International Journal of u- and e- Service, Science and Technology
Vol.9, No. 7 (2016), pp.277-286
http://dx.doi.org/10.14257/ijunesst.2016.9.7.28

A New Multiple Attribute Decision Making Method Based on Generalized Hesitant Fuzzy Aggregation Operator and the Application on the Assessment and Select of Supplier

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Abstract

The supplier is an important member in the supply chain. The work of supplier evaluation is also an essential effect for the good operation of the manufacturing supply chain. However, supply chain has some characteristics. They are dynamic composition, the complicated management and the high risk. These characteristics determine that supplier evaluation is complex and difficult. Therefore, in this paper, we study the supplier evaluation and put forward the assessment framework of supply chain evaluation. This assessment framework with new hesitant fuzzy sets can better express the decision maker's preference more accurately and can be applied in more multiple decision making problems. Finally, we apply this method to evaluate the supplier and get the evaluated results. The experiments show that this method can express better the decision maker's preference more accurately.

Keywords: *hesitant fuzzy set; supplier evaluation; supply chain*

1. Introduction

In the 21th century, the global economic competition becomes more and more fierce increasingly. The competition among the enterprises becomes the competition of supply chain. The market demand of the manufacturing becomes diversified and personalized. The product life cycle shortens constantly. The market uncertainly increases. These competitive environments require that manufacturing enterprises have strong adaptability in order to adapt the market. The supplier is the important member of supply chain. The work of supplier evaluation is also an essential effect for the good operation of the manufacturing supply chain. In addition, due to the complexity of the organization and the differences of the enterprises, the cooperation of supply chain exists the risk. Establishing the scientific and comprehensive supplier evaluation system can provide the help and avoid the cooperation risk. Therefore, studying the supplier has the practical significance.

Many domestic and foreign scholars have studied supply chain evaluation. According to surveying the related data, Bharadwaj N identifies the evaluation index sets and the importance order during the process of purchasing the electronic parts with the empirical research method [1]. Li-Hsing Ho, Shu-Yun Feng, Yu-Cheng Lee and Tieh-Min Yena provided a methodology of Supplier Quality Performance Assessment (SQPA). This paper introduced modified Importance-Performance Analysis (IPA) which used the multiple regression analysis and Decision Making Trial and Evaluation Laboratory (DEMATEL) techniques [2].Gülcin Büyükozkan and Gizem Cifci examined green supply chain management (GSCM) and GSCM capability dimensions to propose an evaluation framework for green suppliers. They integrated the identified components into a novel hybrid fuzzy multiple criteria decision making (MCDM) model combines the fuzzy Decision Making Trial and Evaluation Laboratory Model (DEMATEL), the Analytical Network Process (ANP), and Technique for Order Performance by Similarity to Ideal

ISSN: 2005-4246 IJUNESST

Solution (TOPSIS) in a fuzzy context [3]. Mani.V, Rajat Agarwal, Vinay Sharma researched the socially sustainable supplier selection. They established the social parameters through the analytic hierarchy process (AHP) in decision making. The authors pointed out there were 8 social sustainability indicators. They were equity, health, safety, wages, education, philanthropy, child and bonded labor [4]. In the book of supply chain management, Ma Shihua and Lin Yong divided supply chain evaluation index system to four parts. They were the quality system, the business performance, the business structure and the production ability and the enterprise environment [5]. Shu Xiaohong studied the evolution of supply chain relationship. With the development of supply chain management, he pointed that the relationship between the manufacturers and the suppliers has changed. The relationship changed from the simple buyer and seller relationship to the partnership of supply chain. Then, after analyzing and comparing many different supplier evaluation methods, the author adopted the combination method between the analytic hierarchy process and the factor analysis method to evaluate the supplier [6]. ZhangZhen, Yu Tian-biao, Liang Bao-zhu and Wang Wan-shan proposed a supplier evaluation method which was based on the analytic hierarchy process and the fuzzy comprehensive evaluation. The author used the analytic hierarchy process method to determine the weights of each supplier evaluation index. And he adopted the fuzzy comprehensive evaluation method to process the supplier evaluation information. Then, he established the mathematical model for evaluating the supplier comprehensive evaluation. Finally, according to using the method, the author evaluated many different suppliers in the automobile manufacturing enterprises. He validated the rationality and reliability of the supplier comprehensive evaluation method which was based on the analytic hierarchy process and the fuzzy comprehensive evaluation [7]. In addition, there were many scholars studying the supplier evaluation [8-12].

