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. Zain 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
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. The structural improvement must be considered to support the transfer and distribution of customer requirements in the conceptual design of the PSS.

The hierarchical model of 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 valuedomain 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
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

\[ En \]

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:
shown below. Each cloud model and the mean value. The specific process is used to complete the subsequent calculation. Therefore, 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 $A_i$ ($1 \leq i \leq m$). 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 $S^k_i$ ($1 \leq i \leq m$). $S^k_i$ 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.

(1) Input the quantitative values of the N evaluation indexes: $x_i$ ($i = 1, 2, \ldots, N$).
(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 $En = \sqrt{n}/2 \times (1/N) \sum_{i=1}^{N} |x_i - Ex|$.
(5) Calculate the sample variance $S^2 = (1/(N-1)) \sum_{i=1}^{N} (x_i - Ex)^2$.
(6) Calculate the excess entropy: $He = \sqrt{S^2 - En}$.

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).

$$\bar{A} = \frac{1}{m} \left( A_1 + A_2 + \cdots + A_m \right)$$

$$= \left( \frac{1}{m} \sum_{i=1}^{m} Ex_i, \frac{1}{\sqrt{m}} \sum_{i=1}^{m} Ex_i^2, \frac{1}{\sqrt{m}} \sum_{i=1}^{m} He_i^2 \right)$$

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.

If $A_1, A_2, \ldots, A_m(A_i(Ex_i, En_i, He_i))$ 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 $RP(A_i, \bar{A})$:

$$RP(A_i, \bar{A}) = \frac{1}{2} \times \left( \frac{(Ex_i - Ex) + 2(Ex_i - Ex) + (Ex_i - Ex)}{2 \|T\|} + 1 \right)$$

(2)

where $Ex_i = Ex_i - 3En_i, Ex_{ij} = Ex_j + 3En_i, Ex_i = Ex_j - 3En_i, Ex = Ex + 3En$.

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:

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

(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 $\{G_1, G_2, \ldots, G_p, \ldots, G_t\}$, ($1 \leq j \leq t$), where $G_1$ means the enterprise, and $G_2\sim G_t$ 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 $D_{ij}(E_{ij}, E_{nj}, H_{ij})$. The technical competitiveness evaluation matrix $M$ composed of $D_{ij}$ can then be obtained as follows:

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

(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:

$$M_1 = \begin{bmatrix} RP(D_{11}, D_1) & RP(D_{12}, D_1) & \cdots & RP(D_{1t}, D_1) \\ RP(D_{21}, D_2) & RP(D_{22}, D_2) & \cdots & RP(D_{2t}, D_2) \\ \vdots & \vdots & \ddots & \vdots \\ RP(D_{m1}, D_m) & RP(D_{m2}, D_m) & \cdots & RP(D_{mt}, D_m) \end{bmatrix}$$

(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:

$$\max F(CIR) = \sum_{i=1}^{m} CIR_i$$

$$\sqrt{\frac{1}{t} \sum_{j=1}^{t} \left( RP(D_{ij}, D_j) \right) \cdot \sum_{j=1}^{t} \left( CIR_i \right)^2 - 1}$$

$$0 \leq CIR_i \leq 1$$

The Lagrange function is constructed to solve the above model:

$$L(CIR_i, \lambda) = \sum_{i=1}^{m} CIR_i$$

$$\sqrt{\frac{1}{t} \sum_{j=1}^{t} \left( RP(D_{ij}, D_j) \right) \cdot \sum_{j=1}^{t} \left( CIR_i \right)^2 - 1}$$

$$+ \frac{1}{2} \left( \sum_{i=1}^{m} \left( CIR_i \right)^2 - 1 \right)$$

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

$$\frac{\partial L}{\partial (CIR_i)} = \frac{1}{t} \sum_{j=1}^{t} \left( RP(D_{ij}, D_j) \right) \cdot \sum_{j=1}^{t} \left( CIR_i \right)^2 - 1 = 0$$

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

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

$$CIR_i = \sqrt{\frac{(1/t) \sum_{j=1}^{t} \left( d(RP(D_{ij}, D_j), (1/t) \sum_{j=1}^{t} RP(D_{ij}, D_j)) \right) \cdot \sum_{j=1}^{t} \left( CIR_i \right)^2 \cdot \sum_{j=1}^{t} \left( d(RP(D_{ij}, D_j), (1/t) \sum_{j=1}^{t} RP(D_{ij}, D_j)) \right)^2}{\sum_{i=1}^{m} \left( d(RP(D_{ij}, D_j), (1/t) \sum_{j=1}^{t} RP(D_{ij}, D_j)) \right) \cdot \sum_{j=1}^{t} \left( CIR_i \right)^2 \cdot \sum_{j=1}^{t} \left( d(RP(D_{ij}, D_j), (1/t) \sum_{j=1}^{t} RP(D_{ij}, D_j)) \right)^2}}$$

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.

