Research on customer requirements driven scheme decision-making of product service system

Zhongqi Sheng*, Yazi Wang, Shujian Zhang

School of Mechanical Engineering & Automation, Northeastern University, Shenyang 110819, P. R. China

Received 1 October 2014, www.cmnt.lv

Abstract

Product service system development aims at making manufacturing enterprises adapt to globalized market development trend, and provide overall solutions to meet personalized customer requirements. Conceptual design process of product service system development is very complicated and time-consuming. As the key process of conceptual design, scheme decision-making directly affects the efficiency and success rate of product service system development. According to the classification result of customer requirements, this paper establishes the indicator system of scheme decision-making of CNC machine tools product service system. For the quantitative indicators, entropy weight method is used to determine its objective weight, AHP method is used to determine its subjective weight, and combined weight method is used to determine the comprehensive weight. For the qualitative indicators, fuzzy AHP is used to determine the weights. Finally, this paper uses improved TOPSIS method based on fuzzy Kano model to carry out schemes sorting for CNC machine tools product service system. Taking ETC series horizontal CNC machine tools as an example, the proposed method is verified.

Keywords: product service system, scheme decision-making, customer requirements, improved TOPSIS, CNC machine tools

1 Introduction

Since the last century, for western developed countries the proportion of manufacturing industry in national economy continues to decline, and the proportion of service sector increases rapidly on the contrary. The social formation of developed countries has completed the evolution from industrial society to post-industrial society, and the economic structure has realized the shift from product economy to service economy. In this background, the concept of product service system emerges at the right moment.

The key idea of product service system (PSS) is that what consumers need is not the products but the functions that products and services provide. Product service system meets the consumer requirements through integration of all resources, which improves social production and living standards, and is important for enterprise appreciation as well as environmental protection.

Therefore, research on product service system development aims at making manufacturing enterprises adapt to globalized market development trend, and provide overall solutions to meet personalized customer requirements by combining services and products. Conceptual design process of product service system development is very complicated and time-consuming. As the key process of conceptual design, scheme decision-making directly affects the efficiency and success rate of product service system development. In conceptual design of product service system, it is needed to consider products and services at the same time, which makes final solutions more complicated and varied. So designers must carry out scheme evaluation and choose optimal solution to preferably meet customer requirements.

Scheme decision-making of product service system is complex and multi-solution problem. Applying effective and reasonable method for scheme decision-making can detect the lack of schemes early and revise it in time, improve the efficiency and success rate of product service system design, and develop new product service system to adapt market development and meet customer demands.

2 Literature review

As the beginning of 1960s, H. A. Simon, one famous American managerialist, put forward modern decision-making theory. Later modern scientific evaluation and decision-making theory system forms gradually. Research on scheme decision-making at home and abroad can be divided into two aspects.

2.1 COMPREHENSIVE EVALUATION THEORY

With rapid development of comprehensive evaluation technology, a variety of evaluation methods are put forward and used widely, such as AHP, gray system evaluation method, fuzzy comprehensive evaluation method, data envelopment analysis method, artificial neural network method, etc.

Yeo [1] discussed generalized model of product conceptual design, compared some commonly used decision-making methods for uncertain information processing and decision-making, and proposed a fuzzy AHP method to apply to conceptual design of precision fixture. Sun [2] integrated AHP and neural network method. The importance degree of customer requirements was determined through AHP, demand indicators were quantified and demand mapping was implemented. On the basis of preliminary assessment, product design schemes were comprehensively evaluated by fuzzy reasoning tech-

* ***Corresponding author's*** e-mail: zhqsheng@mail.neu.edu.cn

nology based on feed forward neural network to determine the best solution.

Tang [3] applied a belief rule base (BRB) approach with evidential reasoning and found that BRB was capable of minimizing the human biases in evaluating user satisfaction and can generate more rational and informative evaluation results. Ye [4] put forward fuzzy characteristic vector method and quantitative method of interval judgment to apply in product scheme decision-making. Wang [5] combined fuzzy comprehensive evaluation and AHP, and established the product fuzzy comprehensive decision-making model.

2.2 MULTIPLE ATTRIBUTE DECISION-MAKING THEORY

Most engineering decision-making problems belong to multiple attribute decision-making problems. For those problems, designers usually proposed a set of alternative schemes. Every scheme contains multiple attributes, which need different evaluation criteria to make decisions. Eventually designers selected one most satisfactory solution from alternative schemes. Scheme decision-making of product service system belongs to multiple attribute decision-making problems. A lot of researches are carried out by scholars. The most representative decision-making methods include simple weighting method, AHP, TOPSIS, ELECTRE, PROMETHEE, etc.

Chiou [6] proposed fuzzy multiple attribute decision-making method and applied to evaluate the sustainable fishery development, in which he described the values of fuzzy attributes with triangular fuzzy number, determined the attribute weights with fuzzy AHP and evaluated the alternatives using integral method. Hwang [7] put forward TOPSIS method. First this method built the decision-making matrix of multiple attribute decision-making problems. Then the weighted distance of every scheme to positive ideal point and to negative ideal point were calculated. The scheme that is most close to positive ideal point and away from negative ideal point is the optimal scheme.

Lennon [8] investigated the conceptual design phase of new microplasma devices in order to create metrics that evaluated the efficiency, effectiveness, and overall utility of representative multi-attribute decision making systems. Gu [9] proposed multiple criteria decision-making mathematical model. Through analysis of the factors that influenced product competitiveness, the hierarchy structure of conceptual design scheme evaluation was built, and then FAHP was used to consider the advices of multiple field experts and the risk of product development process. Zhang [10] sorted the alternatives from the integrated viewpoint of products and services.

