

Received April 13, 2022, accepted May 4, 2022, date of publication May 9, 2022, date of current version May 12, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3173331

# A New Evaluation Method for Product Service System Scheme Based on Analytic Network Process and Niche Theory

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**ABSTRACT** In reservation to enhance the enforceability of the product service system scheme and avoid the waste of time and resources caused by the improper design of the scheme, it is necessary to evaluate the scheme effectively before the implementation of the product service system scheme. Therefore, this study proposes a product service system scheme evaluation method based on the analytic network process and niche theory and evaluates the product service system scheme with customer value as the evaluation index. First, an analytic network process is used to calculate the relative importance of various customer value types and stages of the customer activity cycle. Second, niche theory is used to calculate the relative advantages of different product service system schemes in delivering all types of customer value. Then, based on customer value perception, the customer's evaluation of the value delivered by different product service system schemes is obtained, and the schemes are ranked according to the amount of value delivered. Finally, the proposed method is verified by evaluating the CNC machine tool product service system scheme as an example and comparing it with other evaluation methods. The results demonstrate that the proposed method is more accurate and effective.


**INDEX TERMS** Product service system (PSS), scheme evaluation, customer value, analytic network process, niche theory.

## I. INTRODUCTION

In today's market environment, enterprises are becoming increasingly inclined toward products and services. They have shifted from selling products individually to selling a mixture of products and services and have begun to shift to the product service system (PSS) model [1]. This model can reduce the negative impact on the environment, provide value that satisfies customers, increase the market share of the enterprise, and increase revenue [2].

In PSS research, different scholars have defined product service system from different perspectives. Among these, the most widely recognized is the definition of PSS given by Mont in 2002 [3]: a system composed of products, services, organizer networks, and infrastructure that helps enterprises maintain competitiveness [4].

According to the definition of PSS, its goal is to create more value for customers; therefore, the design of PSS

The associate editor coordinating the review of this manuscript and approving it for publication was Baozhen Yao .

should also follow this goal. The customer value that the designed PSS scheme can bring can only be determined after evaluation of the PSS scheme [5]. Therefore, this study considers the customer value delivered by the PSS scheme as the evaluation index and proposes an evaluation method for the PSS scheme based on the analytic network process (ANP) and niche theory. ANP is used to calculate the relative importance of different customer value types and stages of the customer activity cycle. Niche theory is used to calculate the relative advantages of different PSS schemes in delivering various customer values. By integrating the complementary methods of ANP and niche theory, the value delivered by different PSS schemes can be calculated, and the optimal PSS scheme can be obtained.

The present study is novel in this regard. It is an attempt to evaluate the PSS scheme from the perspective of customers and solve the problem of customers' acceptance of the scheme by studying the background of their decision-making. The novelty of this paper can be summarized in two aspects: the quantitative method and analytical perspective. In terms

of quantitative methods, we integrated two complementary methods. ANP provides a systematic program to judge the priority of interrelated qualitative factors, while niche theory provides an effective program to analyze customers' perceptions of different PSS schemes to supplement this. The proposed method had several methodological advantages. From an analytical perspective, we formulate the standards applied to PSS scheme design according to customer value in the customer experience cycle. On this basis, ANP models and a questionnaire form for niche analysis are proposed, which provides a solution to the problem of PSS scheme evaluation.

The remainder of this paper is organized as follows. The research status related to this study and research motivation are introduced in the literature review, and the customer activity cycle and customer value type are introduced in the product service system scheme evaluation index. The next section introduces evaluation methods for product service system schemes, including ANP and niche theory. The proposed method was applied to an actual case to verify its feasibility and effectiveness. Finally, the results of the case study are discussed, and the full paper is summarized.

## II. LITERATURE REVIEW

### A. RESEARCH STATUS

In recent years, researchers have evaluated PSS schemes from various perspectives. In terms of customer satisfaction, Ding *et al.* [6] proposed a service satisfaction evaluation method considering customer preferences, which can ensure that the warehousing PSS scheme is more reliable and reasonable. In this method, the standard impact loss method is used to determine the initial weight. Considering the influence of customer preference, the Kano model is used to adjust the initial weight. Finally, the proposed method is verified by an actual case. Geng *et al.* [7] developed a new importance analysis method using the Kano model and a decision experiment evaluation laboratory tool to evaluate customer satisfaction with a PSS scheme. This method can be used to analyze the nonlinear influence of quality attributes and the causal relationship between the attributes of the PSS scheme. Based on the classical fuzzy set and gray system theory, Alfian *et al.* [8] proposed an evaluation method for the PSS scheme, which is composed of multilevel comprehensive attribute indexes such as service quality, customer satisfaction, and maintainability. Kjaer *et al.* [9] proposed a PSS environmental performance evaluation method based on life cycle assessment, which assessed the environmental performance of PSS through PSS case studies, expert consultation, and structured user feedback. Wang *et al.* [10] proposed a scheme evaluation method based on context-aware for intelligent PSS design iteration. This method originates from the traditional information axiom method, and introduces the context-aware evaluation index recognition module and the system wide recognition process based on natural language processing technology, which reduces human intervention in the design process. Finally, the

design iteration of 3D printer is taken as an example to verify the feasibility of this method.

