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SELECTION OF MEDICAL DEVICE PROVIDERS USING STRAIGHT-LINE UNASCERTAINED MEASURE METHOD

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Abstract. *Decision-makers in sanatoriums often attach great importance to the selection of medical device providers. However, there are many qualitative and quantitative influencing factors in the selection of medical device providers, and various uncertainties exist. Thus, fuzzy based methods are more proper for selecting medical device providers. In this work, we use a straight-line membership function to develop a kind of unascertained measure method, and then propose an evaluation approach of medical device providers, which can identify the evaluation level of each candidate supplier. A case study validates the effectiveness of the developed approach, in comparison with classic fuzzy comprehensive evaluation method.*
Keywords: Sanatoriums, Medical device, Providers selection, Unascertained measure

1. **Introduction.** The medical devices in sanatoriums directly affect the quality of medical services provided by sanatoriums [1]. Thus, decision-makers in sanatoriums often attach great importance to the selection of medical device providers. However, there are many influencing factors in the selection of medical device providers, such as the qualification and reputation of providers, the quality of devices, and the prices [2]. These factors include qualitative and quantitative factors, and various uncertainties exist. It is an intractable issue to select the most proper one from medical device providers with inconsistent and fuzzy indicator values.

Quite a few works have been contributed to the selection methods of suppliers. Deng et al. [3] extended the classical analytic hierarchy process (AHP) method into a D-AHP method for the supplier selection. Scott et al. [4] also used AHP method for supplier selection problem. Kuo et al. [5] divided the extant methods for supplier selection into three categories, and argued that the membership function is the key of fuzzy-based method. The extant membership functions are too complicated to quantify. Motivated by this observation, according to the characteristics of selecting medical device providers, we use a straight-line membership function to develop a kind of unascertained measure method which is proposed by Liu et al. [6], and develop a new selection approach of medical device providers. The unascertained measure model can deal with the decision issues with multiple and uncertain criteria. Our work not only contributes a new method for determining the membership function for unascertained measure model, but also applies the proposed method into selecting medical device providers, which is of good academic and practical significance.

In comparison with extant methods, our proposed method owns some advantages for selecting medical device providers. First, it is easier to use the straight-line membership function for determining the membership of each evaluation value. Second, our method could classify medical device providers into different levels, which could provide supports for decision-makers to select proper providers. In addition, our method could be also used for other evaluation issues.

The rest of the paper is organized as follows. Section 2 analyzes the evaluation criteria of medical device providers from two aspects: the providers and the devices, which constructs ten specific indexes for selecting medical device providers; Section 3 uses the unascertained measure model to develop the evaluation approach of medical device providers; Section 4 gives a case study to show the effectiveness of the developed approach; Section 5 concludes the paper.

2. **Evaluation Criteria of Medical Device Providers.** There are many factors influencing the evaluation of medical device providers in the real-world. In the work, we consider the following three aspects to take the detailed factors: corporate strength, device technical parameters and device business conditions. In detail, the corporate strength aspect involves qualification, financial status, corporate reputation, and so on; The device technical parameters mainly reflect the status of the device itself, including safety, reliability, maintainability and so on; The device business conditions include the expense, technical training, after-sale service, and so on.

(1) Corporate strength

The corporate strength of medical device providers is an important index to judge the quality and level of their produced devices. Generally, the stronger and larger the corporate is, the better and more trustworthy their produced devices are. Thus, sanatoriums often buy medical devices from the providers with good corporate strength. The medical device providers with weak corporate strength are often not selected.

The corporate strength of medical device providers may be measured by various aspects including corporate qualification, financial status, corporate reputation, production and operation and so on. Each aspect may be represented by different specific indexes. In the work, we use three specific indexes to evaluate the corporate strength of medical device providers, that is, corporate qualification level, return on total assets and market share. The qualification level is a qualitative index to represent the corporate qualification, which can be judged as four levels: very good, good, general, bad. Return on total assets and market share respectively represent the financial status and the corporate reputation, which can be judged by their actual values.