<table>
<thead>
<tr>
<th>Value elements are realized</th>
<th>Like</th>
<th>Must-be</th>
<th>Neutral</th>
<th>live with</th>
<th>Dislike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value elements have not been realized</td>
<td>Like</td>
<td>Q</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Must-be</td>
<td>R</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>M</td>
</tr>
<tr>
<td>Neutral</td>
<td>R</td>
<td>I</td>
<td>I</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>live with</td>
<td>R</td>
<td>I</td>
<td>I</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Dislike</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>Q</td>
</tr>
</tbody>
</table>


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.

\[
SI_i = \frac{NA + NO}{NA + NO + NM + NI} \tag{11}
\]
\[
DI_i = \frac{NM + NO}{NA + NO + NM + NI} \tag{12}
\]

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. $NA, NO, NM, NI$ 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 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 $AI_j$ of value element $CV_i$ is shown in the following formula:

\[
AI_j = (1 + \max(SI_i, DI_i))^k_j \tag{13}
\]

where $k_j$ is the Kano classification coefficient. The $k_j$ 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:

\[
FIR_j = BIR_j \cdot CIR_j \cdot AI_j \quad (i = 1, 2, \cdots m) \tag{14}
\]

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...
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 6: Performance domain model.](image-url)
Therefore, the relational matrix $R_1$ consisting of $B_{ij}$ can be constructed.

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

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 $\overline{W(E)}_j(Ex_j, Er_j, He_j)$ of the cloud model $W(E)_j(Ex_j, Er_j, He_j)(1 \leq j \leq n)$ 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 $RP(W(E)_j, \overline{W(E)})$.

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.
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.

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

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**Table 3: Meaning of the value elements.**

<table>
<thead>
<tr>
<th>Value elements</th>
<th>Meaning</th>
<th>Value elements</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CV_1$</td>
<td>Good adaptability</td>
<td>$CV_9$</td>
<td>Personalized professional pre-sale guidance</td>
</tr>
<tr>
<td>$CV_2$</td>
<td>High operational reliability</td>
<td>$CV_{10}$</td>
<td>Flexible payment methods</td>
</tr>
<tr>
<td>$CV_3$</td>
<td>Long service life</td>
<td>$CV_{11}$</td>
<td>Good training professionalism</td>
</tr>
<tr>
<td>$CV_4$</td>
<td>High efficiency</td>
<td>$CV_{12}$</td>
<td>High installation efficiency</td>
</tr>
<tr>
<td>$CV_5$</td>
<td>Low cost</td>
<td>$CV_{13}$</td>
<td>Good operation professionalism</td>
</tr>
<tr>
<td>$CV_6$</td>
<td>Good security</td>
<td>$CV_{14}$</td>
<td>Timely supply of spare parts</td>
</tr>
<tr>
<td>$CV_7$</td>
<td>High support level of maintenance service</td>
<td>$CV_{15}$</td>
<td>High level of recycling service</td>
</tr>
<tr>
<td>$CV_8$</td>
<td>Good human–computer interaction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4: Importance of the customer value elements.**