Using the PSS scheme evaluation index, Chen *et al.* [11] proposed a scheme evaluation method based on the information axiom and constructed a corresponding evaluation index model that effectively solved the randomness and fuzziness of the evaluation index. An *et al.* [12] proposed a PSS scheme optimization method based on a combination of variable granularity weights and group decision-making methods. The relative and absolute weights of the evaluation index are fused as the final weights of the evaluation index. A generalized evidential reasoning group decision-making method was introduced to fuse expert evaluation opinions, and an optimal PSS scheme was obtained. Li and Wu [13] proposed a scheme evaluation method that combines DEA with stochastic multi-objective acceptability analysis because of the randomness of the PSS scheme evaluation index. Wang and Durugbo [14] used the fuzzy Delphi method to determine the attribute weight of the product service system implementation process, combined with fuzzy AHP and fuzzy TOPSIS models, to achieve an effective evaluation of the PSS scheme. Aiming at the fuzziness and diversity of customer requirement in the process of PSS scheme design, Chen *et al.* [15] proposed a requirement identification model based on decision making trial and evaluation laboratory (DEMATEL) and analytical network method (ANP), and applied this method to the scheme design of excavator PSS. The feasibility and potential of the proposed method are proved by comparison with several other different methods. Song *et al.* [16] proposed an integrated weight method based on fuzzy TOPSIS for the evaluation of PSS modular scheme. The method effectively avoids underestimating or overestimating the weight of the evaluation index by integrating the subjective weight and the objective weight, and the feasibility and effectiveness of the proposed method are verified by the compressor rotor service case. Zhang *et al.* [17] proposed an evaluation tool combining life cycle assessment and life cycle cost calculation to support the PSS development of high energy consuming equipment. The evaluation tool includes seven steps: goal and scope definition, system boundary determination, method selection, scenario construction, data collection, quantitative analysis, and result interpretation. Finally, the feasibility and effectiveness of the proposed tool are verified by an actual case. Aiming at the problems of interpersonal language fuzziness and randomness of interpersonal preference in the process of PSS scheme evaluation, Chen *et al.* [18] proposed a new rough-fuzzy data envelopment analysis method to select the appropriate PSS scheme. This method integrates the strength of fuzzy number in capturing interpersonal uncertainty and the feasibility of rough number in perceiving interpersonal uncertainty. Finally, the feasibility and effectiveness of the method are demonstrated through a case study of an intelligent air conditioning service system and its comparison with other methods.

Although researchers have conducted in-depth research on PSS scheme evaluation, the research mainly focuses

on optimizing the calculation method of the PSS scheme evaluation index and making the evaluation process more realistic and effective. There is little research on PSS scheme evaluation based on customer value. When evaluating a PSS scheme, customer value should be used as the evaluation standard, and the advantages and disadvantages of the PSS scheme should be evaluated from the perspective of customer value.

### B. RESEARCH MOTIVATION

The PSS scheme design process is a forward design process with customer value as the source. Most of the key parameters and characteristics of the PSS scheme are determined during the design stage. As to how much customer value the designed PSS scheme can create, it is necessary to evaluate the PSS scheme effectively before it can be known. This is an issue that the author is most concerned with: Therefore, using customer value as an evaluation index, this study proposes an evaluation method for a PSS scheme based on ANP and niche theory. First, considering the relationship between the evaluation indices, the ANP method was used to calculate the weight of the evaluation indexes to effectively eliminate the interaction between the evaluation indexes. Second, niche theory is used to calculate the relative advantages of different PSS schemes in delivering various types of customer values and quantifying the amount of value delivered by different PSS schemes. The proposed method selects the optimal PSS scheme by quantitatively calculating the values delivered by the different PSS schemes. This process can effectively improve the accuracy of the PSS scheme selection and decision-making process, and avoid the waste of resources and time caused by improper selection of the PSS scheme.

To quantify and compare customers' views on the value delivered by different PSS schemes in their customer experience cycles. When evaluating PSS schemes, customer value and experience are qualitative, heterogeneous, and interrelated. As one of the most widely used multi-criteria decision-making (MCDM) methods, ANP can calculate the importance of qualitative, heterogeneous, and particularly interrelated criteria. Considering the correlation of customer value at different stages of the customer experience cycle, ANP is suitable as the primary method for evaluating PSS schemes.

## III. PRODUCT SERVICE SYSTEM SCHEME EVALUATION INDEX

When evaluating PSS schemes using customer value as an evaluation index, it mainly evaluates the customer value delivered by different PSS schemes at each stage of the customer activity cycle. Therefore, it is necessary to determine the stage of the customer activity cycle and type of customer value.

### A. CUSTOMER ACTIVITY CYCLE

The interaction activities between customers and products are usually divided into five stages [19]: purchase, delivery,

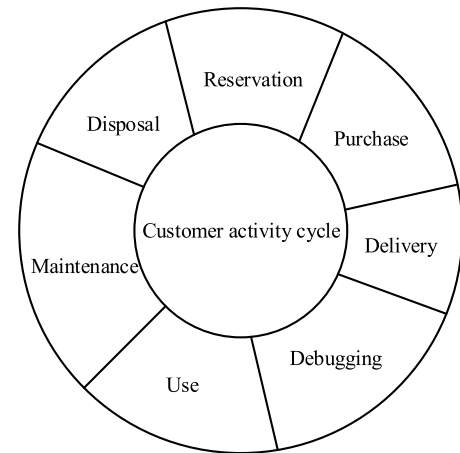


FIGURE 1. Customer activity cycle model.

debugging, use, and maintenance. In the PSS scheme, owing to the various services involved, the scope of customer activities is further expanded to cover the stages before and after product purchase. Therefore, based on these five phases, two phases of reservation and disposal were added, and these seven phases constitute the customer activity cycle. The customer activity cycle model is illustrated in Fig. 1.

The customer activity cycle determines the stages at which the PSS scheme can create value for customers. The seven stages of the customer activity cycle are reservation, purchase, delivery, debugging, use, maintenance, and disposal. Each stage contains a specific customer experience and customers can evaluate each stage according to their value perception. After determining the various stages of the customer activity cycle, the specific customer value types must be determined. Only by knowing the specific customer value types can customers have a specific direction and evaluation basis for their perception and evaluation of the value delivered by the PSS schemes.