3 Scheme decision-making model of product service system

3.1 CHARACTERISTICS OF SCHEME DECISION-MAKING OF PRODUCT SERVICE SYSTEM

The scheme decision-making of product service system is different from general decision-making problems in the following aspects.

1) First of all, the object of general scheme decision-making is only product. However, product service system is the mix of product and services, which makes scheme decision-making object shifting from single product to product together with services. General scheme decision-making only considers the information of tangible product such as specifications, performance, shape, and so on. But the scheme of product service system includes intangible services such as pre-sale service, use training, transportation, installation and after-sale maintenance, recycling service, etc. Because decision-making object becomes complex and more information is needed for decision-making, it make product service system become more complicated, and the evaluation process become more difficult.

2) A mixture of scheme evaluation indicators of product service system: the scheme evaluation indicators of product service system include quantitative indicators and qualitative indicators. Quantitative indicators such as specifications, technical parameters, etc., have strong objectivity, and qualitative indicators such as installation service, remote monitoring service, after-sale service, etc. have certain uncertainty. The mixture of qualitative indicators and quantitative indicators makes indicator attributes more complicated and make decision-making more difficult. Therefore, while determining the weights of evaluation indicators, it is important to ensure that the objectivity of quantitative indicators and the uncertainty of qualitative indicators are not damaged.

3) A mixture of customer requirements information and decision-making information: for traditional decision-making process of product schemes, first the decision-making indicator system is built and the indicator weights are determined. Then, according to different criteria, the evaluation value of each scheme is given by designs. Finally, the optimal scheme is chosen by weighting and sorting treatment. In above processes, the decision-making information is separated from customer requirements information, so it is failed to effectively utilize customer requirements information. The establishment of decision-making indicator system and its weight assessment completely relies on the analysis and evaluation of designers.

The ultimate goal of scheme decision-making of product service system is to improve the customer satisfaction, and to provide better products and services for customers. Therefore, in decision-making process, the designers must consider whether and how much the decision-making indicators meet customer requirements. How to fully map customer satisfaction to scheme evaluation indicator system and decision-making process of product service system is the research focus of product service system scheme decision-making.

3.2 CHOICE OF SCHEME DECISION-MAKING METHODS OF PRODUCT SERVICE SYSTEM

Considering the mixture of scheme evaluation indicator system of product service system, it is necessary to reasonably calculate the weights of decision-making evaluation indicators. In the process of decision-making, the weights reflect the status or function of various indicators in decision-making process, and directly influence the decision-making results. To the objectivity of quantitative indicators and the uncertainty of qualitative indicators, it's necessary to use reasonable and effective algorithms to determine the weights. For qualitative indicators, it is needed to adopt effective mechanism to weaken the influence of their uncertainty to decision-making process. For quantitative indicators, it should make full use of the objectivity of the data so that the decision result is more accurate and reliable. Thus, combining different decision-making algorithms, a hybrid decision-making model is established to realize the reliability of scheme decision-making of product service system.

Mixed decision-making model reflects a mixture of several algorithms. For quantitative indicator, entropy method is used to determine its objective weight, AHP is used to determine its subjective weight, and finally the combination of empowerment method is applied to determine the comprehensive weight. For qualitative indicator, fuzzy AHP is used to determine its weight.

3.2.1 Determine the weights of evaluation indicators

AHP-entropy weight method is used to calculate the comprehensive weight of quantitative indicator. First with original data information, entropy method is used to calculate the objective weight ω_{oi}, AHP is used to calculate the subjective weight ω_{si}, finally combination method is used to get comprehensive weight ω_{ci}. This method can reduce the influence of subjective arbitrary of AHP to decision-making result, and also weaken the problem of inaccurate of entropy weight method due to the lack of sample data. Comprehensive weight is calculated as:

$$\omega_{ci} = \frac{\omega_{si}\omega_{oi}}{\sum_{j=1}^{m}\omega_{sj}\omega_{oj}}, \text{ i=1, 2, …, m} \quad (1)$$

Thus, ultimate comprehensive weights of quantitative indicators are got labelled as $\omega_c = (\omega_{c1}, \omega_{c2}, \ldots, \omega_{cm})$.

Using fuzzy AHP with triangular fuzzy number, the evaluation process of qualitative indicators is list as follows:

1) The value of judgment matrix is determined as shown in Table 1.

TABLE 1 Value of judgment matrix

Scale	Description
1	Factor X is as important as factor Y
(1, 3)	Factor X is slightly more important than factor Y
(3, 5)	Factor X is apparently more important than factor Y
(5, 7)	Factor X is strong more important than factor Y
(7, 9)	Factor X is extremely more important than factor Y

2) Establishment of expert fuzzy judgment matrix: The set of qualitative indicators is $X = \{x_1, x_2, ..., x_m\}$. Triangular fuzzy number is the fuzzy judgment of importance degree of indicator *i* relative to indicator *j* made by experts, in which x_{ij} and z_{ij} express the degree of fuzzy judgment. The greater $(z_{ij}-x_{ij})$ is, expressed fuzzy degree of comparative judgment is higher. The fuzzy judgment matrix is obtained as shown:

$$E = (\varepsilon_{ij})_{m\times m} = \begin{bmatrix} [x_{11}, y_{11}, z_{11}] & & [x_{1m}, y_{1m}, z_{1m}] \\ [x_{21}, y_{21}, z_{21}] & & [x_{2m}, y_{2m}, z_{2m}] \\ & & \\ [x_{m1}, y_{m1}, z_{m1}] & & [x_{mm}, y_{mm}, z_{mm}] \end{bmatrix}, \quad (2)$$

3) Consistency check of fuzzy judgment matrix: for the fuzzy judgment matrix $\tilde{E} = (\tilde{\varepsilon})_{n\times n}$, in which $\tilde{\varepsilon}_{ij}$ is fuzzy number and $\varepsilon_{ij} = y_{ij}$, if $E = (\varepsilon_{ij})_{n\times n}$ is consistency judgment matrix, the triangular fuzzy number judgment matrix $\tilde{E}$ is consistency fuzzy judgment matrix.

