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Medical Equipment Supplier Evaluation Approach in Sustainable Environment

Yuan Luo

School of Economics & Management, Xidian University, Xi'an 710071, China

Abstract

Increasing demand of medical equipment brings both opportunities and challenges for medical equipment manufactures. They need to evaluate suppliers with improving technology and severe standards due to changing medical requirements. Besides, increasing awareness of environment protection has put forward new standard for the manufactures. Therefore, this study takes environment factors and medical standards into consideration, and uses ANP to analyze the inside relationship of evaluation criteria; uses 2-tuple linguistic representation model to describe linguistic evaluations and uses fuzzy TOPSIS to evaluate suppliers. A case study is finally proposed for supplier evaluation in a medical manufacture.

Keywords

ANP, fuzzy TOPSIS, supplier evaluation, medical equipment, 2-tuple linguistic representation model.

1. Introduction

Increasing demand of medical equipment makes medical equipment industry become one of the fastest developing industries across the world, especially during the outbreak of Corona Virus Disease 2019 (COVID-19). The demand for medical resources did not increase suddenly during the outbreak. According to the statistics provided by EU Medical Device Commission statistics, the global medical device market has increased rapidly from 187 billion dollars in 2001 to nearly 537.2 billion dollars in 2014. Great requirements and huge market potential attract increasing number of manufactures to produce and improve their medical equipment or its parts. Due to special and severe requirements and standards in medical industry and increasing awareness among people of protecting environment, how to select suppliers for hospital or medical equipment manufactures becomes a popular research. For this reason, this study proposes an evaluation model considering both environmental factors and special requirements of medical industry.

In this sustainable development environment, the requirements and standards are different from other industries. A comprehensive evaluation criteria system and framework is essential for medical equipment supplier selection. Especially, the evaluation criteria are usually not independent of each other, such as the cost and quality, the product performance of cost will affect the product performance of quality to some degree, and thus a proper trade-off is important in supplier selection. Furthermore, people are more likely to use linguistic terms to express their evaluations on the product, a practicable mechanism to deal with linguistic terms is need to meet the practical needs.

Consequently, this paper provides an integrated method to assist hospital and medical equipment manufactures. ANP is utilized by decision makers to describe the internal relationship of criteria and thus determine the criteria weight. Then, the 2-tuple linguistic representation model is adopted to deal with linguistic terms provided by the decision

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makers in evaluaying supplers, and finally the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method is employed to rank the suppliers.

The organization of the paper is as follow: A brief literature review about evaluation criteria and approach is discussed in Section 2; Section 3 describes the details of proposed evaluation framework and the brief steps of the integrated framework. And a case study is conducted in Section 4. The conclusions are shown in the final section.

2. Literature Review

Existing researches on supplier evaluation and selection mainly focus on criteria determination and method application. For the evaluation criteria, lots of learners have researched and make great contributions on it. There are various approaches for supplier evaluation, such as nalytic network process (ANP) [1], analytic hierarchy process (AHP) [2], data envelopment analysis (DEA) [3], fuzzy Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) [4].

Supplier evaluation is actually a multi-criteria decision-making problem including qualitative criteria and quantitative analysis. Many learners have researched in this filed, which mainly focus on criteria system determination and evaluation approach. Specifically, research on evaluation criteria is originated from America, Dickson [5] firstly identified 23 criteria for supplier evaluation, among which quality, on-time delivery, and performance history are noted as the most significant criteria. From the prospect view of green supply chain, Kuo and Lin [6] proposed several environment factors such as green degree of product, waste treatment, etc. Based on the analysis results, Weber et al. [7] concluded that price, delivery, quality, and production facility and location are the most frequently employed criteria.

Combination of quantitative analysis and qualitative analysis method has been widely used in supplier selection problem. Sanayei et al [8] proposed a multi-objective decision method to solve supplier evaluation problem in supply chain system based on fuzzy set theory and hierarchical VIKOR model. To solve the supplier selection problem, Felix et al [9] presented a comprehensive fuzzy Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) technology. Tavana et al [10] provided an integrated multi-criteria decision-making approach in dealing with sustainable supplier selection problems and solved it by combining analytic network process and quality function deployment.