### B. CUSTOMER VALUE TYPE

Improper design is not the only cause of time and resource waste, and improper design results in time and resource waste. Therefore, in order to avoid improper design, it is necessary to effectively evaluate the PSS scheme. PSS scheme design is a design process with customer value as the source, taking customer value as the evaluation basis of the PSS scheme, evaluating the degree of satisfaction of different PSS schemes to customer value, so as to select the PSS scheme that can best meet customer value.

Before studying types of customer value, it is necessary to define customer value. In the research process of customer value, researchers have provided different definitions, the most representative of which is the definition given by Oxenfeldt [20]: "Customer value represents the trade-off between the customer's perceived gains from the product/service and the perceived loss of the product/service price." For the problem of customer value types, Holbrook identified

TABLE 1. Customer value type.

Customer value type	Description
Function	The beneficial role played by the product/service
Reliability	The ability of the product/service to perform a specific function without failure in a certain period time and under certain conditions
Cost	The cost of accomplishing something or achieving a certain purpose
Service quality	The level and extent to which the service process can meet the requirements
Resource support capability	Resource support capabilities for product functions and service activities

five types of customer value: functional, social, emotional, cognitive, and conditional. Among these, functional value is considered as the main driving force for customers to purchase [21].

Based on the customer value type proposed by Holbrook, combined with the characteristics of products and services in the PSS scheme, as well as the customer’s focus on the PSS scheme, the function, reliability, cost, service quality, and resource support capability are taken as the value criteria of PSS scheme evaluation, as shown in Table 1, located after the references.

IV. PRODUCT SERVICE SYSTEM SCHEME EVALUATION METHOD

The evaluation of the PSS scheme based on customer value can be divided into three stages: The first stage is to evaluate the value delivered by different PSS schemes by customers, the evaluation table is constructed in the form of a matrix, the customer value type is taken as the row, and each stage of the customer activity cycle is taken as the column. At the intersection of rows and columns, customers evaluate and score based on the value delivered by the PSS scheme. In the second stage, ANP is used to determine the relative importance of each stage of the customer activity cycle and different types of customer values. The third stage uses the niche advantage index of niche theory to compare the relative advantages of different PSS schemes in delivering customer value and ranking PSS schemes according to the amount of value.

A. ANP

The ANP method was proposed by Saaty [22] in 1996, and has been widely used in multi-criteria decision-making problems. The ANP method can guide customers to make judgments through pairwise comparisons and quantify the relative importance of evaluation criteria. It can deal with qualitative, heterogeneous, and interrelated criteria as well as interdependence between criteria [23], [24]. It is widely used in complex multi-criteria decision-making problems such as brand marketing [25] and performance evaluation [26]. ANP has been combined with other decision-making methods, such as quality function deployment (QFD) [27], strengths

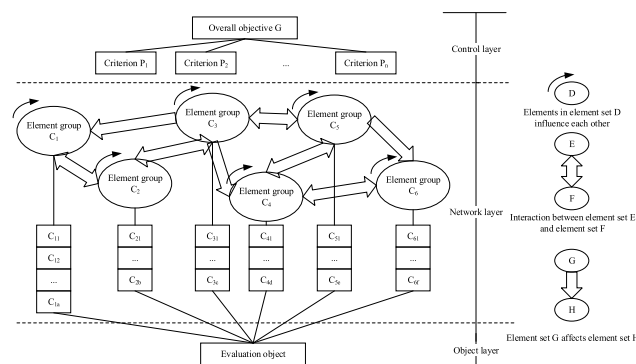


FIGURE 2. ANP model.

weakness opportunities threads (SWOT) [28], technology for order preference by similarity to an ideal solution (TOPSIS) [29], and decision-making trial and evaluation laboratory (DEMATEL) [30]. Choosing the ANP method to determine the relative importance of the evaluation criteria of the PSS scheme can better capture customer preferences during the decision-making process. The ANP model is illustrated in Fig. 2.

B. NICHE THEORY

Niche theory originated from ecology and social science and has been extended to other fields. It has been widely used in media selection, education, and supply chain management [31]. When niche theory is used to evaluate PSS schemes, niche advantage indices are used to compare the relative advantages of different PSS schemes for delivering customer value. The relative advantage is proportional to the customer value brought about by the PSS scheme at different stages of the cycle. The formula for calculating niche advantage is given in Equation (1) [32].

$$SUPERIORITY S_{a>b} = \sum_{n=1}^N \sum_{k=1}^K (m_{a>b}) / N \quad (1)$$

where a and b represent PSS schemes a and b, respectively. m<sub>a>b</sub> represents the score given by the customer on the index that PSS scheme a has a higher score than PSS scheme b. N represents the number of customers who choose PSS scheme a. K indicates the maximum value of a certain dimension.

To evaluate PSS schemes, the advantages of ANP and niche theory can be fully utilized. These two methods compensate for the shortcomings of each other. Lee et al. proposed an evaluation method based on ANP and niche theory for customer acceptability of product schemes and product service schemes, which integrates ANP and niche theory to obtain customer acceptance of different schemes to provide a basis for enterprises to formulate strategies [33]. ANP provides a basis for niche advantage calculations and can capture the basis of customer evaluation [34]. Niche theory reduces the complexity of ANP modeling and calculation and can capture customer preferences for PSS schemes [35]. The integration of ANP and niche theory provides a basis for



TABLE 2. ANP and niche theory.

