service, called the nonfunctional value elements. The following mainly takes the functional value elements as an example to verify the transfer process of the value elements.

5.2. Calculation of the Comprehensive Importance of Shearer's Value Elements

5.2.1. Determination of the Basic Importance of Value Elements. Ten shearer design experts used the evaluation rules in Table 1 to evaluate the importance of various value elements. The score was then transformed into the cloud model using the backward cloud generator. The cloud model of the relative importance of the customer value elements was transformed into an accurate value and normalized using Formulae (2) and (4). Table 4 shows the results.

FIGURE 8: Value domain model of the shearer.

TABLE 3: Meaning of the value elements.

Value elements	Meaning	Value elements	Meaning
CV ₁	Good adaptability	CV ₉	Personalized professional pre-sale guidance
CV ₂	High operational reliability	CV ₁₀	Flexible payment methods
CV ₃	Long service life	CV ₁₁	Good training professionalism
CV ₄	High efficiency	CV ₁₂	High installation efficiency
CV ₅	Low cost	CV ₁₃	Good operation professionalism
CV ₆	Good security	CV ₁₄	Timely supply of spare parts
CV ₇	High support level of maintenance service	CV ₁₅	High level of recycling service
CV ₈	Good human-computer interaction		

TABLE 4: Importance of the customer value elements.

	P^1	P^2	...	P^9	P^{10}	Cloud model	Relative importance $RP(A_i, \bar{A})$	Normalization BIR_i
CV ₁	10	8	...	9	10	(9.6,0.602,0.309)	0.810	0.202
CV ₂	8	9	...	9	8	(8.1,0.677,0.294)	0.619	0.155
CV ₃	5	6	...	7	6	(5.9,0.902,0.218)	0.340	0.085
CV ₄	8	9	...	7	8	(7.3,0.953,0.085)	0.517	0.129
CV ₅	6	8	...	7	5	(6.2,0.602,0.195)	0.378	0.094
CV ₆	7	8	...	6	8	(6.8,0.802,0.146)	0.454	0.113
CV ₇	8	8	...	9	8	(8.0,0.752,0.318)	0.606	0.152
CV ₈	5	5	...	6	7	(5.4,0.702,0.061)	0.276	0.069

5.2.2. *Calculation of the Correction Factor of Shearer's Competitive Importance.* Ten shearer design experts used the evaluation rules in Table 1 to evaluate the competitive grade of their enterprises and two competing enterprises with high market competitiveness in realizing each value element. The backward cloud generator was used to transform the expert score into a cloud model. Table 5 shows the result.

The cloud model in Table 5 was transformed into an exact value using the cloud relative preference relation of

Formula (2). The technical competitiveness evaluation matrix M_1 based on the cloud relative preference relation analysis was obtained.

$$M_1 = \begin{bmatrix} 0.422 & 0.411 & \cdots & 0.667 \\ 0.431 & 0.392 & \cdots & 0.678 \\ \vdots & \vdots & & \vdots \\ 0.380 & 0.420 & \cdots & 0.699 \end{bmatrix} \quad (17)$$

TABLE 5: Evaluation value and cloud model of competitive importance.

	p^1	p^2	$\dots$	p^9	p^{10}	Cloud model of the relational relationship
Q_{11}	6	7	$\dots$	5	7	(6.3,0.778,0.272)
Q_{12}	7	5	$\dots$	5	8	(6.2,1.053,0.204)
Q_{13}	8	7	$\dots$	9	8	(8.5,0.627,0.339)
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
Q_{81}	6	7	$\dots$	5	6	(6.0,0.501,0.439)
Q_{82}	6	8	$\dots$	6	6	(6.3,0.526,0.209)
Q_{83}	8	9	$\dots$	9	7	(8.4,0.752,0.277)

TABLE 6: Value of the competitive correction factor.

Competitive correction factor	CIR_1	CIR_2	CIR_3	CIR_4	CIR_5	CIR_6	CIR_7	CIR_8
Value	0.115	0.123	0.139	0.109	0.141	0.114	0.120	0.138

TABLE 7: Kano classification of the value elements.