(2) Device technical parameters

Although the corporate strength of medical device providers often reflects the quality of their produced devices, one specific purchase should consider the technical parameters of the needed devices. The device technical parameters involve the technical scheme, industrial art, performance, and so on. Similarly, the qualitative and quantitative indexes exist at the same time. For the qualitative indexes, we also apply specialists judging method to divide them into four levels: very good, good, general, bad; For the quantitative indexes, the actual values are used.

In the work, we consider the performance parameters of medical devices as the quantitative indexes. The performance parameters are different for different kinds of medical devices, and we will specify them in the case study. The qualitative indexes reflecting the device technical parameters are summarized as safety, reliability and maintainability in the work [7].

(3) Device business conditions

We not only select the better devices from the stronger providers but also select the devices with proper prices. Thus, the expenses of the devices are also an important index to judge which medical device suppliers should be selected. Here the expenses of the devices include the device price, spare part price, transportation expenses and

TABLE 1. The specific indexes for selecting medical device providers

Index I_j	Nature
I_1: Corporate qualification level	Qualitative
I_2: Return on total assets	Quantitative
I_3: Market share	Quantitative
I_4: Performance parameters	Quantitative
I_5: Safety	Qualitative
I_6: Reliability	Qualitative
I_7: Maintainability	Qualitative
I_8: Expenses	Quantitative
I_9: Technical training	Qualitative
I_{10}: After-sale service	Qualitative

installation charge. Technical training and after-sale service are other indexes to reflect the device business conditions, which are also divided into four levels: very good, good, general, bad.

To sum up, the specific indexes we will consider for selecting medical device providers are as Table 1 shows.

3. The Evaluation Approach Using Straight-Line Unascertained Measure Function.

3.1. The proposed model. $X = \{x_1, x_2, \cdots, x_n\}$ represents the set of medical device providers; there are m evaluation indexes $I = \{I_1, I_2, \cdots, I_m\}$; x_{ij} is the observed value of provider x_i under index I_j; $C = \{c_1, c_2, \cdots, c_K\}$ is the evaluation space, where c_k $(1 \le k \le K)$ is the kth evaluation level.

Let $\mu_{ijk} = \mu(x_{ij} \in c_k)$ represent the degree in which x_{ij} makes provider x_i belong to the kth evaluation level c_k. Then μ_{ijk} is a measurement result of the membership degree, which satisfies:

$$\begin{cases} 0 \le \mu_{ijk} \le 1 \\ \mu\left(x_{ij} \in \bigcup_{k=1}^{K} c_k\right) = \sum_{k=1}^{K} \mu(x_{ij} \in c_k) \\ \mu(x_{ij} \in C) = 1 \end{cases} \tag{1}$$

where $i = 1, 2, \cdots, n$, $j = 1, 2, \cdots, m$, $k = 1, 2, \cdots, K$. μ_{ijk} is called the unascertained measure, and

$$(\mu_{ijk})_{m\times k} = \begin{bmatrix} \mu_{i11}, & \mu_{i12}, & \cdots, & \mu_{i1K} \\ \mu_{i21}, & \mu_{i22}, & \cdots, & \mu_{i2K} \\ \vdots & \vdots & \cdots & \vdots \\ \mu_{im1}, & \mu_{im2}, & \cdots, & \mu_{imK} \end{bmatrix} \tag{2}$$

is called the single index measure evaluation matrix of object x_i.

The unascertained measure function is the base of the unascertained measure model. In the work, we use the straight-line unascertained measure function, which is formulated as:

$$\begin{cases} \mu_i(x) = \begin{cases} \dfrac{-x}{a_{i+1} - a_i} + \dfrac{a_{i+1}}{a_{i+1} - a_i} & a_i < x \le a_{i+1} \\ 0 & x > a_{i+1} \end{cases} \\ \mu_{i+1}(x) = \begin{cases} 0 & x \le a_i \\ \dfrac{x}{a_{i+1} - a_i} - \dfrac{a_i}{a_{i+1} - a_i} & a_i < x \le a_{i+1} \end{cases} \end{cases} \tag{3}$$

where $\mu_i(x)$ represents the membership degree where provider x_i belongs to evaluation level c_k, and a_i represents the corresponding value of the evaluation level c_k.