Method	Application	Favorable features	Complementarity
ANP	Determine the relative importance of evaluation criteria	Dealing with interrelated evaluation criteria	Provide a basis for niche advantage calculation
Niche theory	Determine the relative advantage of the PSS scheme in delivering the customer value	Provide a reasonable and powerful explanation for the evaluation of the PSS scheme	Reduce the complexity of ANP modeling and calculation

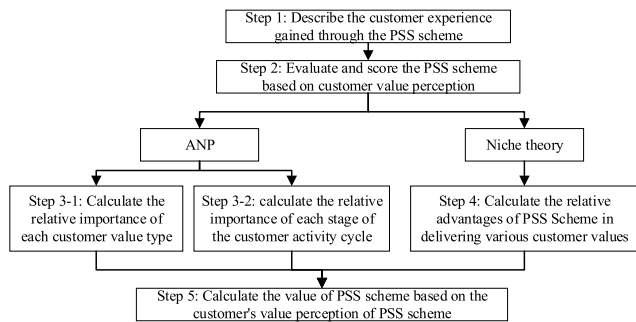


FIGURE 3. PSS scheme evaluation process.

calculating customer value delivered by the PSS scheme. The ANP and niche theories are presented in Table 2.

C. EVALUATION MODEL

The PSS scheme differs at different stages of the customer-activity cycle. Through the integration of ANP and niche theory, the customer’s perception of the customer value delivered by the PSS scheme in the customer activity cycle is quantified, and the customer’s evaluation of the pros and cons of different PSS schemes is obtained. The evaluation process of the PSS scheme is illustrated in Fig. 3.

The specific steps of the PSS scheme evaluation are as follows:

Step 1: Describe the customer experience.

The product functions and service activities of different PSS schemes in each stage of the customer activity cycle are described in detail, and the experience that PSS schemes can bring to customers is described in detail.

Step 2: Evaluate and score the PSS scheme based on customer value perception.

The customer scores each matrix unit based on value perception and the score interval is [0, 5]. The corresponding relationship between the value and score is shown in Table 3, located after the references. If a customer feels that they have obtained an experience of a certain value type at a certain stage of the customer activity cycle, they can fill in the score at the intersection of the corresponding customer activity cycle

TABLE 3. Correspondence table of value and score.

Value quantity	Value quantity description	Score
Mickle	The amount of perceived value is large	5
More	The amount of perceived value is greater	4
General	The amount of perceived value is average	3
Less	The amount of perceived value is less	2
Rarely	The amount of perceived value is small	1
No	There is no perceived value	0

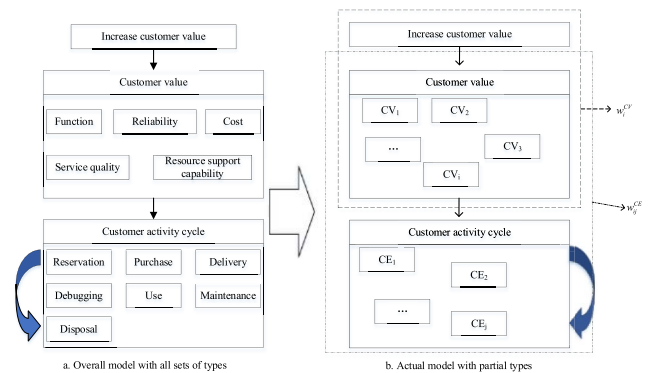


FIGURE 4. ANP evaluation model.

stage and customer value type, and the score is assigned by the customer according to the value.

Step 3: The relative importance of each customer value type and stage of the customer activity cycle is calculated.

An ANP evaluation model was built to determine the relative importance of each customer value type and stage of the customer activity cycle. The relationship between elements is described in the form of a network, as shown in Fig. 4. Each customer value type contributes differently to the total customer value and the relative importance of each customer value type varies according to the different stages of the customer activity cycle. Fig. 4 (a) shows the overall model, which contains a set of decision-making elements. Fig. 4 (b) shows the actual model. Not all customer value types or customer activity cycle stages are critical for a PSS scheme.

Using the ANP evaluation model, the following three specific importance results were obtained: 1. Relative importance of each customer value type. 2. Importance of customer value type at each stage of the customer activity cycle. 3. Relative importance of each stage of the customer activity cycle. The relative importance of each customer value type was derived from the local priority vector in the pairwise comparison matrix, as shown in Fig. 4 (b). The relative importance of each customer value type to each customer activity cycle stage is indicated by the dotted line in Fig. 4 (b). The importance of customer value type  $i$  relative to the stage  $j$  of the customer activity cycle can be calculated using

Equation (2).

$$w_{ij}^{CE} = w_{ij}^D \times w_j^I \quad (2)$$

Among them,  $w_{ij}^{CE}$  represents the relative importance of the customer value type  $i$  from ANP (normalized value) to the customer activity cycle stage  $j$ .  $w_{ij}^D$  represents the relative importance of the customer value type  $i$  relative to the customer activity cycle stage  $j$ .  $w_j^I$  represents the relative importance of the customer value type  $i$  relative to the customer activity cycle stage  $j$ .  $w_j^I$  represents the relative importance of the stage  $j$  in the customer activity cycle.

Step 4: Calculate the relative advantages of PSS schemes in delivering various customer values

Niche advantage is used to calculate the relative advantage of each customer value type for each stage of the customer activity cycle. The calculation method for the niche advantage of the PSS scheme is shown in equation (3).

$$ns_{PSS_a > PSS_b}^i = \frac{\sum_{n=1}^N \sum_{j=1}^J w_{ij}^{CE} r_{PSS_a > PSS_b,ijn}}{N} \quad (3)$$

Among these,  $ns_{PSS_a > PSS_b}^i$  represents the competitive advantage of the PSS scheme in terms of customer value-type  $i$ .  $n$  represents the number of customers,  $n = 1, 2, \dots, N$ .  $j$  represents the number of stages in a customer activity cycle  $j = 1, \dots, J$ .  $r_{PSS_a > PSS_b,ijn}$  represents the score of the  $n$ -th customer in stage  $j$  of the customer activity cycle when the score of customer value type  $i$  of PSS scheme  $a$  is greater than that of customer value type  $i$  of PSS scheme  $b$ .

