Decision-making of product-service system solution selection based on integrated weight and technique for order preference by similarity to an ideal solution

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Abstract: Product-service system (PSS) solution selection is of great significance to better meet the personalised needs of customers and ensure the subsequent implementation. The problems of incomplete index system, difficulty to obtain the value of the qualitative index and unreasonable single index weighting have a significant impact on the decision-making of PSS solution selection. In response to these problems, a decision-making framework of PSS solution selection is constructed. A comprehensive index system is established from the perspectives of multiple stakeholders. Expert evaluating with the fuzzy number and multi-expert evaluation opinion combination is adopted for index value solving. Integration of objective and subjective weights is achieved based on the multi-weight information consistency model and the candidate PSS solutions are ranked by technique for order preference by similarity to an ideal solution finally. An application case of automobile PSS solution selection is given to verify the effectiveness and rationality of the constructed decision-making framework.

Nomenclature

\( \hat{\phi} \quad \) a triangle fuzzy number
\( \hat{\phi} \quad \) corresponding non-fuzzy number of \( \hat{\phi} \)
\( m \quad \) expert quantity
\( n \quad \) candidate PSS solution quantity
\( h \quad \) index quantity
\( i \quad \) expert label, \( i = 1,2,\ldots,m \)
\( j \quad \) candidate PSS solution label, \( j = 1,2,\ldots,n \)
\( k \quad \) index label, \( k = 1,2,\ldots,h \)
\( \hat{\phi}_{ijk} \quad \) triangular fuzzy number form semantic variable of solution \( j \) on index \( k \) evaluated by expert \( i \)
\( \tilde{\phi}_{jk} \quad \) triangular fuzzy number form group decision value of PSS solution \( j \) on index \( k \)
\( x_{jk} \quad \) index value in non-fuzzy number form of PSS solution \( j \) on index \( k \)
\( X \quad \) index value matrix of \( n \) PSS solutions on \( h \) indexes
\( \omega' \quad \) objective weight vector
\( \omega'' \quad \) subjective weight vector
\( \omega'_k \quad \) objective weight value of index \( k \)
\( \omega''_k \quad \) subjective weight value of index \( k \)
\( \omega \quad \) integrated weight vector
\( \omega_k \quad \) integrated weight value of index \( k \)
\( \alpha \quad \) objective weight coefficient
\( \alpha_k \quad \) subjective weight coefficient
\( y_{jk} \quad \) weighted index value of PSS solution \( j \) on index \( k \)
\( Y \quad \) weighted index value matrix
\( Y^+ \quad \) positive ideal point
\( Y^- \quad \) negative ideal point
\( \delta^+ \quad \) Euclidean distance between PSS solution \( j \) and positive ideal point \( Y^+ \)
\( \delta^- \quad \) Euclidean distance between PSS solution \( j \) and negative ideal point \( Y^- \)
\( p \quad \) relative proximity from PSS solution \( j \) to ideal points

1 Introduction

Under the service-oriented manufacturing mode, the integration of services and products promotes the value-added of all stakeholders in the manufacturing value chain. Services are no longer attached to products. To a great extent, the service of products determines the value of products in the market and gradually becomes an important factor for enterprises to expand market space and play their core competitiveness. In this context, an integrated solution, product-service system (PSS), has been developed for manufacturing enterprises to provide users with personalised products and services. Through the integration of tangible products and intangible services, PSS provides enterprises with an overall solution to create high value-added products [1–3]. However, in the design process of PSS, due to the fuzziness of customer demand and the understanding deviation of the designer to customer demand, there are multiple candidate PSS solutions. The quality of the PSS solution is directly related to customer satisfaction. In order to better meet the personalised needs of customers, ensure the successful future implementation of PSS solution and improve the market share of enterprises; evaluation and selection of multiple candidate PSS solutions is particularly important.

The decision-making problem of candidate PSS solution evaluation and selection is essentially a multi-criteria decision-making (MCDM) process in an uncertain environment [4–6]. In MCDM, the selection of the evaluation index and the determination of index weight directly affect the result of decision-making. At present, scholars have done some research on the index system establishment and the index weight determination of PSS solution evaluation and selection.