If the single index measure evaluation matrix of provider x_i has been known, we can get the evaluation vector of x_i using the following formulas:

$$\mu_{ik} = \mu(x_i \in c_k) = \sum_{j=1}^{m} \omega_j \mu_{ijk} \tag{4}$$

$$(\mu_{ik})_{n\times k} = \begin{bmatrix} \mu_{11} & \cdots & \mu_{1k} \\ \mu_{21} & \cdots & \mu_{2k} \\ \cdots & \cdots & \cdots \\ \mu_{n1} & \cdots & \mu_{nk} \end{bmatrix} \tag{5}$$

where ω_j represents the weight of index I_j, and matrix (5) is called multi-indexes synthetic evaluation matrix.

If $c_1 > c_2 > \cdots > c_K$, we call $\{c_1 > c_2 > \cdots > c_K\}$ an ordered division on the evaluation space. When the division is ordered, we usually take the confidence degree as identification criterion [8,9]. λ represents the confidence degree ($\lambda > 0.5$), and it is usually adapted to 0.6 or 0.7. Let:

$$k_0 = \min_k \left\{ \sum_{i=1}^{k} \mu_{ik} \geq \lambda,\ 1 \leq k \leq K \right\} \tag{6}$$

Then, we can judge that provider x_i belongs to the k_0th evaluation level c_{k_0}.

3.2. **The index level division.** The ten specific indexes mentioned in Section 2 are considered for selecting proper medical device providers. Among the indexes, the qualitative indexes, including corporate qualification level, safety, reliability, maintainability, technical training and after-sale service, are quantified by hundred-mark system; Return on total assets and market share are measured by percentage; Performance parameters take the rotate speed parameter as the standard; Expenses take the million Yuan as the unit. The division levels of these indexes are as Table 2 shows. According to the division levels, we can get the unascertained measure functions, as Figure 1 shows.

In Figure 1, A, B, C and D are respectively "Very good", "Good", "General" and "Bad". The detailed criterion for each evaluation index corresponds to the division level in Table 2. For example, the corresponding values of A, B, C and D for index I_1 are "< 25", "$[25, 50)$", "$[50, 75)$" and "$>= 75$".

Table 2. The index level division of selecting medical device providers

Index I_j	Units	Index division level c_k			
		Bad	General	Good	Very good
I_1: Corporate qualification level	NA	< 25	[25, 50)	[50, 75)	>= 75
I_2: Return on total assets	%	< 0	[0, 30)	[30, 60)	>= 60
I_3: Market share	%	< 10	[10, 30)	[30, 50)	>= 50
I_4: Performance parameters	Revolutions per Sec	< 160	[160, 200)	[200, 240)	>= 240
I_5: Safety	NA	< 25	[25, 50)	[50, 75)	>= 75
I_6: Reliability	NA	< 25	[25, 50)	[50, 75)	>= 75
I_7: Maintainability	NA	< 25	[25, 50)	[50, 75)	>= 75
I_8: Expenses	Million Yuan	< 125	[125, 150)	[150, 175)	>= 175
I_9: Technical training	NA	< 25	[25, 50)	[50, 75)	>= 75
I_{10}: After-sale service	NA	< 25	[25, 50)	[50, 75)	>= 75