4) Calculation of fuzzy relative weight vector: in fuzzy judgment matrix, the fuzzy relative weight vector of indicator *i* is calculated as follows: triangular fuzzy matrix element *E*, the fuzzy relative weight is calculated as:

$$x_i = \left[\prod_{j=1}^{m} x_{ij}\right]^{1/m}, y_i = \left[\prod_{j=1}^{m} y_{ij}\right]^{1/m}, z_i = \left[\prod_{j=1}^{m} z_{ij}\right]^{1/m}$$
$$x = \sum_{i=1}^{m} x_i, y = \sum_{i=1}^{m} y_i, z = \sum_{i=1}^{m} z_i \quad (3)$$

and the fuzzy relative weight vector of elements ε_{ij} is $(x_i z^{-1}, y_i y^{-1}, z_i x^{-1})$, in which $i \in \{1, 2, \cdots, m\}$.

5) Anti-fuzzy calculation of fuzzy relative weight vector: for the ranking selection of schemes, each triangle fuzzy number of fuzzy relative weight vector should be clarified. Finally, the weight of qualitative indicator is obtained as shown:

$$W_\varepsilon = \frac{x_i z^{-1} + 2y_i y^{-1} + z_i x^{-1}}{4}, \quad (4)$$

After determined the indicator weight, it is needed to carry out comprehensive sorting and selection for schemes. For product service system, this process belongs to multiple-attribute and multiple-indicator comprehensive evaluation problems. And from mathematical viewpoint, this process merges multiple indicator values into one comprehensive evaluation value through mathematical model. At present, there are a variety of comprehensive evaluation methods, of which the theory of each single evaluation method has been very mature. However, the comprehensive evaluation method and theory of product service system scheme is not perfect, and the application research is still in development stage. Common comprehensive evaluation methods include simple weighting method, AHP, TOPSIS method, gray correlation method, and so on. This paper chooses improved TOPSIS method for product service system of CNC machine tools to make scheme decision-making.

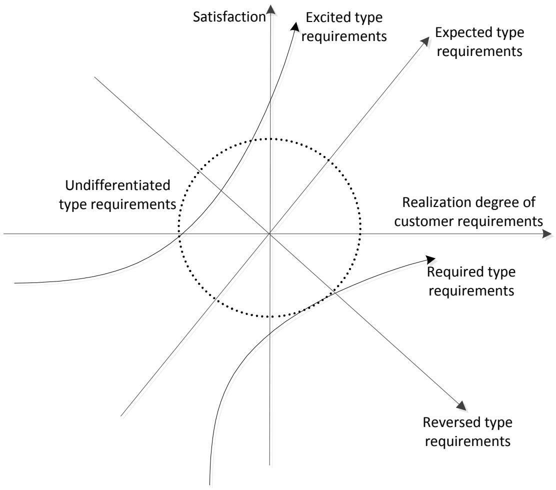

FIGURE 1 Kano model

Traditional TOPSIS method expresses the relationship between customer satisfaction and scheme indicator as linear relationship, which is too simple and is easy to cause the decision-making result deviate the facts. Through the analysis on Kano model as shown in Figure 1, it can find that between excited type requirements, required type requirements and realization degree of customer requirements there is nonlinear relationship, so it is needed to treat the relationship between customer satisfaction and indicator values as nonlinear relationship. For product service system scheme, the attributes of decision-making indicators are complicated. If simple linear relationship is used, it will greatly reduce the reliability of decision-making result. Therefore, it is needed to identify the diversity relationship between indicator values and customer satisfaction, to classify the attributes reasonably for design indicators, and to identify the customer desire for indicator level (that is the degree how much each indicator can meet the customer needs).

3.2.2 Classification model of fuzzy Kano evaluation indicators

For the fuzziness characteristic of customer satisfaction judgment on products and services, fuzzy Kano model is put forward, which combines fuzzy theory with Kano model and forms a new attribute classification method. Fuzzy Kano model can well reflect the fuzziness of customer requirements, which has big advantage on the demand classification. Questionnaire is designed for fuzzy Kano model, which is more humanized and provides customers more options. Customer can choose more than one answer according to his favor. With his feeling of multiple options, the customer marks any score between [0, 1], and just is needed to make sure the sum of each row score be 1. Based on the processing of customer requirements fuzziness, this model can get customer requirements information more accurately. The steps of applying fuzzy Kano model are as follows:

1) Build fuzzy classification evaluation matrix: U and V express the positive problem set and the negative problem set respectively. Function matrix is $P = \{P_1, P_2, ... , P_p\}$. Non-function matrix is $N = \{N_1, N_2, ... , N_m\}$. P, N is the language variables of U, V. P and N form the classification evaluation matrix as shown:

$$S_{pn} = P^T \times N = \begin{bmatrix} r_{11} & r_{11} & \cdots & r_{1n} \\ r_{21} & r_{11} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{p1} & r_{p2} & \cdots & r_{pn} \end{bmatrix}. \quad (5)$$

2) Determine attributes of design indicators: combining with the value of matrix element and the attribute of design indicator in Kano indicators classification evaluation table, the attribute membership vector of design indicator $\{T_k\}$ is got. Choosing the maximum value in the vector, this attribute is set as the attribute of design indicator.