In terms of index system establishment, Yoon et al. [7] established the evaluation index of the PSS scheme from the perspective of suppliers and customers. Chou et al. [8] proposed a multi-standard hierarchy evaluation model of sustainable product-service efficiency based on the perspective of customers and enterprises. These studies only consider one or two aspects of the index system establishment, which is not comprehensive.
In terms of index weight determination, to improve the objectivity and effectiveness of concept evaluation in the early phases of PSS concept design in a fuzzy-stochastic environment, Chen et al. [9] developed a new evaluation approach integrating information axiom and the theory of fuzzy random variable. Bertoni [10] investigates how MCDM models shall be applied to select PSS concepts from a value perspective, by considering sustainability as one of the attributes of a design contributing to the overall value of a solution. Aimed at controlling the risk and uncertainty existing in the process of PSS design concepts selection, Xiao and Geng [11] proposed an extended technique for order preference by similarity to an ideal solution (TOPSIS) approach combined with cumulative prospect theory to evaluate the PSS design concepts. Considering customer requirements to determine the concept evaluation criteria weights, Geng and Qiu [12] proposed a group decision-making method of design concept based on hesitant fuzzy PROMETHEE II. To solve the optimal selection problems of PPS design scheme, An et al. [13] proposed a novel integrated evaluation method under uncertain circumstances, which consisted of multi-attribute variable granule weight and group decision-making. Aiming at most of the traditional evaluation methods do not consider the randomness of the evaluation information, Dong et al. [14] proposed the concept evaluation approach based on grey incidence analysis and cloud model. The methods to determine the weight mainly include a subjective method and objective method. The former [9–11] considers more knowledge experience and preference of decision-makers, which is too subjective. To some extent, the latter [12–14] can make up for the deficiency of subjective empowerment, but it only considers the differences between the index and ignores the correlation between evaluation indexes.

Furthermore, the premise of weight integration is to obtain multiple weights. The main methods to obtain the weight are entropy weight method, coefficient of variation method, analytic hierarchy process (AHP) method etc. [15–19]. Among them, AHP can form a clear hierarchical structure of the components of complex problems according to the dominant relationship, and test the consistency of results. Therefore, it is widely used in the subjective weighting of the MCDM problem. However, there is a general correlation and dependence among the indexes of PSS solution selection. Therefore, AHP is not suitable for solving the index weight of PSS solution selection. Analytic network process (ANP) [20–23] divides the system elements into two parts: control layer and network layer. As the internal structure of the network layer is interactive, ANP can solve the index weight problems. In multi-index comprehensive decision-making, TOPSIS is a classical ranking method and is widely applied in many fields [24–26].

In addition, using the experience and wisdom of multiple experts to assess the performance of candidate PSS solution on any index is a convenient way to obtain the index value. However, due to the fuzziness of thinking and the uncertainty of language in practical decision-making, the comparison of evaluation grades by experts often has some fuzziness. It is unreasonable to express the expert's evaluation opinion with an accurate number.

Thus, this paper investigates several crucial research questions, which are listed as follows. (i) How to establish a comprehensive index system for PSS solution evaluation and selection? (ii) How to express the fuzziness of expert's evaluation opinion and combine the evaluation opinion of multiple experts? (iii) How to integrate the two types of index weight and take advantage of them?

In order to answer the above research questions, we propose a new decision-making methodology of PSS solution selection. In the proposed methodology, the indexes in above-mentioned researches are summarised, screened and expanded, and the evaluation index system of PSS solution selection is established from the perspective of multiple stakeholders. Expert's evaluation opinion is expressed in fuzzy number form to deal with its fuzziness. Due to the existence of relationship among indexes, ANP method is adopted for subjective weight solving. Then the index weight integrating subjective and objective weight is determined by multi-weight information consistency model. At last, TOPSIS is using to rank multiple PSS solutions according to their weighted index values and the optimal PSS solution is selected.

The rest of this paper is organised as follows. Section 2 introduces the decision-making framework of PSS solution selection. Section 3 defines and gives the details of key enabling technologies, including the establishment of evaluation index system from the perspectives of multiple stakeholders, semantic evaluation fuzzy processing of index value, determination of integrated weight and ranking the candidate PSS solutions by TOPSIS. Section 4 gives an application case to verify the feasibility of the proposed decision-making framework. Section 5 discusses the effectiveness of semantic evaluation fuzzy processing and the rationality of integrated weight compared with a single weight. Section 6 provides some concluding remarks.