The competitive advantage obtained by Equation (3) is a relatively independent and absolute value that must be transformed into a form independent of scale. The calculation method for the relative advantage of PSS schemes is shown in Equation (4), which ranges from 0 to 1 and is an independent rating scale.

$$rs_i = ns_{PSS_a > PSS_b}^i / \left( ns_{PSS_a > PSS_b}^i + ns_{PSS_b > PSS_a}^i \right) \quad (4)$$

$rs_i$  represents the relative advantage of PSS schemes in delivering customer value-type  $i$ .  $ns_{PSS_a > PSS_b}^i$  represents the advantage of PSS scheme  $a$  over PSS scheme  $b$  when delivering customer value type  $i$ .  $ns_{PSS_b > PSS_a}^i$  represents the advantage of PSS scheme  $b$  over PSS scheme  $a$  when delivering customer value-type  $i$ .

Step 5: Calculate the value delivered by the PSS scheme based on customer value perceptions.

If PSS scheme  $a$  has a higher priority for delivering customer value types, then PSS scheme  $a$  is superior to PSS scheme  $b$ . The relative advantage of PSS scheme  $b$  is calculated as 1 minus the relative advantage of PSS scheme  $a$ . The superiority of PSS scheme  $a$  is recorded in the  $S_{PSS_a}$  section.  $S_{PSS_a}$  is the value  $V_{PSS_a}$  of PSS scheme  $a$  minus the value  $V_{PSS_b}$  of PSS scheme  $b$ , as shown in Equation (5). If the result is positive, PSS scheme  $a$  is better than

PSS scheme  $b$ .

$$S_{PSS_a} = V_{PSS_a} - V_{PSS_b} = \sum w_i^{CV} \times rs_i - \sum w_i^{CV} \times (1 - rs_i) \quad (5)$$

$S_{PSS_a}$  is the superiority of PSS scheme  $a$ .  $V_{PSS_a}$  is the value of PSS scheme  $a$ .  $V_{PSS_b}$  is the value of PSS scheme  $b$ .  $w_i^{CV}$  is the relative importance of the customer value type  $i$  obtained from ANP (normalized value).  $rs_i$  is the relative advantage of a PSS scheme in delivering customer value  $i$ .

## V. CASE STUDY

Enterprises plan to provide PSS schemes for CNC machine tools, not only selling CNC machine tools, but also providing maintenance and repair, fault diagnosis, technical training, and other services. In the PSS scheme design stage, five feasible PSS schemes are determined according to the customer value and constraints:  $a, b, c, d$ , and  $e$ .

In the process of PSS scheme evaluation, if the components of the PSS scheme are simply described, customers may not be able to find the key points of the PSS scheme evaluation and the basis for comparing different PSS schemes, let alone the differences between them. Therefore, to make customers have the basis to compare different PSS schemes and truly feel the differences between different PSS schemes, this study makes the PSS scheme specific to the key indexes to make the PSS scheme information more specific and more conducive to customers' objective evaluation of the PSS scheme. The key indices of the five PSS schemes are presented in Table 4.

In this study, due to the differences in the perception of different types of customer value between male and female customers, to ensure the accuracy and authenticity of the evaluation results, the PSS scheme evaluation team is composed of five male and five female customers. A PSS scheme evaluation team composed of ten customers was established to evaluate the PSS scheme of CNC machine tools. The PSS scheme was evaluated in two ways. First, from the aspect of the customer activity cycle, the customer experience at each stage of the cycle is described in detail. Second, from the perspective of customer value type, the value of each customer value type transferred by different PSS schemes is evaluated. The specific evaluation process of the PSS scheme is as follows:

Step 1: Describe the customer experience.

Five types of customer value are described in detail, and the product functions and service activities of the PSS schemes at each stage of the customer activity cycle are described in detail to enable customers to evaluate different PSS schemes.

Step 2: Evaluate and score the PSS scheme based on customer value perception.

Referring to the corresponding relationship between the value and score in Table 3, customers score each matrix unit of the PSS scheme evaluation table according to the value perception.

Step 3: The relative importance of each customer value type and stage of the customer activity cycle is calculated.

TABLE 4. PSS scheme.

PSS scheme	PSS scheme key indexes
a	The precision level of CNC machine tools is micron level; The spindle speed is 10 <sup>4</sup> r/min; The number of linkage axes of the CNC machine tools is five; It is equipped with a cutter head and automatic tool change function; Real-time monitoring of the operation status; Remote maintenance support; Free on-site maintenance; Operation training; Intelligent programming function; Five-year complete machine quality warranty; Spare parts supply; Support for old-for-new.
b	The precision level of CNC machine tools is micron level; the spindle speed is 10 <sup>4</sup> r/min; The number of linkage axes of the CNC machine tools is five; It is equipped with a cutter head and automatic tool change function; Real-time monitoring of the running status; Remote maintenance support; Free on-site maintenance; Operation training; Intelligent programming function; Three-year complete machine quality warranty; Spare parts supply; Support for old-for-new.
c	The precision level of CNC machine tools is micron level; The spindle speed is 10 <sup>4</sup> r/min; The number of linkage axes of the CNC machine tools is four; No tool head and automatic tool change function; Real-time monitoring of the running status; Remote maintenance support; Free on-site maintenance; Operation training; Intelligent programming function; Three-year complete machine quality warranty; Spare parts supply; Support for old-for-new.
d	The precision level of the CNC machine tool is micron level; The spindle speed is 10 <sup>3</sup> r/min; The number of linkage axes of the CNC machine tool is four; No tool head and automatic tool change function; No real-time monitoring of the running status; Remote maintenance support; No free on-site maintenance; No operation training; No intelligent programming function; Three-year machine quality warranty; Spare parts supply; Support for old-for-new.
e	The precision level of CNC machine tools is millimeter level; The spindle speed is 10 <sup>3</sup> r/min; The number of linkage axes of the CNC machine tool is four; No cutter head and automatic tool change function; No real-time monitoring of running status; Remote maintenance support; No free on-site maintenance; No operation training; No intelligent programming function; Three-year machine quality warranty; Spare parts supply; Support for old-for-new.