3) Screen design indicator attributes: if for one evaluation indicator there are multiple attributes, it is needed to introduce screen factor α to make further screening. For fixed α, if the element of membership vector is greater than or equal to α, the attribute corresponding to this element is expressed by 1, otherwise expressed by 0. The value of α has big impact on screening result. A smaller value causes the screening not complete, which can't reach the purpose of screening simplification. A higher value causes excessive filtering, which will loss data. In this paper, α is set to 0.4.

4) Repeat above steps, and ultimately determine the attribute of each evaluation indicator. Count the occurrences number of the attribute of evaluation indicator. Take the attribute with the highest occurrences number as the attribute of design indicator. If there are multiple attributes with same occurrences number, rank the attributes according to the prioritization of them.

3.3.3 Expert group decision-making theory

Aimed at existed disadvantages of traditional TOPSIS method, improved TOPSIS method is used, in which it is needed to establish decision-making matrix firstly.

Scheme decision-making of product service system belongs to multiple attribute decision-making problems. Usually designers propose an optional set of alternatives. Each scheme contains multiple attributes, which need different evaluation criteria to make decision-making. Finally from many alternatives the most satisfactory scheme is chosen. This paper uses the expert group decision-making theory to construct TOPSIS method of decision-making matrix. Because the experts' evaluation on some indicators is often vague and uncertain, this paper uses triangular fuzzy number to express the fuzziness. The distance between barycentric coordinates of triangular fuzzy number and origin of coordinates is used to represent the triangular fuzzy number. The specific process is as follows:

Experts use the evaluation set of language variables to evaluate each alternative, which is [good (G), relatively good (N), general (F), relatively poor (Q), poor (V)] (each element corresponds to a triangular fuzzy number).

Set a triangular fuzzy number labelled as $A(a, b, c)$. When $x \in [a, b]$, the membership function is $f_A^T=(x-a)/(b-a)$, and the inverse function is $g_A^T=c+(b-c)/y$. When $x\in[b, c]$, the membership function is $f_A^T=(x-c)/(b-c)$, and the inverse function is $g_A^T=a+(b-a)/y$. The barycentric coordinates of A is (x_0, y_0) as calculated:

$$x_0(A)=\frac{\int_a^b x\cdot f_A^L dx+\int_b^c x\cdot f_A^T dx}{\int_a^b f_A^L dx+\int_b^c f_A^T dx}=\frac{a+b+c}{3}, \quad (6)$$

$$y_0(A)=\frac{\int_a^b y\cdot g_A^L dy\int_b^c y\cdot g_A^T dy}{\int_a^b g_A^L dy+\int_b^c g_A^T dy}=\frac{a+4b+c}{3(a+2b+c)}. \quad (7)$$

The distance equation of triangular fuzzy number is as shown:

$$d(A)=\sqrt{x_0^2+y_0^2}. \quad (8)$$

Calculate average score given by expert group as the evaluation result of expert group, and transform it into the distance value. The distance values form evaluation matrix $R=(r_{ij})_{m\times n}$.

3.3 IMPROVED TOPSIS METHOD BASED ON FUZZY KANO MODEL

First of all, set the scheme set of CNC machine tools product service system as A = $\{A_1, A_2, \dots, A_m\}$, the attribute set as F = $\{f_1, f_2, \dots, f_n\}$, and the decision-making matrix as X = $(x_{ij})_{m\times n}$. x_{ij} is the attribute value of the jth attribute in the ith scheme, where, $I\in M$, $j\in N$, $M=\{1, 2,\dots, m\}$, $N=\{1, 2,\dots, n\}$. Scheme $A_i=(x_{i1}, x_{i2},\dots, x_{in})$, $I\in M$. Attribute weight vector is $\omega=(\omega_1, \omega_2, \dots, \omega_n)$, which meets $\sum_{j=1}^{n}\omega_j=1, \omega_j\geq 0$, $j\in N$. Basic steps are as follows:

1) Build normalized decision-making matrix $R=(r_{ij})_{m\times n}$. by expert group decision-making theory

2) Build weighted normalized decision-making matrix $C=(z_{ij})_{m\times n}$, $z_{ij}=\omega_i r_{ij}$, $i\in M, j\in N$ as shown:

$$C=(\omega_i r_{ij})=\begin{pmatrix}\omega_1 r_{11} & \omega_2 r_{12} & \cdots & \omega_n r_{1n}\\ \omega_1 r_{21} & \omega_2 r_{22} & \cdots & \omega_n r_{2n}\\ \cdots & \cdots & \cdots & \cdots\\ \cdots & \cdots & \cdots & \cdots\\ \cdots & \cdots & \cdots & \cdots\\ \omega_1 r_{m1} & \omega_2 r_{m2} & \cdots & \omega_n r_{mn}\end{pmatrix} \quad (9)$$

3) Determine positive ideal solution P^+ and negative ideal solution P^-, and define two ideal schemes (positive ideal scheme and negative ideal scheme).