Based on literature review, the present research on medical supplier evaluation problem is not adequate. Criteria for evaluating healthcare equipment supplier didn't take environmental factors and medical standards into consideration. Based on the literatures, this paper recognizes the evaluation criteria and solves the supplier evaluation problem using ANP, 2-tuple linguistic representation model and TOPSIS method.

3. The Proposed Medical Equipment Supplier Evaluation Framework

This paper proposes a novel hybrid approach based on ANP, 2-tuple linguistic representation model and TOPSIS methodologies to assist in medical equipment supplier decisions. Based on the methodologies, we firstly identify the medical equipment supplier evaluation criteria, and then provides detailed framework for medical equipment suppliers selection.

3.1. Criteria for Medical Equipment Supplier Selection

By precisely collecting evaluation criteria from related researches and expert opinions about the medical equipment supplier, some elements are founded to assist in medical equipment supplier selection as the foundation of the evaluation framework. They are listed as below:

Product dimension: Major elements of the product dimension typically include: price, service, on-time delivery, and green degree. Price usually is the typical factor that influences

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customers' choice, and the hospital is not the exception, however, it doesn't have such great influence as it does in other felids. Service and the price are common elements when considering which supplier to select, including pre and after sale service, maintenance response time and technical train service. For a hospital, time means life, thus, timely delivery is vital for both hospital and patient because the hospital needs to operate normally and the patients need to be treated in time. With the deepening of the application of sustainable development, people's awareness of environment protection is becoming strong, thus, this paper introduces green degree of product in criteria framework, measuring the waste disposal and waste product treatment

Organization of supplier dimension: For equipment suppliers of the hospital, various requirements are listed for the organization. Five major elements are: reputation, credibility, technology and R&D ability, qualification, and financial performance. Reputation mainly influences the supplier's product quality, market influence and other factors; it shows one aspect of supplier performance. Credibility assists in evaluating the stable relationship between hospital and suppliers, which affects a stable cooperative relationship to some extent. Technology influences hospital's performance and will provide strong technical support for doctors. Qualification ensures essential license of suppliers, such as business license and medical instrument product registration certificate. There is no doubt that financial position of the supplier is fundamental for the daily operation of the suppliers.

Quality dimension: Three major elements are safety, reliability and ISO13485. For the tougher requirements of the hospital, safety and reliability of the equipment is of great importance in supplier selection. A safety monitoring system is essential for all the suppliers to assure that the product is safe and the result provided is reliable. ISO13485, a medical equipment quality management system, is used to guarantee the equipment quality for health and safety of people.

Relationship with partner dimension: Cooperative research and relationship management are two main elements that influence the cooperation relationship between hospital and its suppliers. Cooperative research conducted between supplier firms and hospital can benefit both of them on product competitiveness and practicality. Relationship management is a factor influencing constant exchanges and cooperation with supplier firms on sharing true information and communicating ability.

3.2. The Medical Equipment Supplier Selection Framework

Stage 1 Using ANP to determine criteria weight

As is known to all, ANP is a general form of the analytical hierarchy process first introduced by Saaty [1], which can handle the interdependence of elements by obtaining the composite weights of the criteria. In this paper, the Super Decision software is adopted to determine the criteria weight by decision makers.

Stage 2 Using 2-tuple linguistic representation model to transform the linguistic terms

Suppose $S=\{s_0, s_1, \cdots, s_t\}$ represents a set of evaluation language phrases, where s_i is the ith language term in S and S is a predefined ordered set of odd elements. This paper adopts a language evaluation set S composed of five language phrases, such as

$$S=\{s_0 = VL(VeryLow), s_1 = L(Low) s_2 = M(Medium) s_3 = H(High), s_4 = VH(VeryHigh)\}$$

The language evaluation set S is required to meet the following properties:

① Element is S has a order: if $i \geq j$, then $s_i "\geq" s_j$, where "$\geq$" means "better than or equal to";

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② A negative operator " neg ": if $j = t - i$, then $neg(s_i) = s_j$, where t+1 represents the number of elements in S;

③ A max calculation: if $s_i \text{"} \geq \text{"} s_j$, then $\max\left(s_i, s_j\right) = s_i$;

④ A min calculation: if $s_i \text{"} \geq \text{"} s_j$, then $\min\left(s_i, s_j\right) = s_j$.