Value elements	SI_i	DI_i	Kano classification
CV_1	0.267	0.933	M
CV_2	0.600	0.667	O
CV_3	0.800	0.533	O
CV_4	0.867	0.800	O
CV_5	0.333	0.800	M
CV_6	0.400	0.800	M
CV_7	0.600	0.667	O
CV_8	0.600	0.533	O

A mean square deviation maximization model was constructed to obtain the correction factor of the competitive importance of the customer value. Table 6 presents the results.

5.2.3. Calculation of the Kano Factor of the Value Elements. Fifteen Kano questionnaires were distributed to the shearer users to investigate the impact of the realization of various value elements on their satisfaction. The Kano questionnaire designed two opposite questions for each value element, each with five answers to choose from (Table 2). Each value element was classified according to the evaluation results (Table 7).

Table 7 shows that CV_1 , CV_5 , and CV_6 are the “must-be” value elements, while CV_2 , CV_3 , CV_4 , CV_7 , and CV_8 are the “one-dimensional” value elements. The Kano factor was then determined according to Formula (13). Table 8 shows the result.

5.2.4. Calculation of the Comprehensive Importance of the Value Elements. The basic importance of the value elements was modified using Formula (14) and then normalized after

obtaining the basic importance of the value elements of the shearer. Table 9 presents the results.

5.3. Transfer and Distribution from the Value Elements to the Performance Characteristics. After obtaining the value elements and its importance, we can now plan the PSS performance and then transform the value element importance into the importance of the performance characteristic. The product and service performance characteristics in the performance domain model were obtained according to the black box of the performance domain model in Figure 6 (Figure 9). Accordingly, E_1-E_8 are the product performance characteristics, and E_9-E_{11} are the service performance characteristics. Table 10 shows the meaning of the performance characteristics.

5.3.1. Calculation of the Correlation between the Value Elements and the Performance Characteristics. The experts scored the relationship between the customer value and the performance characteristics and then generated a cloud model of the relationship between the customer value and the performance characteristics using the backward cloud generator. Table 11 shows the results.

5.3.2. Computation of the Importance of Performance Characteristics. The cloud model of the performance characteristics was calculated by Formula (16) according to the comprehensive importance of the value elements and the relationship between the value elements and the performance characteristics. It can then be transformed into an exact value by using Formula (2). Table 12 presents the results.

5.4. Comparative Analysis. The methods proposed herein were compared and analyzed from the following three aspects to verify the validity and the feasibility of the proposed methods: calculation of the basic importance of the value elements and the existing methods, comparative analysis before and after the revision of the importance of the value elements, and calculation of the importance of the performance characteristics and the existing methods.

(1) Calculation of the Basic Importance of the Value Elements and the Existing Methods. The cloud model method mentioned herein was compared with the exact value method to verify the effectiveness of the cloud model in group decision-making. When calculating the importance of the value elements using the exact value method, the group decision-making value of the importance of each customer value element was calculated as the average value. The importance of the customer value elements was then determined by dividing the average value by the sum of the average values. Table 13 shows the basic importance values of the value elements obtained by the exact value method and the cloud model method.

Table 13 shows that when the exact value method is used to calculate the importance of value elements, the order of value elements from small to large is CV_8 , CV_3 , CV_5 , CV_6 , CV_4 , CV_7 , CV_2 , and CV_1 . When using the

TABLE 8: Kano factor of the value elements.

Kano factor	AJ_1	AJ_2	AJ_3	AJ_4	AJ_5	AJ_6	AJ_7	AJ_8
Value	1.390	1.667	1.800	1.867	1.342	1.342	1.667	1.600

TABLE 9: Comprehensive importance of the value elements.

Value elements	FIR_1	FIR_2	FIR_3	FIR_4	FIR_5	FIR_6	FIR_7	FIR_8
Value	0.168	0.165	0.110	0.137	0.093	0.090	0.158	0.079

TABLE 10: Meaning of the performance characteristic.