With more and more researchers realizing advantages of fuzzy sets in terms of expressing human preferences, Zadeh (1965) presented the basic model of fuzzy sets based on the theory of fuzzy mathematics, which has been successfully used for handling fuzzy decision making problems [13]. Recently, some researchers find sometimes it is difficult to determine the membership and non-membership of an element into a fixed set and which may be caused by a doubt among a set of different values. Therefore, Torra and Narukawa defined hesitant fuzzy sets(HFSs) to deal with decision making problems, which allows the membership of an element to a set presented as several possible values between 0 and 1 [14]. Since the basic concepts on HFSs were defined by Torra, HFS has been widely studied [15-19].Huchang Liao, ZeshuiXua, Xiao-Jun Zeng, José M. Merigó proposed several different types of correlation coefficients for HFLTSs. The prominent properties of these correlation coefficients are then investigated and the weighted correlation coefficients and ordered weighted correlation coefficients are further investigated [20]. Deqing Lia, Wenyi Zeng, Junhong Li introduced the concept of hesitance degree of hesitant fuzzy element and Several novel distance and similarity measures between hesitant fuzzy sets (HFSs) were developed with considering both the values and the numbers of values of HFE [21].B. Farhadinia introduced a series of score functions for hesitant fuzzy sets (HFSs) which provides us with a variety of new methods for ranking HFSs [22].

In practice, how to select and manage the supplier becomes the important problem of supply chain management. The enterprise often makes supplier evaluation as the foundation and standard when selecting, managing, supervising and improving. Therefore, the supplier evaluation is more important. In this paper, firstly, we establish the supplier evaluation system. Then, we put forward a new multiple attribute decision making method based on generalized hesitant fuzzy aggregation operator. Finally, we use the algorithm to evaluate the supplier. The structure of this paper is as follows. The first part is the introduction. In this part, we introduce the supplier evaluation, multiple attribute decision making method and the state of hesitant fuzzy sets. The second part is the supplier evaluation index system. In this part, we establish the supplier rating system. The third part is a new assessment framework with hesitant fuzzy set. In this part, we put forward a new multiple attribute decision making method based on generalized hesitant fuzzy aggregation operator. The fourth part is the case study. The last part is the conclusion.

2. The Supplier Evaluation Index System

In order to make the selected indicators can reflect the suppliers more scientifically and objectively, we should follow these principles when establishing the evaluation indicators.

The first principle is the scientific principle. The evaluated content should have the scientific stipulation. Each evaluation index should have the clear definition, explanation, calculation method and the classification. And these principles should be scientific, authentic and normative.

The second principle is the comprehensive principle. The evaluation index system must reflect comprehensively the present level of suppliers. It concludes the all aspects indicators of the enterprise development prospects. In addition, we need to consider the external economic environment. The index system not only concludes the hard indexes which reflect the strength of supplier, but also concludes the soft indexes which reflect the competitive advantages of suppliers.

The third principle is the utility principle. We need to guarantee the objectivity of the evaluation. And the index system should be simplified as much as possible. We should reduce and remove some indexes which have the little influence on the evaluation results. The calculating evaluation method should be simple and easy to operate. Finally, the evaluation index data should be easy to collect and quantify. It can adapt the current management level.

The fourth principle is the combination between the stability and dynamic. It can not only reflect the current index, but also reflect the dynamic index. However, the index system should keep a relatively stable state in a certain period in order to measure the development state of the suppliers.

The fifth principle is the combination between the quantitative and the qualitative. When evaluating comprehensively the competitiveness of suppliers, we should consider the quantitative and the qualitative indexes of the supplier's ability. Especially for the qualitative index, it must confirm its meaning. According to some standard assignment, it can reflect the nature of the index. The qualitative and quantitative indicators must have a clear concept and exact representation method.

The sixth principle is the reconstruction and the extension. The evaluation system not only has the changes of number, but also has the changes of the indexes and the contents. According to different requirements, the users can modify, add and delete the index system. According to the specific situation, the users can specific further the evaluation index.

The seventh principle is the coordination principle between the index system and the evaluation method. For example, the principal component analysis and the factor analysis has the function to eliminate the mutual influence among the evaluation indexes in multivariate statistical analysis. When using these methods to evaluate comprehensively, we need to pay more attention to the comprehensive indexes. The conventional multi index comprehensive evaluation method and the fuzzy evaluation method do not have the function. When we select the indexes, we need to consider the representation of the indicators and reduce the mutual influence among the indicators.