$$P^+=(z_1^+, z_2^+, \cdots, z_n^+), i=1,2,\cdots,m,$$

$$P^-=(z_1^-, z_2^-, \cdots, z_n^-), i=1,2,\cdots,m.$$

4) Calculate the distance of various schemes to positive ideal point and negative ideal point by:

$$d_i^+=\left[\sum_{j=1}^{n}(z_{ij}-z_j^+)^{\alpha}\right]^{1/2}, i=1,2,\cdots,m, \quad (10)$$

$$d_i^-=\left[\sum_{j=1}(z_{ij}-z_j^-)^{\alpha}\right]^{1/2}, i=1,2,\cdots,m. \quad (11)$$

in which, when the evaluation indicator is excited type indicator, $\alpha = 0.5$; when the evaluation indicator is expected type indicator, $\alpha = 1$; when the evaluation indicator is the required type indicators, $\alpha = 2$. The relative close degree of design scheme to ideal scheme is determined by Equation (12), by which the schemes are sorted:

$$C_i=\frac{d_i^-}{d_i^-+d_i^+} \quad i=1,2,\cdots,m, \quad (12)$$

4 Design of scheme decision-making indicator system of product service system

Driving force of product design mainly comes from customer requirements, so to set up the indicator system for scheme decision-making, it is needed to carry out deep cognition, mining and use of customer requirements, and to consider customer demand during the establishment process of scheme decision-making indicator system.

4.1 CLASSIFICATION OF CUSTOMER REQUIREMENTS

Product service system is a new production systems formed in the paradigm that product manufacturers is responsible for whole life cycle, in which product and service are highly integrated, and overall optimized. Product service system development includes the involvement of manufacturers, suppliers, service providers and customers, thus forming the interests community by design personnel, marketing personnel, engineering and technical personnel, customers and other stakeholders as shown in Figure 2.

It can be seen from Figure 2, the manufacturers meet customer demands on product performance, technology by designers, the suppliers indirectly meet customer demands by machining parts for manufacturers, the operators meet customer demands through sales staff, and service providers meet customer demands by maintenance personnel and technical personnel.

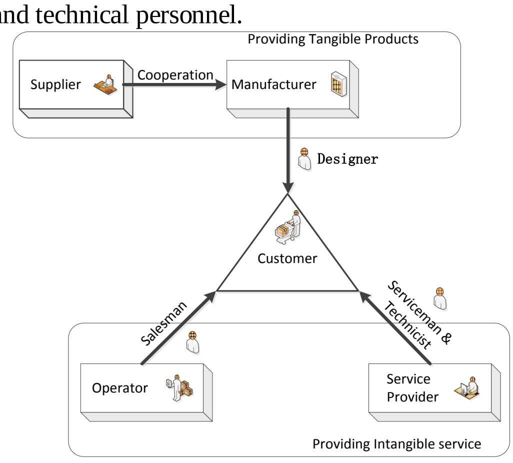

FIGURE 2 Stakeholders structure of product service system

Thus, to achieve customer requirements need the participation of multiple roles. Therefore, while analyzing customer requirements information, customer requirements can be classified from the viewpoint of different participants satisfying different needs, which can be divided into function requirements, form demand, price demand, service requirements as shown in Figure 3.

1) Function requirements. Function requirements are the most basic requirements while a customer consumes product or services. The function requirements are supplied by manufacturers and suppliers. Function requirements include two parts: dominant function requirements and auxiliary function requirements such as machining range of CNC machine tool, main parameters, reliability, flexibility, etc.

2) Form requirements. Form requirements are the customers' requirements on quality level of product material, appearance, and so on. Because the normal realization of product function depends on the performance of product form, the customer demands on product form is essentially an extension of function requirements. The form requirements are very important too, which are provided by manufacturer and suppliers. Form requirements mainly include the applicability of the products such as the effectiveness of CNC machine tools, the safety and the reliability of products in expected use time such as average trouble-free working time of machine tools, etc.

3) Price requirements. Price requirements are the requirements out of products, which play decisive role on the judgment of customer requirements. Only the product that customers can afford will meet customer requirements. The price requirements are offered by the operators, and include several aspects as price, cost performance, price elasticity, and so on.

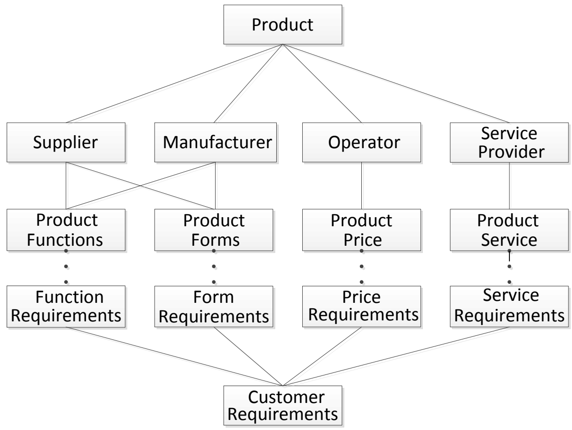

FIGURE 3 Classification of customer requirements

4) Service requirements. Service requirements refer to the additional requirements besides function requirements and form requirements, which are provided by service providers. For product service system, service requirements are the core part of customer requirements, and also the focus of enterprise competition. Today manufacturing industry becomes more and more servitization, and service competition has become the important content of enterprise competition.