According to the research of Herrera and Martinez [11,12],the linguistic term s_i can be transformed to 2-tuple linguistic representation model by the following transformation model θ:

$$\theta : S \to S \times [-0.5, 0.5] \tag{1}$$

$$\theta(s_i) = (s_i, 0), \quad s_i \in S \tag{2}$$

Let the real number $\beta \in [0, \ t]$ represent the aggregation result of language phrase, then (s_i, α_i) is defined as the corresponding 2-tuple linguistic representation for β, which can be obtained by function Δ:

$$\Delta : [0, \ t] \to S \times [-0.5, 0.5) \tag{3}$$

$$\Delta(\beta) = (s_i, \alpha_i) = \begin{cases} s_i, & i = round(\beta) \\ \alpha_i = \beta - i, & \alpha_i \in [-0.5, 0.5) \end{cases} \tag{4}$$

where $round$ means rounding operation; s_i is the ith language term in S; α_i is the symbol transfer value, indicating the information deviation between s_i and β.

Obviously, if (s_i, α_i) is 2-tuple linguistic representation model, and s_i is the ith language term in S, $\alpha_i \in [-0.5, 0.5)$, then a diverse function Δ^{-1} can transform the 2-tuple linguistic representation model (s_i, α_i) into the corresponding real number $\beta \in [0, \ t]$, such as

$$\Delta^{-1} : S \times [-0.5, 0.5) \to [0, \ t] \tag{5}$$

$$\Delta^{-1}(s_i, \alpha_i) = i + \alpha_i = \beta \tag{6}$$

Stage 3 Using TOPSIS to rank the alternative supplies

TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is a multi-criteria decision-making method that identifies the ideal solution based on defining the positive ideal solution and the negative ideal solution, while the ideal solution has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. Human's judgments are always imprecise and subjective; therefore, evaluations are expressed by linguistic terms and convert to fuzzy numbers.

First, since the evaluation criteria are divided by cost criteria (CC) and benefit criteria (BC), and the evaluation result s_i^{mi} for supplier m on criteria j should be normalized, it is as:

$$e_{ij} = \frac{\max(\Delta^{-1}(s_i^{mi}, \alpha_i)) - \Delta^{-1}(s_i^{mi}, \alpha_i)}{\max(\Delta^{-1}(s_i^{mi}, \alpha_i)) - \min(\Delta^{-1}(s_i^{mi}, \alpha_i))} (j \in CC) \tag{7}$$

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$$e_{ij} = \frac{\Delta^{-1}(s_i^{mi}, \alpha_i) - \min(\Delta^{-1}(s_i^{mi}, \alpha_i))}{\max(\Delta^{-1}(s_i^{mi}, \alpha_i)) - \min(\Delta^{-1}(s_i^{mi}, \alpha_i))} (j \in BC) \quad (8)$$

Second, determining the positive ideal point and the negative ideal point, the positive ideal point and the negative ideal point for the cost criteria (CC) is $e_{ij}^{+} = \max(e_{ij})$ and $e_{ij}^{-} = \min(e_{ij})$, respectively; the positive ideal point and the negative ideal point for the benefit criteria (BC) is $e_{ij}^{-} = \min(e_{ij})$ and $e_{ij}^{+} = \max(e_{ij})$, respectively.

Third, obtain the positive ideal distance and negative ideal solution for both cost criteria (CC) and benefit criteria (BC).

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} (e_{ij}^{+} - e_{ij})^2 \times w_j} \quad (9)$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} (e_{ij}^{-} - e_{ij})^2 \times w_j} \quad (10)$$

And then the closeness coefficient can be obtained as:

$$Co = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad (11)$$

It means that the ideal solution has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

4. Case Study

G Company is a large medical equipment manufacturer mainly producing X-Ray, CT, etc., having a series of suppliers to provided needed parts. Facing the fierce competition among peers, the company needs to select some high-quality suppliers to improve the competitiveness of its products. After a preliminary filtering, five suppliers are filtered out. The company hopes to select the most competitive one, so the proposed ANP-fuzzy TOPSIS method is used to evaluate the selected five suppliers. 6 managers and 12 quality engineers are invited to join the evaluation process to provide the evaluations for the suppliers considering the provided criteria.