The ANP method was used to obtain the relative importance of each customer value, relative importance of each stage of the customer activity cycle, and relative importance of the customer value to each stage of the customer activity cycle. The steps to obtain the relative weight of customer value type are as follows: (1) build a judgment matrix. The ten customers of the PSS scheme evaluation team make pairwise comparison of customer value types based on the general model (as shown in Figure 4 (a)), obtain the relative importance value through pairwise comparison, and arithmetically sum the relative importance values given by the ten customers to obtain the average value. The judgment matrix obtained by calculation is shown in Table 5.

(2) Calculate the relative weight of customer value types. First, normalize all the columns in Table 5. The calculation

TABLE 5. Judgment matrix.

	Function	Reliability	Cost	Service quality	Resource support capability
Function	1.000	1.740	1.080	1.940	3.190
Reliability	1.380	1.000	1.180	2.060	2.080
Cost	1.980	2.300	1.000	3.130	2.670
Service quality	1.240	1.260	0.760	1.000	1.370
Resource support capability	1.480	1.340	0.800	1.810	1.000

TABLE 6. Normalized judgment matrix.

	Function	Reliability	Cost	Service quality	Resource support capability
Function	0.680	0.470	0.340	0.310	0.490
Reliability	0.390	0.660	0.370	0.330	0.320
Cost	0.560	0.620	0.550	0.500	0.410
Service quality	0.350	0.340	0.240	0.280	0.210
Resource support capability	0.420	0.360	0.250	0.290	0.260

formula is as follows.

$$H_{ij} = \frac{d_{ij}}{\sum_{i=1}^n d_{ij}}, i = 1, 2, 3, 4, 5, j = 1, 2, 3, 4, 5 \quad (6)$$

Taking the first column as an example to illustrate the normalization calculation process, the first column of the normalized vector is as follows.

$$h_{11} = \frac{1}{1 + 1.38 + 1.98 + 1.24 + 1.48} = 0.68$$

$$h_{12} = \frac{1.38}{1 + 1.38 + 1.98 + 1.24 + 1.48} = 0.39$$

$$h_{13} = \frac{1.98}{1 + 1.38 + 1.98 + 1.24 + 1.48} = 0.56$$

$$h_{14} = \frac{1.24}{1 + 1.38 + 1.98 + 1.24 + 1.48} = 0.35$$

$$h_{15} = \frac{1.48}{1 + 1.38 + 1.98 + 1.24 + 1.48} = 0.42$$

The solution process of other columns is similar, and the normalized judgment matrix obtained by calculation is shown in Table 6.

(3) Add the normalized judgment matrix by row.

$$h_i = \sum_j^n h_{ij}, i = 1, 2, 3, 4, 5 \quad (7)$$

It can be obtained by calculation:

$$h_1 = 0.68 + 0.47 + 0.34 + 0.31 + 0.49 = 2.29$$

**TABLE 7. Relative importance of customer value type.**

Customer value type	Relative importance
Function	0.229
Reliability	0.207
Cost	0.264
Service quality	0.142
Resource support capability	0.158

$$\begin{aligned}
 h_2 &= 0.39 + 0.66 + 0.37 + 0.33 + 0.32 = 2.07 \\
 h_3 &= 0.56 + 0.62 + 0.55 + 0.50 + 0.41 = 2.64 \\
 h_4 &= 0.35 + 0.34 + 0.24 + 0.28 + 0.21 = 1.42 \\
 h_5 &= 0.42 + 0.36 + 0.25 + 0.29 + 0.26 = 1.58
 \end{aligned}$$

(4) Calculate the weight vector.

$$h_i^o = \frac{h_i}{\sum_{i=1}^n h_i}, i = 1, 2, 3, 4, 5 \tag{8}$$

The eigenvectors of the judgment matrix can be obtained by calculating.

$$\begin{aligned}
 h_1^o &= \frac{2.29}{2.29 + 2.07 + 2.64 + 1.42 + 1.58} = 0.229 \\
 h_2^o &= \frac{2.07}{2.29 + 2.07 + 2.64 + 1.42 + 1.58} = 0.207 \\
 h_3^o &= \frac{2.64}{2.29 + 2.07 + 2.64 + 1.42 + 1.58} = 0.264 \\
 h_4^o &= \frac{1.42}{2.29 + 2.07 + 2.64 + 1.42 + 1.58} = 0.142 \\
 h_5^o &= \frac{1.58}{2.29 + 2.07 + 2.64 + 1.42 + 1.58} = 0.158
 \end{aligned}$$

Finally, the weight vector of customer value type is obtained.

$$h = \begin{pmatrix} 0.229 \\ 0.207 \\ 0.264 \\ 0.142 \\ 0.158 \end{pmatrix}$$

The relative importance of different customer values is presented in Table 7.

According to Equation (2), the relative importance of customer value type in each stage of the customer activity cycle is calculated, and the calculation results are shown in Table 8, located after the references.