<table>
<thead>
<tr>
<th>$P_1^1$</th>
<th>$P_2^1$</th>
<th>$\cdots$</th>
<th>$P_9^1$</th>
<th>$P_{10}^1$</th>
<th>Cloud model</th>
<th>Relative importance $RP(A_p, A)$</th>
<th>Normalization $BIR$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CV_1$</td>
<td>10</td>
<td>$8$</td>
<td>$\cdots$</td>
<td>9</td>
<td>10</td>
<td>(9.6, 602, 0.309)</td>
<td>0.810</td>
</tr>
<tr>
<td>$CV_2$</td>
<td>8</td>
<td>9</td>
<td>$\cdots$</td>
<td>9</td>
<td>8</td>
<td>(8.1, 677, 0.294)</td>
<td>0.619</td>
</tr>
<tr>
<td>$CV_3$</td>
<td>5</td>
<td>6</td>
<td>$\cdots$</td>
<td>7</td>
<td>6</td>
<td>(5.9, 902, 0.218)</td>
<td>0.340</td>
</tr>
<tr>
<td>$CV_4$</td>
<td>8</td>
<td>9</td>
<td>$\cdots$</td>
<td>7</td>
<td>8</td>
<td>(7.3, 953, 0.085)</td>
<td>0.517</td>
</tr>
<tr>
<td>$CV_5$</td>
<td>6</td>
<td>8</td>
<td>$\cdots$</td>
<td>7</td>
<td>5</td>
<td>(6.2, 602, 0.195)</td>
<td>0.378</td>
</tr>
<tr>
<td>$CV_6$</td>
<td>7</td>
<td>8</td>
<td>$\cdots$</td>
<td>6</td>
<td>8</td>
<td>(6.8, 802, 0.146)</td>
<td>0.454</td>
</tr>
<tr>
<td>$CV_7$</td>
<td>8</td>
<td>8</td>
<td>$\cdots$</td>
<td>9</td>
<td>8</td>
<td>(8.0, 752, 0.318)</td>
<td>0.606</td>
</tr>
<tr>
<td>$CV_8$</td>
<td>5</td>
<td>5</td>
<td>$\cdots$</td>
<td>6</td>
<td>7</td>
<td>(5.4, 702, 0.061)</td>
<td>0.276</td>
</tr>
</tbody>
</table>
5.2. 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.

5.3.2. 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 $CV_6$, $CV_5$, $CV_7$, $CV_4$, $CV_2$, and $CV_1$. When using the
For example, the value of the importance of the value element changed to a certain extent after revision. 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 $CV_j$ decreased after revision for two reasons. On the one hand, the competitive correction factor of $CV_j$ 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 $CV_j$ 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 $CV_j$ 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.

<table>
<thead>
<tr>
<th>Performance characteristics</th>
<th>( E_1 )</th>
<th>( E_2 )</th>
<th>( E_3 )</th>
<th>( E_4 )</th>
<th>( E_5 )</th>
<th>( E_6 )</th>
<th>( E_7 )</th>
<th>( E_8 )</th>
<th>( E_9 )</th>
<th>( E_{10} )</th>
<th>( E_{11} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance</td>
<td>0.607</td>
<td>0.438</td>
<td>0.539</td>
<td>0.419</td>
<td>0.506</td>
<td>0.582</td>
<td>0.444</td>
<td>0.520</td>
<td>0.569</td>
<td>0.405</td>
<td>0.471</td>
</tr>
<tr>
<td>Normalization</td>
<td>0.110</td>
<td>0.080</td>
<td>0.098</td>
<td>0.076</td>
<td>0.092</td>
<td>0.106</td>
<td>0.081</td>
<td>0.094</td>
<td>0.103</td>
<td>0.074</td>
<td>0.086</td>
</tr>
</tbody>
</table>

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

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

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 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.
Production phase, which will bring serious economic losses. Cause hundreds of workers to stop working in the whole 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.

![Figure 12: Comparison of the importance values of the performance characteristics between the exact value method and PHOQ-ECM.](image)

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

<table>
<thead>
<tr>
<th>Value elements</th>
<th>Exact value method</th>
<th>Cloud model method</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV₁</td>
<td>0.168</td>
<td>(9.6, 0.602, 0.309) 0.202</td>
</tr>
<tr>
<td>CV₂</td>
<td>0.141</td>
<td>(8.1, 0.677, 0.294) 0.155</td>
</tr>
<tr>
<td>CV₃</td>
<td>0.103</td>
<td>(5.9, 0.902, 0.218) 0.085</td>
</tr>
<tr>
<td>CV₄</td>
<td>0.127</td>
<td>(7.3, 0.953, 0.085) 0.129</td>
</tr>
<tr>
<td>CV₅</td>
<td>0.108</td>
<td>(6.2, 0.602, 0.195) 0.094</td>
</tr>
<tr>
<td>CV₆</td>
<td>0.119</td>
<td>(6.8, 0.802, 0.146) 0.113</td>
</tr>
<tr>
<td>CV₇</td>
<td>0.140</td>
<td>(8.0, 0.752, 0.318) 0.152</td>
</tr>
<tr>
<td>CV₈</td>
<td>0.094</td>
<td>(5.4, 0.702, 0.061) 0.069</td>
</tr>
</tbody>
</table>

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 $E₂$ should be greater than its auxiliary capacity $E₄$. 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.

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

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

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References