2 Decision-making framework of PPS solution selection

PSS solution design is a process of obtaining several feasible candidate solutions after considering the needs of multi-stakeholders and through the requirement mapping and solution configuration. The decision-making of PPS solution selection is an important part of PSS design and development. The purpose of PPS solution selection is to select the best solution to meet the needs of multi-stakeholders to the greatest extent. The overall decision-making framework is shown in Fig. 1.

There are four layers in the framework built by us. The first layer is the candidate solution layer which contains all feasible solutions. The second layer is the index system layer. It is started from multi-stakeholders involved in the PSS solution design. From the aspects of customers, enterprises, suppliers, society and environment, the structure of the index system is determined from the perspectives of different stakeholders. On this basis, with reference to a large number of literatures, some commonly used PSS solution selection indexes are finally summarised selectively, and these indexes are classified and applied to the built index system. The third and fourth layers are the approach and the decision-making result layer, respectively. These two layers contain the key enabling technologies which will be given in detail in the following.

3 Key enabling technologies

3.1 Index system establishment

With the comprehensive consideration of opinions of multiparty experts, such as customer demand analysts, senior entrepreneurs, senior social and environmental researchers and PSS solution design engineers, the detailed indexes are appropriately deleted, added and merged. As a result, the index system is established from the perspectives of multiple stakeholders as shown in Fig. 2. There are $h$ ($h = 19$) indexes.

The meaning of the index symbol is shown in Table 1.
Table 2  Meaning of index symbol

| Stakeholders | Index symbol | Index meaning |
|--------------|--------------|---------------|
| customer     | $l_1$        | customer expectation |
|              | $l_2$        | customer acceptance |
|              | $l_3$        | system convenience |
|              | $l_4$        | service quality |
|              | $l_5$        | product quality |
| business     | $l_6$        | employment opportunities provided |
|              | $l_7$        | profit ability |
|              | $l_8$        | working environment of employees |
|              | $l_9$        | service cost of providing PSS |
| vendor       | $l_{10}$     | service positioning |
|              | $l_{11}$     | market size |
|              | $l_{12}$     | investment cost |
|              | $l_{13}$     | relationship with competitors |
| society      | $l_{14}$     | government financial support |
|              | $l_{15}$     | government laws and regulations |
|              | $l_{16}$     | user health and safety assurance |
| environment  | $l_{17}$     | CO$_2$ emissions |
|              | $l_{18}$     | harmful substance emissions |
|              | $l_{19}$     | resource consumption |

3.2 Semantic evaluation fuzzy processing

Triangular fuzzy number is used to process the expert semantic evaluation information, and the index value is obtained by calculating the semantic evaluation information. Each triangle fuzzy number corresponds to a non-fuzzy number. It is assumed that $\hat{\varphi} = (a, b, c)$ is a triangle fuzzy number, $a \leq b \leq c$ and $0 \leq a, b, c \leq 1$. Its corresponding non-fuzzy number is as follows:

$$\varphi = \frac{a + 2b + c}{4} \quad (1)$$

Take the commonly used five-level semantic evaluation variables as an example, the transformation relationship between semantic evaluation variables and triangular fuzzy numbers is shown in Table 2.

Assuming that $m$ experts evaluate $n$ candidate PSS solutions, expert $i$ ($i = 1, 2, \ldots, m$) evaluates the performance of PSS solution $j$ ($j = 1, 2, \ldots, n$) on index $k$ ($k = 1, 2, \ldots, h$), and the semantic variable in triangular fuzzy number form is expressed as $\hat{\varphi}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$.

The group decision value of all experts is calculated by the arithmetic average method and the fuzzy evaluation value of PSS solution $j$ on index $k$ is obtained as follows:

$$\tilde{\varphi}_{jk} \approx \left( \frac{\sum_{i=1}^{m} a_{ijk}}{m}, \frac{\sum_{i=1}^{m} b_{ijk}}{m}, \frac{\sum_{i=1}^{m} c_{ijk}}{m} \right) \quad (2)$$

Then the index value in non-fuzzy number form of PSS solution $j$ on index $k$ can be obtained as $x_{jk}$ by (1). Finally, we can obtain the index value matrix of $n$ PSS solutions on $h$ indexes as $X = \{x_{jk}\}_{n \times h}$.