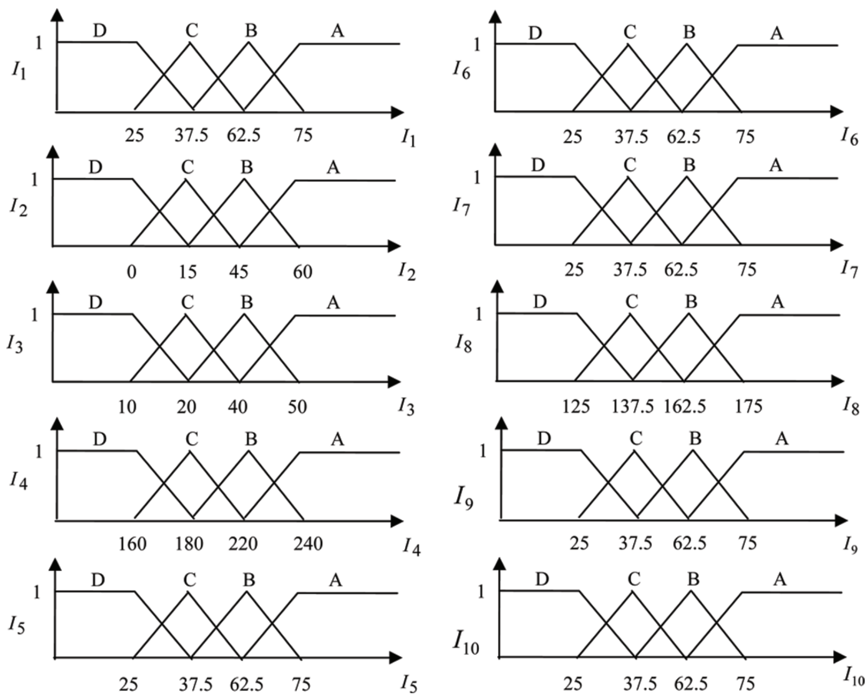

Figure 1. The straight-line unascertained measure functions of the evaluation indexes

4. **Case Study.** In the Section, we use a case to show the effectiveness of the proposed method. In the case, a sanatorium wants to buy one 64 Slice CT scanner. Six medical device providers are determined as the candidates, whose index values are as Table 3 shows.

Table 3. The index values of six medical device providers

Communities X	Index I_j									
	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}
x_1	60	35	52	190	62	55	70	160	70	70
x_2	45	40	32	170	30	55	40	130	30	35
x_3	80	75	48	235	80	72	65	170	70	65
x_4	30	15	5	170	20	30	40	120	40	20
x_5	70	65	40	220	70	60	65	165	60	70
x_6	40	25	45	230	60	50	65	125	50	75

Using the developed approach in Section 3, we can calculate the single index measure evaluation matrix:

$$(\mu_{1jk})_{10\times 4}=\begin{bmatrix} 0 & 0.1000 & 0.9000 & 0 \\ 0 & 0.3330 & 0.6670 & 0 \\ 0 & 0 & 0 & 1.0000 \\ 0 & 0.7500 & 0.2500 & 0 \\ 0 & 0.0200 & 0.9800 & 0 \\ 0 & 0.3000 & 0.7000 & 0 \\ 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0.1000 & 0.9000 & 0 \\ 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0 & 0.4000 & 0.6000 \end{bmatrix},\ (\mu_{2jk})_{10\times 4}=\begin{bmatrix} 0 & 0.7000 & 0.3000 & 0 \\ 0 & 0.1670 & 0.8330 & 0 \\ 0 & 0.4000 & 0.6000 & 0 \\ 0.5000 & 0.5000 & 0 & 0 \\ 0.6000 & 0.4000 & 0 & 0 \\ 0 & 0.3000 & 0.7000 & 0 \\ 0 & 0.9000 & 0.1000 & 0 \\ 0.6000 & 0.4000 & 0 & 0 \\ 0.6000 & 0.4000 & 0 & 0 \\ 0.2000 & 0.8000 & 0 & 0 \end{bmatrix}$$

$$(\mu_{3jk})_{10\times4}=\begin{bmatrix} 0 & 0 & 0 & 1.0000 \\ 0 & 0 & 0 & 1.0000 \\ 0 & 0 & 0.2000 & 0.8000 \\ 0 & 0 & 0.2500 & 0.7500 \\ 0 & 0 & 0 & 1.0000 \\ 0 & 0 & 0.2400 & 0.7600 \\ 0 & 0 & 0.8000 & 0.2000 \\ 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0 & 0.8000 & 0.2000 \end{bmatrix}, \quad (\mu_{4jk})_{10\times4}=\begin{bmatrix} 0.6000 & 0.4000 & 0 & 0 \\ 0 & 1.0000 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 \\ 0.5000 & 0.5000 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 \\ 0.6000 & 0.4000 & 0 & 0 \\ 0 & 0.9000 & 0.1000 & 0 \\ 1.0000 & 0 & 0 & 0 \\ 0 & 0.9000 & 0.1000 & 0 \\ 1.0000 & 0 & 0 & 0 \end{bmatrix}$$