Step 4: Calculate the relative advantages of PSS schemes in delivering various customer values

The relative advantage of PSS schemes in delivering all types of customer value is calculated according to the relative importance of each customer value and the customer’s score of the value delivered by PSS schemes in different stages of the customer activity cycle.

Step 5: Calculate the value delivered by the PSS scheme based on customer value perceptions.

**TABLE 8. Relative importance of customer value types in each stage of customer activity cycle.**

Type \ Stage	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
Reservation	0.015	0.009	0.021	0.011	0.012
Purchase	0.020	0.012	0.028	0.015	0.016
Delivery	0.021	0.013	0.030	0.016	0.017
Debugging	0.025	0.015	0.036	0.019	0.021
Use	0.083	0.064	0.068	0.036	0.039
Maintenance	0.081	0.065	0.065	0.035	0.037
Disposal	0.012	0.007	0.017	0.009	0.010

**TABLE 9. Niche analysis result of the scheme a and scheme b.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.260	1.851	1.642	1.538	3.685
$ns_{PSS_b > PSS_a}^i$	0.745	1.764	2.115	2.596	1.288
$rs_{PSS_a > PSS_b}^i$	0.752	0.512	0.437	0.372	0.741
$rs_{PSS_b > PSS_a}^i$	0.248	0.488	0.563	0.628	0.259

**TABLE 10. Niche analysis result of the scheme a and scheme c.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_c}^i$	2.126	1.852	1.624	1.534	2.209
$ns_{PSS_b > PSS_a}^i$	0.724	1.794	2.050	2.492	1.292
$rs_{PSS_a > PSS_b}^i$	0.746	0.508	0.442	0.381	0.631
$rs_{PSS_b > PSS_a}^i$	0.254	0.492	0.558	0.619	0.369

The comparative results for the niche advantages of PSS schemes a and b are presented in Table 9.

The comparative results for the niche advantages of PSS schemes a and c are presented in Table 10.

The comparative results for the niche advantages of PSS schemes a and d are presented in Table 11.

The comparative results for the niche advantages of PSS schemes a and e are presented in Table 12.

The comparative results for the niche advantages of PSS schemes b and c are presented in Table 13.

The comparative results for the niche advantages of PSS schemes b and d are presented in Table 14.



**TABLE 11. Niche analysis result of the scheme a and scheme d.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.423	1.826	1.742	0.786	0.822
$ns_{PSS_b > PSS_a}^i$	0.528	1.606	2.347	2.448	1.275
$rs_{PSS_a > PSS_b}^i$	0.821	0.532	0.426	0.243	0.392
$rs_{PSS_b > PSS_a}^i$	0.179	0.468	0.574	0.757	0.608

**TABLE 12. Niche analysis result of the scheme a and scheme e.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	1.662	1.882	1.621	1.524	0.821
$ns_{PSS_b > PSS_a}^i$	0.519	1.188	2.046	2.445	1.263
$rs_{PSS_a > PSS_b}^i$	0.762	0.613	0.442	0.384	0.394
$rs_{PSS_b > PSS_a}^i$	0.238	0.387	0.558	0.616	0.606

**TABLE 13. Niche analysis result of the scheme b and scheme c.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.124	1.862	1.642	2.640	0.821
$ns_{PSS_b > PSS_a}^i$	0.832	1.698	2.073	2.476	1.317
$rs_{PSS_a > PSS_b}^i$	0.702	0.523	0.442	0.516	0.384
$rs_{PSS_b > PSS_a}^i$	0.299	0.477	0.558	0.484	0.616

The comparative results for the niche advantages of PSS schemes *b* and *e* are presented in Table 15.

The comparative results for the niche advantages of PSS schemes *c* and *d* are presented in Table 16.

The comparative results for the niche advantages of PSS schemes *c* and *e* are presented in Table 17.

The comparative results for the niche advantages of PSS schemes *d* and *e* are presented in Table 18.

The calculation results for the values of the five PSS schemes are presented in Table 19. The order of the values delivered by the five PSS schemes is as follows:

**TABLE 14. Niche analysis result of the scheme b and scheme d.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.421	1.010	1.624	1.631	0.842
$ns_{PSS_b > PSS_a}^i$	0.744	1.712	2.188	2.616	1.339
$rs_{PSS_a > PSS_b}^i$	0.765	0.371	0.426	0.384	0.386
$rs_{PSS_b > PSS_a}^i$	0.235	0.629	0.574	0.616	0.614

**TABLE 15. Niche analysis result of the scheme b and scheme e.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.264	1.852	1.033	1.634	0.851
$ns_{PSS_b > PSS_a}^i$	0.731	1.682	2.042	2.599	0.431
$rs_{PSS_a > PSS_b}^i$	0.538	0.524	0.336	0.386	0.664
$rs_{PSS_b > PSS_a}^i$	0.462	0.476	0.664	0.614	0.336

**TABLE 16. Niche analysis result of the scheme c and scheme d.**

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.125	1.862	1.634	1.562	0.846
$ns_{PSS_b > PSS_a}^i$	1.704	1.678	2.054	2.506	1.296
$rs_{PSS_a > PSS_b}^i$	0.555	0.526	0.443	0.321	0.395
$rs_{PSS_b > PSS_a}^i$	0.445	0.474	0.557	0.679	0.605

$a > e > d > b > c$ . PSS scheme *a* delivers the most customer value and PSS scheme *a* is the optimal scheme.

## VI. DISCUSSIONS

To illustrate the effectiveness of the proposed method, the calculation results obtained by the proposed method are compared with those obtained by Fuzzy AHP, Fuzzy TOPSIS, and DEMATEL, as shown in Fig. 5, located after the references. Among them,  $M_0$  is the result obtained using the proposed method, and the order of value quantity from highest to lowest is  $a > e > d > b > c$ .  $M_1$  is the result obtained using fuzzy AHP, and the order of value from

TABLE 17. Niche analysis result of the scheme c and scheme e.