3.3 Integrated weight determination

The objective weight comes from the actual index value of the evaluation object set, which is the representation of the inherent relationship between the index values of each evaluation object. The subjective weight comes from the artificial evaluation of the influence degree of each index on the total evaluation target, which can make full use of the experience and wisdom of the decision-maker, but it is greatly influenced by the subjective factors of the decision-maker. The integrated weighting method not only considers the objective difference of index data but also considers the subjective preference of decision-makers, which can reduce the information loss of individual weighting to a certain extent.

Using the objective weighting method, such as entropy method, coefficient of variation method or criteria importance through intercriteria correlation method [24], we can obtain the objective weight vector which is assumed as $\omega = [\omega_{1}, \omega_{2}, \ldots, \omega_{h}]^{T}$.

Meanwhile, we can obtain the subjective weight vector $\omega^{''} = [\omega_{1}^{''}, \omega_{2}^{''}, \ldots, \omega_{h}^{''}]^{T}$ by ANP method [27]. Here, $\omega_{i}$ and $\omega_{i}^{''}$ are the objective and subjective weight values of index $i$.

It is assumed that the integrated weight vector is $\omega = [\omega_{1}, \omega_{2}, \ldots, \omega_{h}]^{T}$, $\omega$ is calculated as follows:

$$\omega = \alpha_{1}\omega' + \alpha_{2}\omega^{''} \quad (3)$$

where $\alpha_{1}$ is the objective weight coefficient and $\alpha_{2}$ is the subjective weight coefficient, $\alpha_{1} + \alpha_{2} = 1$ and $0 \leq \alpha_{1}, \alpha_{2} \leq 1$.

Aiming at the consistency of multi-weight information, a mathematical model is established as follows:

$$\min \sum_{j=1}^{h} \sum_{k=1}^{n} (\alpha_{1}\omega'_{j}x_{jk} - \alpha_{2}\omega^{''}_{j}x_{jk})^2$$

s.t. $\alpha_{1} + \alpha_{2} = 1, 0 \leq \alpha_{1}, \alpha_{2} \leq 1 \quad (4)$

The values of $\alpha_{1}, \alpha_{2}$ can be solved as follows:

$$\alpha_{1} = \frac{\sum_{j=1}^{n} \sum_{k=1}^{n} (\omega'_{j} + \omega^{''}_{j})^2 (x_{jk})^2}{\sum_{j=1}^{n} \sum_{k=1}^{n} (\omega_{j} + \omega_{j}^{''})^2 (x_{jk})^2}$$

$$\alpha_{2} = \frac{\sum_{j=1}^{n} \sum_{k=1}^{n} (\omega_{j} + \omega_{j}^{''})^2 (x_{jk})^2}{\sum_{j=1}^{n} \sum_{k=1}^{n} (\omega_{j} + \omega_{j}^{''})^2 (x_{jk})^2} \quad (5)$$

Therefore, the integrated weight vector $\omega = [\omega_{1}, \omega_{2}, \ldots, \omega_{h}]^{T}$ is obtained.

3.4 PSS solution selection

In a limited number of evaluation objects, a group of optimal index values and a group of the worst index values are taken as a positive ideal point and negative ideal point. Then the Euclidean distances
between the evaluation object and two ideal points are calculated, respectively. By solving the relative proximity from evaluation object to ideal points, the evaluation objects are sorted and the optimal object is selected. The above process is the basic principle of TOPSIS.

According to the integrated weight vector $\omega$ and the index value matrix $X = [x_{jk}]_{n \times k}$, we can obtain the weighted index value matrix $Y = [y_{jk}]_{n \times k}$. Here, $\omega_k$ is the integrated weight value of index $k$. The positive ideal point $Y^+$ and negative ideal point $Y^-$ are obtained as follows:

$$
Y^+ = \{y_1^+, y_2^+, \ldots, y_n^+\}
$$

$$
Y^- = \{y_1^-, y_2^-, \ldots, y_n^-\}
$$

where $y_n^+ = \max\{y_{jk}^+, y_{jk}^+, \ldots, y_{jk}^+\}$ and $y_n^- = \min\{y_{jk}^-, y_{jk}^-, \ldots, y_{jk}^-\}$.