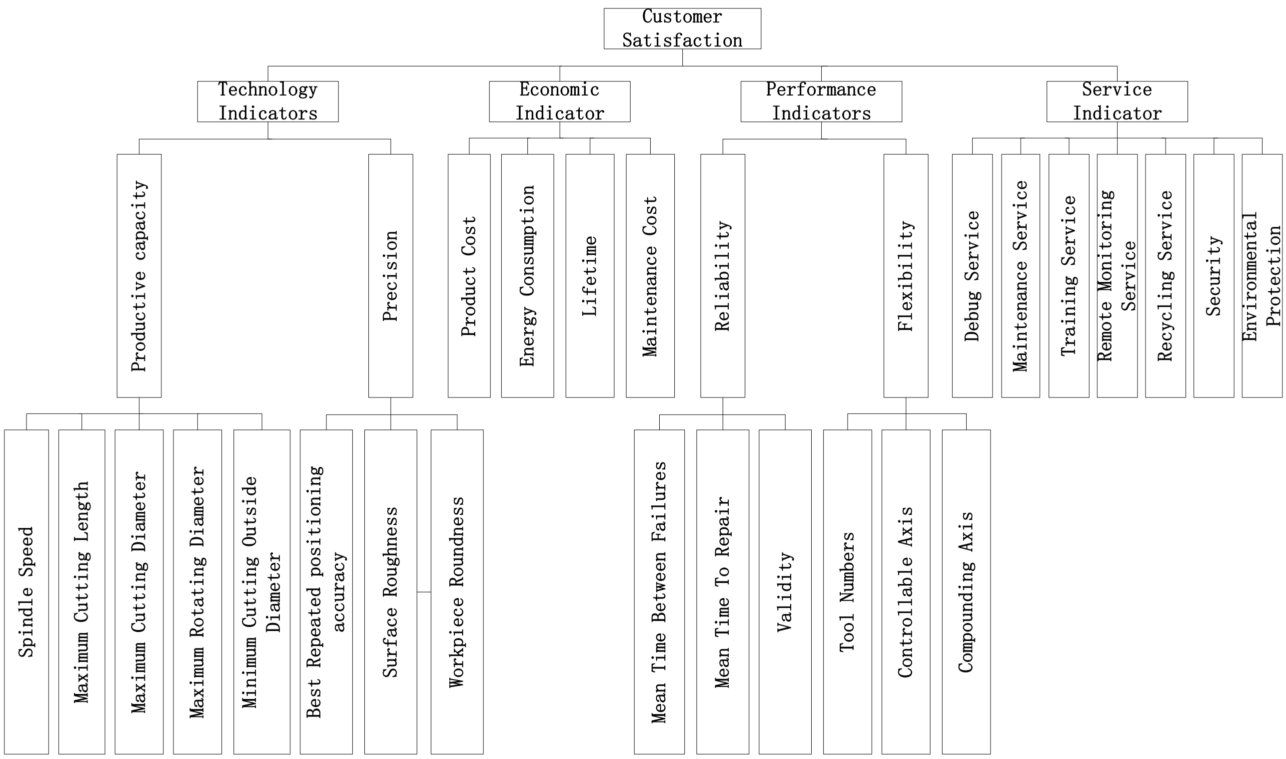

FIGURE 4 Decision-making indicator system of CNC machine tools product service system

4.2 ESTABLISHMENT OF SCHEME DECISION-MAKING INDICATOR SYSTEM OF PRODUCT SERVICE SYSTEM

Selecting CNC machine tools as an example, this paper establishes the scheme decision-making indicator system of CNC machine tool product service system after analyzing customer requirements information as shown in Figure 4. The evaluation indicators include four aspects, which are technology indicators, performance indicators and economic indicators and service indicators. Among them, technology indicators, performance indicators and economic indicators are quantitative indicators, and service indicators are qualitative indicators.

5 Case analysis

This paper selects ETC series CNC machine tools as the case to verify the practicability and validity of proposed method for scheme decision-making of product service system.

TABLE 2 Technology indicators

Indicator	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Spindle Speed/rpm	3500	3000	4500	4000
Maximum Cutting Length/mm	500	450	520	480
Maximum Cutting Diameter/mm	360	330	320	310
Maximum Rotating Diameter/mm	500	600	450	550
Minimum Cutting Outside Diameter/mm	10	15	15	20
Best Repeated positioning accuracy/mm	0.006	0.005	0.005	0.006
Surface Roughness/mm	0.8	1.6	3.2	1.6
Workpiece Roundness/mm	0.2	0.15	0.1	0.15

ETC series CNC machine tools are developed aiming at the customer requirements. This paper collects the scheme parameters of four kinds of ETC series CNC machine tools. The data of technology indicators, performance indicators and economic indicators is shown in Tables 2-4. Service indicators are qualitative indicators including maintenance service, training service, remote monitoring service, commissioning service, recycling service, security, environmental protection, and so on. Service indicators have no specific parameters, and are scored by several experts to get fuzzy judgment matrix.

TABLE 3 Performance indicators

Indicator	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Mean Time Between Failures/Hour	500	520	550	530
Mean Time To Repair/Hour	5.5	4.5	4	3.5
Validity	0.989	0.991	0.993	0.993
Tool Numbers	45	50	55	50
Controllable Axis	9	8	10	11
Compounding Axis	3	3	4	5

TABLE 4 Economic indicators

Indicator	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Product Cost/Ten thousand Yuan	20	25	28	27
Energy Consumption/KWH/year	8.5	9	9	8.8
Life Time/Year	4	4.5	5	4.5
Maintenance Cost/Ten thousand/year	1	0.8	1.2	1.5

5.1 ATTRIBUTE CLASSIFICATION OF EVALUATION INDICATORS

Fuzzy Kano model is used to classify the attributes of scheme evaluation indicators. The classification result is shown in Table 5, in which *R, A, E, I, Q* stand for required type, excited type, expected type, undifferentiated type and reversed type requirements respectively.. It can be seen that production capacity (a_1), flexibility (a_2), precision (a_4), reliability (a_{16}) belong to required type requirements, debugging service (a_3), maintenance service (a_6), remote monitoring service (a_8), recycling service (a_9), security (a_{10}) belong to excited type needs, maintenance cost (a_5) , product cost(a_7), energy consumption (a_{11}), and life (a_{14}) belong to expected type requirements.