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.627	1.925	1.826	1.624	0.821
$ns_{PSS_b > PSS_a}^i$	3.598	1.620	2.241	2.990	1.221
$rs_{PSS_a > PSS_b}^i$	0.422	0.543	0.449	0.352	0.525
$rs_{PSS_b > PSS_a}^i$	0.578	0.457	0.551	0.648	0.475

TABLE 18. Niche analysis result of the scheme d and scheme e.

	Function	Reliability	Cost	Service quality	Resource support capability
Weight value	0.229	0.207	0.264	0.142	0.158
$ns_{PSS_a > PSS_b}^i$	2.254	1.856	1.649	1.537	0.795
$ns_{PSS_b > PSS_a}^i$	1.177	1.741	2.116	2.518	1.270
$rs_{PSS_a > PSS_b}^i$	0.657	0.516	0.472	0.379	0.385
$rs_{PSS_b > PSS_a}^i$	0.343	0.484	0.528	0.621	0.615

TABLE 19. PSS scheme value calculation result.

	$S_{ab}$	$S_{ac}$	$S_{ad}$	$S_{ae}$	$S_{bc}$	$S_{bd}$	$S_{be}$	$S_{cd}$	$S_{ce}$	$S_{de}$
Result	0.054	0.093	0.014	0.093	0.039	-	-	-	-	-
						0.040	0.040	0.078	0.079	0.007

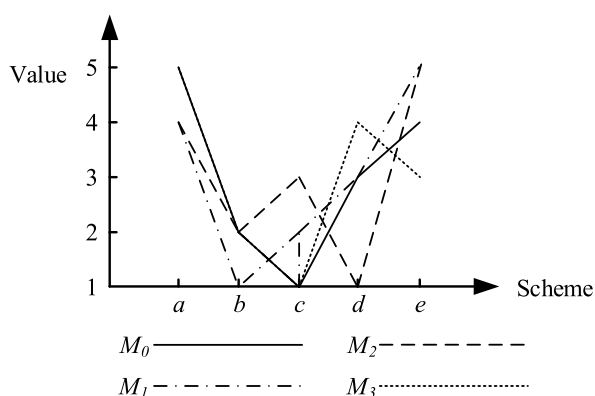


FIGURE 5. Comparison of evaluation results.

highest to lowest is  $e > a > d > c > b$ .  $M_2$  is the result obtained using fuzzy TOPSIS, and the order of value from highest to lowest is  $e > a > c > b > d$ .  $M_3$  is the result obtained using DEMATEL, and the order of value quantity from highest to lowest is  $a > d > e > b > c$ .

$M_0$  (the proposed method) considers the mutual relationship between the evaluation indices and uses the ANP method to calculate the weights of the evaluation indices. To evaluate the relative advantages of different schemes in delivering customer value, five schemes are compared in pairs, and the ranking results of the five schemes are obtained under the evaluation index of customer value.

The main reason for the difference between  $M_0$  (the proposed method) and  $M_1$  (fuzzy AHP) is that fuzzy AHP considers the ambiguity and uncertainty of the evaluation process, where the method does not consider the interaction between evaluation indexes. ANP can calculate the weight value of each evaluation index under the condition of comprehensively considering the mutual relationship of the evaluation index, and the evaluation result is more in line with objective facts.

The main reason for the difference between  $M_0$  (the proposed method) and  $M_2$  (fuzzy TOPSIS) is that, although fuzzy TOPSIS eliminates the fuzziness of the evaluation process, it does not consider the interaction between the evaluation indexes. However, in the actual decision-making process, there are often overlapping and complementary relationships between evaluation indexes. If these relationships are not considered, there will be a gap between the evaluation results and real results. The method proposed in this study considers the interaction between indices, and the calculation results are more accurate and reliable.

The main reason for the difference between  $M_0$  (the proposed method) and  $M_3$  (DEMATEL) is that DEMATEL can solve the interrelationship between evaluation indices, but the weights of the evaluation indices must be determined by experts through evaluation. Expert opinion is often subjective and cannot be objective.

### VII. CONCLUSION

Aiming at the problem of PSS scheme evaluation, taking customer value as an evaluation index and from the perspective of customer value perception, this study proposes a PSS scheme evaluation method based on ANP and niche theory. Customers perceive the value delivered by different PSS schemes in the customer activity cycle and evaluate PSS schemes according to the amount of value. First, ANP is used to obtain the relative importance of different types of customer values and each stage of the customer activity cycle. Second, niche theory is used to calculate the relative advantages of different PSS schemes in delivering all types of customer value, and the value delivered by different PSS schemes is calculated based on the customer's value perception of different PSS schemes. The greater the customer value delivered, the better the PSS scheme. Finally, the proposed method is verified by evaluating the PSS scheme of the CNC machine tool as an example and comparing it with other evaluation methods. The results demonstrate that the proposed method is more accurate and effective.

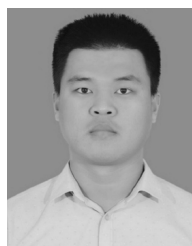
As an evaluation method based on customer perception, differences in customer perception affect the evaluation

results of the PSS schemes. Therefore, a more specific description of the customer experience is required to better understand the contents involved. The interpretation of the evaluation results must be more detailed to further explain how the results can help manufacturers make better decisions.

In addition, enterprises can consider how to enhance the customer experience of the PSS scheme and understand the value preferences of customers based on evaluation information. Simultaneously, customer evaluation information provides management inspiration and a strategic basis for enterprises.

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