Therefore, the Euclidean distance $D^{j+}$ between PSS solution $j$ and positive ideal point $Y^+$ and the Euclidean distance $D^{j-}$ between PSS solution $j$ and negative ideal point $Y^-$ are given as follows:

$$
D^{j+} = \left( \sum_{k=1}^{k} (y_{jk}^+ - y_{jk}^+)^2 \right)^{\frac{1}{2}}
$$

$$
D^{j-} = \left( \sum_{k=1}^{k} (y_{jk}^- - y_{jk}^-)^2 \right)^{\frac{1}{2}}
$$

The relative proximity $P^j$ from PSS solution $j$ to ideal points is obtained as follows:

$$
P^j = \frac{D^{j-}}{D^{j+} + D^{j-}}
$$

At last, all PSS solutions are listed by the descending order of relative proximity value and the PSS solution with the largest relative proximity value will be selected as the optimal one.

### 4 Case study

At present, with the increasingly fierce competition in the automobile market, the major automobile manufacturers pay more and more attention to the decision-making of automobile PSS solution selection. After analysing the historical sales data, configuration files, customer files and other documents of a company's automobile product service, we have found that the product service provided by the company mainly include the whole automobile and its various accessories, covering more than ten automobile service fields, such as repair, navigation, beautification, decoration, renovation, claim settlement, club establishment etc. During the research and development process of designing the new automobile PSS, the automobile company has determined five candidate PSS solutions. The method proposed by us will be used for decision-making of PSS solution selection.

As decision-making of PSS solution selection involves many stakeholders, we select ten customer demand analysts, ten senior social and environmental researchers and ten PSS solution design engineers to form an expert group. In total, 40 experts evaluate the company's candidate PSS solutions semantically. For example, on index $I_1$, five experts think the performance of PSS solution 1 is 'very bad', 17 experts think the performance of PSS solution 1 is 'bad', 9 experts think the performance of PSS solution 1 is 'middle', five experts think the performance of PSS solution 1 is 'good' and four experts think the performance of PSS solution 1 is 'very good'. Expert group's semantic evaluation result of the performance of PSS solution 1 on each index is shown in Table 3.

| Index | Semantic evaluation: 'very bad' | Semantic evaluation: 'bad' | Semantic evaluation: 'middle' | Semantic evaluation: 'good' | Semantic evaluation: 'very good' |
|-------|---------------------------------|-----------------------------|-------------------------------|-----------------------------|---------------------------------|
| $I_1$ | 5                               | 17                          | 9                            | 5                           | 4                               |
| $I_2$ | 0                               | 12                          | 6                            | 4                           | 18                              |
| $I_3$ | 7                               | 5                           | 7                            | 12                          | 9                               |
| $I_4$ | 7                               | 3                           | 13                           | 0                           | 17                              |
| $I_5$ | 3                               | 14                          | 4                            | 18                          | 1                               |
| $I_6$ | 6                               | 3                           | 22                           | 5                           | 4                               |
| $I_7$ | 3                               | 14                          | 4                            | 18                          | 1                               |
| $I_8$ | 0                               | 3                           | 26                           | 9                           | 2                               |
| $I_9$ | 3                               | 12                          | 18                           | 1                           | 6                               |
| $I_{10}$ | 11                          | 6                           | 15                           | 2                           | 6                               |
| $I_{11}$ | 5                            | 0                           | 1                            | 2                           | 32                              |
| $I_{12}$ | 5                            | 17                          | 0                            | 13                          | 5                               |
| $I_{13}$ | 14                          | 6                           | 4                            | 10                          | 6                               |
| $I_{14}$ | 3                            | 1                           | 4                            | 6                           | 26                              |
| $I_{15}$ | 2                            | 5                           | 1                            | 6                           | 26                              |
| $I_{16}$ | 20                          | 18                          | 0                            | 0                           | 2                               |
| $I_{17}$ | 4                            | 9                           | 0                            | 22                          | 5                               |
| $I_{18}$ | 10                          | 5                           | 17                           | 7                           | 1                               |
| $I_{19}$ | 4                            | 0                           | 33                           | 1                           | 2                               |
Based on the multi-weight information consistency model shown by (4), the weight coefficients are solved as \( \omega = [0.0521, 0.0635, 0.0308, 0.0693, 0.0655, 0.0570, 0.0735, 0.0526, 0.0557, 0.0493, 0.0567, 0.0648, 0.0306, 0.0316, 0.0527, 0.0482, 0.0478, 0.0648, 0.0336] \) by (3).