TABLE 5 Attribute classification result of evaluation indicators while α=0.4

Indicator	*R*	*A*	*I*	*E*	*Q*	Category
a_1	46	18	14	25	0	*R*
a_2	48	22	10	19	0	*R*
a_3	20	45	12	16	0	*A*
a_4	49	20	10	14	0	*R*
a_5	14	22	15	44	0	*E*
a_6	22	39	18	16	0	*A*
a_7	25	22	12	42	0	*E*
a_8	11	46	8	11	0	*A*
a_9	13	49	22	9	0	*A*
a_{10}	11	50	10	8	0	*A*
a_{11}	10	4	8	46	0	*E*
a_{12}	24	54	4	12	0	*A*
a_{13}	22	47	12	17	0	*A*
a_{14}	19	21	11	38	0	*E*
a_{15}	12	46	8	12	0	*A*
a_{16}	56	11	23	12	0	*R*

5.2 DETERMINE THE WEIGHTS OF EVALUATION INDICATORS

AHP-entropy method is used to calculate the final weights of quantitative indicators. By entropy weight method and AHP the final results of indicators weights are calculated by Equation (1).

Technology indicators:

ω = (0.2378, 0.1715, 0.0811, 0.0565, 0.1049, 0.1965, 0.0616, 0.0902)

Performance indicators:

ω = (0.3427, 0.1015, 0.2239, 0.1860, 0.0941, 0.0518)

Economic indicators:

ω = (0.4570, 0.1417,0.2253, 0.1760)

Triangular fuzzy number AHP is applied to evaluate services indicators. Using Equation (3) the weight vector is calculated: [(0.306, 0.359, 0.306), (0.201, 0.240, 0.201), (0.136, 0.158, 0.136), (0.101, 0.113, 0.101), (0.051, 0.058, 0.051), (0.037, 0.041, 0.037), (0.028, 0.031, 0.034)]. By formula (4) the fuzzy relative weight vector is calculated to get anti fuzzy weight vector to get the final result is: ω=(0.363, 0.240, 0.159, 0.363, 0.240, 0.041, 0.031).

TABLE 6 Expert evaluation indicators and values

Indicators	Value			
	Scheme 1	Scheme 2	Scheme 3	Scheme 4
D_1	(0.9,1,1) (0.6,0.7,0.8) (0.4,0.5,0.6)	(0.6,0.7,0.8) (0.6,0.7,0.8) (0.6,0.7,0.8)	(0.9,1,1) (0.9,1,1) (0.9,1,1)	(0.9,1,1) (0.9,1,1) (0.6,0.7,0.8)
D_2	(0.9,1,1) (0.9,1,1) (0.6,0.7,0.8)	(0.6,0.7,0.8) (0.4,0.5,0.6) (0,0.2,0.3)	(0.9,1,1) (0.9,1,1) (0.6,0.7,0.8)	(0.9,1,1) (0.6,0.7,0.8) (0.6,0.7,0.8)
…	…	…	…	…
D_8	(0.6,0.7,0.8) (0.6,0.7,0.8) (0.6,0.7,0.8)	(0.9,1,1) (0.6,0.7,0.8) (0.4,0.5,0.6)	(0.9,1,1) (0.9,1,1) (0.6,0.7,0.8)	(0.9,1,1) (0.6,0.7,0.8) (0.4,0.5,0.6)

5.3 SCHEME RANK BY IMPROVED TOPSIS METHOD

According to the weights of scheme evaluation indicators for CNC machine tools product service system, four alternative schemes are sorted as follows.

According to the evaluation values given by experts on each scheme, the evaluation matrix is got. This paper asks three experts to evaluate four schemes of CNC machine tools product service system by language variables evaluation sets. The language variable evaluation set is [good (G), relative good (N), general (F), relative poor (Q), poor (V)], and corresponding triangular fuzzy numbers of elements are G = (0.9, 1, 1), N = (0.6, 0.7, 0.6), F = (0.4, 0.5, 0.4), Q = (0,0.2, 0.3), V = (0,0,0.2). Convert the language evaluation given by experts on each scheme into evaluation value as list in Table 6.

While calculating the distance from alternative scheme to positive ideal point as well as to negative ideal point, performance indicators are required type attributes, so α=2; economic indicators are expected type attributes, so α=1; services indicators are excited attributes, so α=0.5. The overall evaluation value of each scheme can be got by weighting synthesis of 4 kinds of indicators. The weight distribution of technology indicators, economic index, performance index and service index is (0.24, 0.14, 0.07, 0.24), according to which the relative close degree is weighted calculated. The final results of the distances from four schemes to positive ideal point as well as to negative ideal point are as shown in Table 7 and Figure 5.

TABLE 7 Distance and relative close degree of alternative scheme

Scheme	Distance to positive ideal point	Distance to negative ideal point	Relative close degree	Rank
Scheme1	0.370336	0.45784	0.5489	3
Scheme2	0.378422	0.499616	0.5113	4
Scheme3	0.279181	0.599777	0.6842	2
Scheme4	0.227316	0.639081	0.7417	1

5.4 DECISION-MAKING RESULTS ANALYSIS

Use AHP-entropy method to calculate final weights of quantitative indicators. By the calculation result, it can be known that spindle speed, product cost, life time, average trouble-free working time, debugging service, and maintenance service has more weight in indicator system, which shows that these indicators are important for whole evaluation system and can be focused in the future to improve scheme.