Performance characteristic	Meaning	Performance characteristic	Meaning
E_1	Coal cutting capacity	E_7	Man-machine safety guarantee
E_2	Coal loading capacity	E_8	Life
E_3	Traction capacity	E_9	Maintenance capacity
E_4	Auxiliary capacity	E_{10}	Maintenance cost
E_5	Product cost	E_{11}	Remote assistance capacity
E_6	Module reliability		

TABLE 11: Evaluation result and cloud model of the relationship between the customer value and the performance characteristics.

	p^1	p^2	...	p^9	p^{10}	Cloud model of the relational relationship
B_{11}	10	9	...	9	8	(9.4,0.752,0.277)
B_{21}	8	7	...	7	6	(7.7,0.953,0.084)
B_{31}	1	2	...	1	1	(1.8,0.602,0.195)
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
B_{611}	5	6	...	5	7	(5.2,0.602,0.195)
B_{711}	7	8	...	6	8	(6.7,0.702,0.192)
B_{811}	8	9	...	7	8	(7.9,0.677,0.294)

cloud model method, the cloud model of the value elements was transformed into a cloud map using the forward cloud generator (Figure 10). The order of the importance of the value elements was the same as that in the exact value method. However, the exact value method can only compare the value of the importance of the value elements, which cannot judge the reliability of the group decision-making evaluation information. When using the cloud model method, the cloud maps not only reflect the importance of the value elements, but also reflect the fuzziness and randomness of the evaluation information by the span and thickness of the cloud maps. The larger the cloud image span, the greater the fuzziness of the evaluation information. The greater the thickness, the greater the randomness of the evaluation information. For example, when comparing CV_7 and CV_2 , the importance of CV_7 and CV_2 is basically the same. The exact value method cannot be effectively used for further analysis. However, the cloud model method showed that the thickness and the span of the CV_7 cloud image were larger than CV_2 ; hence, the fuzziness and the randomness of the group decision evaluation information of the value element

CV_7 were greater than CV_2 ; that is, the reliability of the group decision evaluation information of CV_2 was greater than CV_7 .

The abovementioned analysis showed that compared with the traditional exact value method, the cloud model method can not only reflect the value of importance, but also reflect the fuzziness and randomness of the evaluation information of group decision-making.

(2) *Comparative Analysis before and after the Revision of the Importance of the Value Elements.* The ranking of the basic importance of the value elements did not consider the impact of market competition and the impact of the realization of value factors on customer satisfaction; thus, the basic importance was revised. The importance values before and after revision were compared to verify the necessity of revising the basic importance of the value elements and the change of values before and after revision. Figure 11 depicts the results.

The comparison results of Figure 11 showed that each value element changed to a certain extent after revision. For example, the value of the importance of the value element CV_1 decreased after revision for two reasons. On the one hand, the competitive correction factor of CV_1 was 0.115, which was smaller than that of the most other competitive correction factors. This result indicates that a small gap exists between the good adaptability CV_1 of various competitive enterprises; that is, the shearers produced by each competitive enterprise can meet the needs of users for production operations, and this value factor is at the general level of the industry. Therefore, its importance must be reduced to more rationally allocate resources. On the other hand, good adaptability CV_1 belonged to the basic value elements, and the improvement of the customer satisfaction by the basic value elements was relatively small. In other words, the basic value elements should be satisfied and cannot improve customer satisfaction very well. Therefore,

FIGURE 9: Performance domain model of the shearer.

TABLE 12: Importance of the performance characteristics.

Performance characteristics	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}
Importance	0.607	0.438	0.539	0.419	0.506	0.582	0.444	0.520	0.569	0.405	0.471
Normalization	0.110	0.080	0.098	0.076	0.092	0.106	0.081	0.094	0.103	0.074	0.086

FIGURE 10: A cloud picture of the importance of the customer value.

the importance of the basic value elements should be reduced. The importance of the value elements with a small gap among enterprises and little impact on customer satisfaction must also be reduced along with the increase in the importance of the value elements with a large gap among enterprises and a

FIGURE 11: Comparison of the value factors before and after revision.

greater impact on customer satisfaction. This amendment is in accordance with the actual situation.

Using the competitive correction factor and the Kano correction factor to fine-tune the basic importance of value elements, the result of the correction can more reasonably rank the importance of value elements, improve the importance ranking accuracy, and help designers more rationally allocate resources.

(3) *Calculation of the Importance of the Performance Characteristics and the Existing Methods.* The importance of the performance characteristics calculated by the PHOQ-ECM and that of the exact value method were compared to verify the effectiveness of the proposed method. The relationship between the value elements and the performance characteristics was calculated by the exact value method

FIGURE 12: Comparison of the importance values of the performance characteristics between the exact value method and PHOQ-ECM.