Therefore, the weighted index value matrix \( Y = [y_{ik} \times \omega] \) can be obtained. According to \( Y = [y_{ik} \times \omega] \), the positive ideal point is obtained as \( Y^+ = [0.0638, 0.0458, 0.0075, 0.0527, 0.0564, 0.0430, 0.0435, 0.0463, 0.0201, 0.0361, 0.0198, 0.0390, 0.0080, 0.0256, 0.0110, 0.0123, 0.0479, 0.0358, 0.0253] \) and the negative ideal point is obtained as \( Y^- = [0.0308, 0.0297, 0.0055, 0.0331, 0.0267, 0.0232, 0.0327, 0.0220, 0.0129, 0.0361, 0.0198, 0.0390, 0.0080, 0.0256, 0.0110, 0.0123, 0.0479, 0.0358, 0.0253] \).

### Table 4  Index values in triangular fuzzy number form and non-fuzzy form of PSS solution 1

| Index | Index value in triangular fuzzy number form | Index value in non-fuzzy form |
|-------|-------------------------------------------|-----------------------------|
| \( l_1 \) | (0.2000, 0.4275, 0.6200) | 0.4188 |
| \( l_2 \) | (0.4100, 0.6850, 0.7950) | 0.6437 |
| \( l_3 \) | (0.3600, 0.5600, 0.7325) | 0.5531 |
| \( l_4 \) | (0.3950, 0.6100, 0.7425) | 0.5894 |
| \( l_5 \) | (0.2875, 0.5350, 0.6875) | 0.5112 |
| \( l_6 \) | (0.2975, 0.4850, 0.6800) | 0.4869 |
| \( l_7 \) | (0.2725, 0.4950, 0.6975) | 0.4900 |
| \( l_8 \) | (0.3425, 0.5550, 0.7450) | 0.5494 |
| \( l_9 \) | (0.2525, 0.4825, 0.6600) | 0.4694 |
| \( l_{10} \) | (0.2425, 0.4175, 0.6150) | 0.4231 |
| \( l_{11} \) | (0.5925, 0.8475, 0.9000) | 0.7969 |
| \( l_{12} \) | (0.2500, 0.4800, 0.6675) | 0.4694 |
| \( l_{13} \) | (0.2600, 0.4200, 0.6250) | 0.4313 |
| \( l_{14} \) | (0.5600, 0.8125, 0.8900) | 0.7688 |
| \( l_{15} \) | (0.5375, 0.8050, 0.8800) | 0.7569 |
| \( l_{16} \) | (0.0350, 0.1850, 0.4250) | 0.2075 |
| \( l_{17} \) | (0.3625, 0.5775, 0.7625) | 0.5700 |
| \( l_{18} \) | (0.2325, 0.3975, 0.6175) | 0.4112 |
| \( l_{19} \) | (0.2950, 0.4800, 0.6800) | 0.4837 |

5.2 Rationality of integrated weight compared with single weight

Based on the non-fuzzy index value solved by semantic evaluation fuzzy processing, the relative proximity values of five PSS solutions using objective weight \( \omega' \) is obtained as 0.6013, 0.4962, 0.3856, 0.5518 and 0.6509, and the relative proximity values of five PSS solutions using subjective weight \( \omega' \) is obtained as 0.4533, 0.5675, 0.3071, 0.6309 and 0.7066.

5. Discussion

5.1 Effectiveness of semantic evaluation fuzzy processing

In order to clarify the effectiveness of the semantic evaluation fuzzy processing method, the decision-making result through accurate scoring of the expert group is compared with the decision-making result through the proposed semantic evaluation fuzzy processing method.

Since the membership degree of triangular fuzzy number \( \bar{\phi} = (a, b, c) \) is the largest at \( b \), the \( b \) value of the fuzzy evaluation value in Table 3 is directly taken as the accurate scoring result of the expert group. Based on the data, using the integrated weighting method and TOPSIS, the relative proximity values of five PSS solutions is solved and listed as 0.5106, 0.5233, 0.4525, 0.3978 and 0.5972. By the descending order of relative proximity value, the ranking result of all the PSS solutions is PSS solution 5 > PSS solution 2 > PSS solution 1 > PSS solution 4 > PSS solution 3. The comparison of semantic evaluation fuzzy processing and accurate scoring is shown in Fig. 3.