The evaluation criteria are generated as Table 1, and the evaluations on the suppliers considering each criteria are collected and then transformed by 2-tuple linguistic representation model as shown in Table 3. Here are the detailed computational steps of the integrated framework:

Stage 1 Using ANP to determine criteria weight

By employing Super Decision software, the decision makers provide the comparison results between each pair of criteria, and the network structure of the evaluation criteria is showed in Fig. 1, and then the criteria weight are obtained by the technique as showed in Fig. 2, with the criteria weights are generated in Table 2.

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Table 1. Evaluation criteria for selecting medical equipment suppliers

Product dimension	Green degree	C_1
	On-time delivery	C_2
	Price	C_3
	Service	C_4
Relationship with partner dimension	Cooperative research	C_5
	Relationship management	C_6
Organization of supplier dimension	Credibility	C_7
	Financial performance	C_8
	Qualification	C_9
	Reputation	C_{10}
	Technology	C_{11}
Quality dimension	ISO13485	C_{12}
	Reliability	C_{13}
	Safety	C_{14}

Table 2. Evaluation criteria for selecting medical equipment suppliers

Product dimension	Green degree (C_1)	0.0637
	On-time delivery (C_2)	0.0201
	Price (C_3)	0.1726
	Service (C_4)	0.0339
Relationship with partner dimension	Cooperative research (C_5)	0.0941
	Relationship management (C_6)	0.1213
Organization of supplier dimension	Credibility (C_7)	0.1168
	Financial performance (C_8)	0.0049
	Qualification (C_9)	0.0043
	Reputation (C_{10})	0.0532
	Technology (C_{11})	0.0233
Quality dimension	ISO13485 (C_{12})	0.0050
	Reliability (C_{13})	0.1583
	Safety (C_{14})	0.1285

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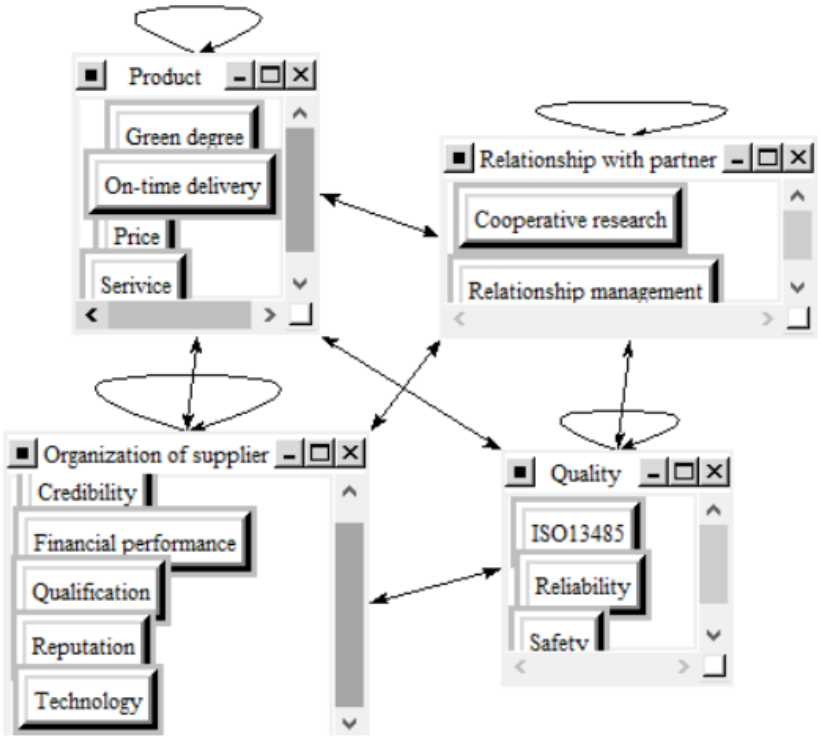

Fig. 1 Network structure of the evaluation framework

Here are the priorities.