When determining the weights, traditional decision-making method usually treats whole evaluation indicator system as a whole. When the evaluation indicator system is very complex, it makes the weight of each indicator too small to reflect the differences between indicators, which will affect the ranking results of TOPSIS. For product service system of CNC machine tool, the scheme evaluation objects have complex structure with more levels. So when using TOPSIS method for ranking, firstly the relative close degree values of four kinds of indicators are calculated separately, then relative close degree value of the final scheme is obtained by weighted calculated, which can reflect actual solution than traditional method.

Final ranking results are as follows: scheme 4 is optimal, and scheme 2 is the worst, followed by scheme 3, and scheme 1. In Fig. 5, the black bar corresponds to the distance to positive ideal point, which should be as small as possible, and the gray bar corresponds to the distance to negative ideal point, which should be as big as possible. It can be seen from Fig. 5, the order of four schemes is 2<1<3<4. The distance from alternative scheme to positive ideal point distance is becoming smaller and smaller, and the distance from alternative scheme to negative ideal point distance is bigger and bigger. This is completely in line with the principle of TOPSIS: the evaluation scheme that is the most close to positive ideal solution and at the same time away from negative ideal solution is the optimal scheme, otherwise it is the worst scheme.

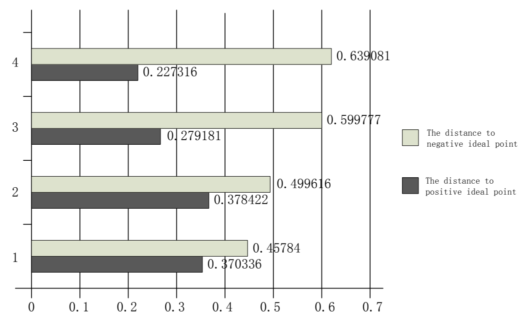

FIGURE 5 Distance between alternative scheme and ideal point

6 Conclusions

Scheme decision-making is a key process in conceptual design of product service system and directly determines the success or failure of product service system development. On the basis of related decision-making methods at home and abroad, this paper selected the scheme decision-making of CNC machine tools product service system as research object, put forward improved

TOPSIS decision-making method based on fuzzy Kano model, and implemented the scheme decision-making process of product service system.

Analysis on the case of CNC machine tools showed that proposed decision-making method has good versatility, high maneuverability, and can solve the multiple-objective, multiple-attribute, complex and multiple scheme decision-making problems well. Through improved TOPSIS method, this paper solved the complexity problem of scheme indicator attributes well. Indicator attribute α was introduced into the distance formula and the influence of customer satisfaction on scheme decision-making result was considered, which made the results more close to the objective fact and improved the efficiency and success rate of product service system conceptual design.

Acknowledgement

This work is supported by the Fundamental Research Funds for the Central Universities (N120403003), the Science and Technology Funds of Liaoning Province (2013020052, 2011216010) and the Research Funds of State "Twelve Five" Support Program (2012BAF12B08).

References

[1] Yeo S H, Mak M W, Balon S A P 2004 Analysis of decision-making methodologies for desirability score of conceptual design *Journal of Engineering Design* **15**(2) 195-208

[2] Sun J, Kalenchuk D K, Xue D, Gu P 2000 Design candidate identification using neural network-based fuzzy reasoning [J], Robotics and Computer Integrated Manufacturing **16**(5) 383-96

[3] Tang D, Wong T C, Chin K S, Kwong C K 2014 Evaluation of user satisfaction using evidential reasoning-based methodology *Neurocomputing* **142**(22) 86-94

[4] Ye W, Dai Y, Wang Y 2002 Fuzzy Judgment Based Product Scheme Integrated Decision-Making *Journal of Nanjing University of Aeronautics & Astronautics* **34**(2) 134-8

[5] Wang H, Yang T, Shang J 2001 Research on the methods of product design quality fuzzy evaluation and project decision *Journal of Northwest Sci-Tech University of Agriculture and Forestry* **29**(6) 104-7

[6] Chiou H, Tzeng G, Cheng D 2005 Evaluating sustainable fishing development strategies using fuzzy MCDM approach *Omega* **33**(11) 223-34

[7] Hwang C, Yoon K 1981 Multiple attribute decision-making methods and applications: A state-of-the-art survey Springer **15**(3) 86-9

[8] Lennon E, Farr J, Besser R 2013 Evaluation of multi-attribute decision making systems applied during the concept design of new microplasma devices *Expert Systems with Applications* **40**(16) 6321-9

[9] Gu Y, Yang Z 2007 Fuzzy multi-criteria decision-making model for conceptual design candidates evaluation [J]. Computer Integrated Manufacturing Systems **13**(8) 1504-10

[10] Zhang Z, Chu X 2009 A new integrated decision-making approach for design alternative selection for supporting complex product development *International Journal of Computer Integrated Manufacturing* **22**(3) 179-98

Authors

Zhongqi Sheng, May 1972, Shandong, P.R. China

Current position, grades: faculty member in Northeastern University.
University studies: PhD in mechanical manufacturing and automation (2003) from Northeastern University, P.R. China.
Scientific interests: modern design theory and methods, computer aided design, mechanical manufacturing and automation.

Yazi Wang, November 22, 1990, Shanxi, P.R. China

Current position, grades: graduate student at school of mechanical engineering and automation in Northeastern University, P.R. China.
University studies: B.Eng. in material shaping and control engineering (2013) from Dalian Polytechnic University.
Scientific interests: product service system development, computer aided design.

Shujian Zhang, November 17, 1988, Liaoning, P.R. China

Current position, grades: graduate student at school of mechanical engineering and automation in Northeastern University, P.R. China.
University studies: B.Eng. in industrial engineering (2012) from Shenyang University of Technology.
Scientific interests: mechanical manufacturing and automation, modern design theory and methods.