As shown in Fig. 3, the results of the two methods are slightly different. Among them, the ranking results of PSS solution 5, PSS solution 2 and PSS solution 1 are the same, but the ranking results of PSS solution 3 and PSS solution 4 are different. The main reason for this difference is that most of the indexes in the index system shown in Fig. 2 in the evaluation index system are qualitative and unquantifiable, such as system convenience (1), employment opportunities provided (8), service positioning (10), relationship with competitors (15), government laws and regulations (15) etc. The error of accurate scoring method is large, and it cannot really reflect the evaluation intention of the expert group. The semantic evaluation fuzzy processing adopted by us reflects the fuzzy information of the expert group in the process of PSS solution selection decision-making to the evaluation results, which remedies the problem of large error in the accurate scoring and better expresses the evaluation intention of the expert group. As a result, it is more accordant with the actual decision-making environment.
government financial support ($I_4$), customer expectation ($I_1$) and resource consumption ($I_9$) have relatively smaller weight values, all <0.0400 (0.0328, 0.0330, 0.0332 and 0.0341, respectively). Here, the objective weight value is obtained by the entropy method which is completely based on index value information. The greater the dispersion degree of the index value is, the smaller the entropy value of the index is, and the greater the weight given to the index is. Objective weighting method only calculates the weight based on the index value information without considering the subjective preference of decision-makers for the index. In addition, although the method effectively transmits the data difference of index value, it ignores the interaction between different indexes. So it is not comprehensive to use only the objective weight for the decision-making of PSS solution selection.

Among the subjective weight values, customer expectation ($I_1$), product quality ($I_3$), service quality ($I_4$), CO$_2$ emissions ($I_13$) have larger weight values, all exceeding 0.0800 (0.0976, 0.0951, 0.0864 and 0.0838, respectively) and relationship with competitors ($I_{13}$), system convenience ($I_5$), government laws and regulations ($I_{13}$), user health and safety assurance ($I_6$) have relatively smaller weight values, all <0.0100 (0.0032, 0.0036, 0.0048 and 0.0099, respectively). Here, the subjective weight value is obtained by the ANP method which comprehensively considers the interaction between indexes. Customer expectation ($I_1$) and product quality ($I_3$) drive the design of PSS, service quality ($I_4$) is the key factor for the normal operation of the whole PSS, and CO$_2$ emissions ($I_{13}$) is a factor that must be attached great importance to when the environmental problems are becoming more and more serious. From the perspectives of weighting results, these indexes are given a greater subjective weight which is consistent with the actual situation. Although subjective weight has many advantages, it ignores the objective dispersion between index values.

Therefore, considering both the objective discreteness of index value and the subjective preference of decision-makers, the weight integrating method proposed by us is more reasonable.

6 Conclusion

The decision-making of PSS solution evaluation and selection is the key link to ensure the normal subsequent implementation of PSS. It is of great significance for the further development of the enterprise to select the appropriate PSS solution.

Aiming at the existing problems in the decision-making of PSS solution selection, we build a decision-making framework with four layers of PSS solution selection. Then several key enabling technologies of the decision-making framework are given, such as index system establishment, index value acquisition by semantic evaluation fuzzy processing, integrated weight determination and the candidate PSS solution ranking by TOPSIS. The characteristics of the built decision-making framework are as follows:

(i) The index system is established from the perspectives of multiple stakeholders, which makes the decision-making results more comprehensive.

(ii) The semantic evaluation fuzzy processing reflects the fuzzy information of the expert group to the decision-making results, which is more accordant with the actual decision-making environment.

(iii) The weight integrating method considers both the objective discreteness of index value and the subjective preference of decision-makers, which is more reasonable.

By the application of the candidate PSS solution selection of an automobile company, the feasibility and effectiveness of the proposed decision-making framework are demonstrated. The managerial implications of the proposed PSS solution evaluation and selection methodology can be summarised as follows. It provides a practical decision-making tool for similar management issues with the characteristics such as qualitative index existing, evaluation opinion combining of multiple experts, integrating multiple weight types etc. As the index system of decision-making of PSS solution selection is very complex, the established index
system is not strictly comprehensive. In future work, the proposed idea will be extended to the decision-making situation with complex node relationships. Additionally, we will try to map the relationship between indexes into complex networks and take advantage of complex networks theory to determine the index weight.

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