$$(\mu_{5jk})_{10\times4}=\begin{bmatrix} 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0 & 0 & 1.0000 \\ 0 & 0 & 1.0000 & 0 \\ 0 & 0 & 1.0000 & 0 \\ 0 & 0 & 0.4000 & 0.6000 \\ 0 & 0.1000 & 0.9000 & 0 \\ 0 & 0 & 0.8000 & 0.2000 \\ 0 & 0 & 0.8000 & 0.2000 \\ 0 & 0.1000 & 0.9000 & 0 \\ 0 & 0 & 0.4000 & 0.6000 \end{bmatrix}, \quad (\mu_{6jk})_{10\times4}=\begin{bmatrix} 0 & 0.9000 & 0.1000 & 0 \\ 0 & 0.6670 & 0.3330 & 0 \\ 0 & 0 & 0.5000 & 0.5000 \\ 0 & 0 & 0.5000 & 0.5000 \\ 0 & 0.1000 & 0.9000 & 0 \\ 0 & 0.5000 & 0.5000 & 0 \\ 0 & 0 & 0.8000 & 0.2000 \\ 1.0000 & 0 & 0 & 0 \\ 0 & 0.5000 & 0.5000 & 0 \\ 0 & 0 & 0 & 1.0000 \end{bmatrix}$$

After getting the single index measure evaluation matrix, we can further calculate the multi-indexes synthetic evaluation matrix using Equations (4) and (5). In the work, we assume the weight vector of the indexes as the following:

$$\{\omega_1, \cdots, \omega_{10}\} = \{0.103, 0.109, 0.096, 0.124, 0.110, 0.116, 0.098, 0.0820, 0.0910, 0.0710\}.$$

Using the weight vector to multiply the single index measure evaluation matrix, we can get the multi-indexes synthetic evaluation matrix of supplier evaluation:

$$(\mu_{ik})_{6\times4} = \begin{array}{c} \begin{array}{cccc} D & C & B & A \end{array} \\ \begin{bmatrix} 0 & 0.1848 & 0.5632 & 0.2520 \\ 0.2460 & 0.4837 & 0.2703 & 0 \\ 0 & 0 & 0.2824 & 0.7176 \\ 0.5524 & 0.4287 & 0.0189 & 0 \\ 0 & 0.0207 & 0.6639 & 0.3154 \\ 0.0820 & 0.2799 & 0.4375 & 0.2006 \end{bmatrix} \end{array}$$

After getting the multi-indexes synthetic evaluation matrix, we can use the confidence degree criterion to identify the evaluation level of each medical device supplier, as Table 4 shows. Here we take the confidence degree as 0.6.

Seen from the identification results in Table 4, we can see that the supplier X_3 is evaluated as "very good" with the confidence being 0.7176, and other supplies are evaluated as "good", "general" and "bad". Thus, the supplier X_3 is the best candidate from whom

TABLE 4. The identification results and comparison

	Confidences	Levels	Orders	Orders by FCE [10]
X_1	0.8152	good	3	3
X_2	0.7540	general	5	5
X_3	0.7176	very good	1	1
X_4	1	bad	6	6
X_5	0.9793	good	2	2
X_6	0.9180	general	4	4

the sanatorium buys one 64 Slice CT scanner. Meanwhile, we compare our results with those by classic fuzzy comprehensive evaluation (FCE) method. FCE is one widely-used method for multi-attribute decision making problems. As Table 4 shows, our evaluation orders for the six medical device suppliers are consistent with those by FCM, both of which are $X_3 > X_5 > X_1 > X_6 > X_2 > X_4$. This consistency verifies the effectiveness of our proposed method.

5. **Conclusions.** There are many qualitative and quantitative influencing factors in the selection of medical device providers, and the uncertainty exists. To deal with the characteristics, we apply the straight-line unascertained measure function to develop the evaluation approach of medical device providers. A case study tested the effectiveness of the developed approach, and showed that the developed approach is easy to operate. The comparison with classic fuzzy comprehensive evaluation method verifies the effectiveness of our method. However, in the work we failed to focus on how to get the weights of indexes, which will be considered in the future studies.

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