TABLE 13: Importance of the value elements obtained by the exact value method and the cloud model method.

Value elements	Exact value method	Cloud model method	
CV_1	0.168	(9.6,0.602,0.309)	0.202
CV_2	0.141	(8.1,0.677,0.294)	0.155
CV_3	0.103	(5.9,0.902,0.218)	0.085
CV_4	0.127	(7.3,0.953,0.085)	0.129
CV_5	0.108	(6.2,0.602,0.195)	0.094
CV_6	0.119	(6.8,0.802,0.146)	0.113
CV_7	0.140	(8.0,0.752,0.318)	0.152
CV_8	0.094	(5.4,0.702,0.061)	0.069

after the comprehensive importance of the value elements was obtained. The importance of the value elements was then transferred to the importance of the performance characteristics according to the QFD calculation process shown in Formula (16). Table 14 shows the importance of the performance characteristics calculated by the exact value method and the PHOQ-ECM.

Figure 12 shows the comparison results of the importance of the performance characteristic obtained by the exact value method and PHOQ-ECM.

Figure 12 shows that the importance of the performance characteristics calculated by the exact value method is in the order of $E_1, E_6, E_9, E_3, E_8, E_5, E_{11}, E_7, E_4, E_2$, and E_{10} , while the importance of the performance characteristics obtained by using PHOQ-ECM to process the group decision values is in the order of $E_1, E_6, E_9, E_3, E_8, E_5, E_{11}, E_7, E_2, E_4$, and E_{10} . Comparing the results of these two methods, the ranking of the importance of the performance characteristics was found consistent, except for E_2 and E_4 . For the shearer, first, we needed to pay attention to the cutting capacity, which was the core indicator of whether or not the shearer can complete the production task. Second, the reliability, that is, whether or not the shearer can complete the cutting task “very well,” must be considered because the failure of the shearer will cause hundreds of workers to stop working in the whole production phase, which will bring serious economic losses.

Therefore, on the premise of ensuring an efficient and reliable mining of the shearer, users will not pay too much attention to the maintenance cost. This result is in line with the actual situation. According to the actual production process of the shearer, the shearer must load the coal into the conveyor, and the importance of the loading capacity E_2 should be greater than its auxiliary capacity E_4 . The exact value method does not consider the acceptable range of the group decision-making value and the probability that the value can represent the true importance value; hence, the result deviates from the actual situation. In this study, PHOQ-ECM was used to deal with the value of group decision-making, which solved the problems of fuzziness and randomness of group decision-making and improved the accuracy of the ranking of the performance element importance.

The comparative analysis showed that PHOQ-ECM can not only transfer and distribute value elements to different objects of product and service, but also more accurately determine the importance of the performance characteristics to effectively guide the PSS design.

6. Conclusion

This study proposed methods of capturing and transferring customer value in the PSS to solve the problem of the traditional demand analysis method not capturing the intrinsic value demand of customers and deal with the fuzziness and randomness of group decision-making information and the distribution of the value elements to two different types of products and services. This method was applied to capture and transfer the customer value of a certain type of shearer. The results were then compared with those of the other methods. Consequently, significant conclusions were drawn. The value domain model based on the hierarchical theory of the customer value, which was constructed from the result and target layers of customer expectation, can more deeply capture the customer demand. The cloud model solved the fuzziness and randomness of the group decision-making information. The cloud relative preference relationship solved the problem of the two sets of cloud models not being directly used for calculation. The basic importance of the value element was subsequently obtained. A competitiveness analysis and the Kano model were used to modify the basic importance of the value elements, which improved the importance analysis accuracy. Constructing the PHOQ-ECM to replace the traditional HOQ can complete the transfer and distribution of the customer value to two different types of objects in the PSS and improve the accuracy of the importance of the performance characteristics. This process is a potential resource optimization model, and our results provide a reference for designers to more rationally allocate resources.

Data Availability

All relevant data are within the paper.

TABLE 14: Importance of the performance characteristics calculated by the exact value method and PHOQ-ECM.

Performance characteristics	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}
Exact value method	0.106	0.079	0.095	0.084	0.092	0.101	0.087	0.093	0.099	0.076	0.088
PHOQ-ECM	0.110	0.080	0.098	0.076	0.092	0.106	0.081	0.094	0.103	0.074	0.086

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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