Name	Normalized by Cluster	Limiting
Reputation	0.26290	0.053235
Credibility	0.57705	0.116845
Technology	0.11493	0.023272
Qualification	0.02107	0.004267
Financial performance	0.02405	0.004869
Safety	0.44042	0.128520
Reliability	0.54241	0.158283
ISO13485	0.01717	0.005009
Cooperative research	0.43695	0.094167
Relationship management	0.56305	0.121345
Price	0.59478	0.172598
Serivice	0.11676	0.033882
On-time delivery	0.06936	0.020127
Green degree	0.21911	0.063582

Fig. 2 The weight of the evaluation criteria

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Stage 2 Using 2-tuple linguistic representation model to transform the linguistic terms

In this stage, the evaluations given by the decision-makers on these five suppliers are transformed by 2-tuple linguistic representation model, and the collected information is listed in Table 3.

Table 3. Evaluation results for selecting medical equipment suppliers

	MS_1	MS_2	MS_3	MS_4	MS_5
Green degree (C_1)	(S_1,0)	(S_3,0)	(S_2,0)	(S_1,0)	(S_4,0)
On-time delivery (C_2)	(S_0,0)	(S_1,0)	(S_5,0)	(S_4,0)	(S_2,0)
Price (C_3)	(S_1,0)	(S_1,0)	(S_4,0)	(S_3,0)	(S_1,0)
Service (C_4)	(S_2,0)	(S_2,0)	(S_4,0)	(S_5,0)	(S_5,0)
Cooperative research (C_5)	(S_4,0)	(S_4,0)	(S_1,0)	(S_1,0)	(S_0,0)
Relationship management (C_6)	(S_0,0)	(S_1,0)	(S_3,0)	(S_5,0)	(S_4,0)
Credibility (C_7)	(S_3,0)	(S_1,0)	(S_2,0)	(S_4,0)	(S_0,0)
Financial performance (C_8)	(S_1,0)	(S_3,0)	(S_1,0)	(S_4,0)	(S_0,0)
Qualification (C_9)	(S_0,0)	(S_3,0)	(S_1,0)	(S_2,0)	(S_1,0)
Reputation (C_{10})	(S_4,0)	(S_3,0)	(S_1,0)	(S_0,0)	(S_3,0)
Technology (C_{11})	(S_4,0)	(S_1,0)	(S_2,0)	(S_2,0)	(S_2,0)
ISO13485 (C_{12})	(S_3,0)	(S_5,0)	(S_0,0)	(S_1,0)	(S_5,0)
Reliability (C_{13})	(S_2,0)	(S_2,0)	(S_2,0)	(S_5,0)	(S_5,0)
Safety (C_{14})	(S_1,0)	(S_4,0)	(S_2,0)	(S_5,0)	(S_3,0)

Stage 3 Using TOPSIS to rank the alternative supplies

In this section, the technique of TOPSIS is adopted to rank the medical equipment suppliers by identifying the positive ideal solution and the negative ideal solution. And the final ranking results are listed in Table 4.

Table 4. The final ranking of the criteria

Supplier	S_1	S_2	S_3	S_4	S_5
d_i^+	3.1092	2.6565	2.3297	1.6253	2.4466
d_i^-	1.9151	1.9651	2.0304	3.1491	2.3387
Co	0.3812	0.4252	0.4657	0.6596	0.4887

Therefore, according to the coefficient obtained from the positive ideal distance and the negative ideal distance, S_4 (0.6596) is selected as the most proper medical equipment supplier considering evaluation on all the criteria.

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5. Conclusion

This paper proposes a hybrid multi-criteria decision-making approach for medical equipment supplier evaluation problem. Based on the literature review and expert opinions, a medical equipment supplier evaluation criteria system is defined and ANP-fuzzy TOPSIS evaluation model is formulated. The proposed model was implemented in the G Company in case study which showed the scientificity and practicability of the model. Taking environment factors and hospital condition into consideration, our evaluating criteria is practicable applied to medical supplier selection. The combination of ANP, 2-tuple linguistic representation model fuzzy TOPSIS offered accurate and efficient analysis for supplier selection. As a novel model, it can be improved in criteria determination with the development of the medical supplier selection research.

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