According to the above principles, we establish the supplier evaluation index system.

Tabel 1. The Supplier Evaluation Index System

The supplier evaluation index system	The competitiveness of the enterprises	Product quality
		Cost
		Production ability
		Product structure
		Financial situation
		Product flexibility
		Management level
		Development level
	The cooperation ability	Delivery
		Communication
		Cooperative compatibility
		Information level
	External environment	Geographical position
		Economic and technical policies
		Social cultural environment
		Political and legal environment
	Social benefit	Environment impact
		Energy consumption
		Recycling
		Ecological efficiency
		Social contribution rate

3. A New Assessment Framework with Hesitant Fuzzy Set

3.1. Some Concepts of Hesitant Fuzzy Set

Definition 1 [14-15].Let$X$be a universe of discourse, then a HFS E over X is defined as

$$E = \{< x, h_E(x) > | x \in X\}, \tag{1}$$

where$h_E(x)$ symbolizes possible membership degrees of x to E, each of which is limited to [0,1].

In hesitant fuzzy sets, the length of the membership of M denoted by $l(h_M(x_i))$ does not mostly equal to that of N denoted by $l(h_N(x_i))$. In order to solve this problem, many studies have been conducted in this area. Xu and Xia[18] suggested that we should extend the shorter one depending on the decision maker's risk preferences until both of them have the same length. Optimists expect desirable results and should add the maximum value, while pessimists anticipate unfavorable outcomes and should add the minimal value. But it does not consider that the decision maker preference is risk-neutral. Therefore, according to the decision maker's all risk preference, Xu and Xia [19]develop a new method to overcome the drawback of [18].

An extension value $\bar{h} = \eta h^{+} + (1-\eta)h^{-}$ $(0 \le \eta \le 1)$ is introduced to obtain the decision results. The parameter η can reflect the decision maker's risk preference more accurately.

(1) if $\eta = 1$, it indicates that the decision maker's risk preference is risk-seeking;

(2) if $\eta = 0$,it indicates that the decision maker's risk preference is risk-averse;

(3) if $\eta = \frac{1}{2}$, it indicates that the decision maker's risk preference is risk-neutral .

Definition 2 [14-15]. Given three HFNs denoted by h, h_1 and h_2, their basic operations are defined as

(1) $h^c = \cup_{\gamma \in h}\{1-\gamma\}$;

(2) $h_1 \cup h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \max\{\gamma_1, \gamma_2\}$;

(3) $h_1 \cap h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} \min\{\gamma_1, \gamma_2\}$.

Here, h^c represents the complement of the HFN h.

Definition 3 [18]. Given three HFNs denoted by h, h_1 and h_2, their new basic operations are defined by Xia and Xu as follows:

(1) $h^\lambda = \cup_{\gamma \in h}\{\gamma^\lambda\}$;

(2) $\lambda h = \cup_{\gamma \in h}\{1-(1-\gamma)^\lambda\}$;

(3) $h_1 \oplus h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2}\{\gamma_1+\gamma_2-\gamma_1\gamma_2\}$;

(4) $h_1 \otimes h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2}\{\gamma_1\gamma_2\}$.

3.2. Aggregation Operators and Score Function

Based on the above operations, Xia and Xu [18] proposed a series of aggregation operators with hesitant fuzzy information.

Definition 4 [18]. Let $h_j (j = 1, 2, \ldots, n)$ be a collection of HFSs. A hesitant fuzzy weighted averaging (HFWA) operator is a mapping $H^n \rightarrow H$ such that

$$\mathrm{HFWA}(h_1, h_2, \ldots, h_n) = \mathop{\oplus}_{j=1}^{n}(w_j h_j) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n}\{1-\prod_{j=1}^{n}(1-\gamma_j)^{w_j}\}, \tag{2}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $h_j (j = 1, 2, \ldots, n)$ with $0 \le w_j \le 1$ $(j = 1, 2, \ldots, n)$ and $\sum_{i=1}^{n} w_j = 1$.

When $w = (1/n, 1/n, \ldots, 1/n)^T$, the HFWA operator reduces to the hesitant fuzzy averaging (HFA) operator:

$$\mathrm{HFA}(h_1, h_2, \ldots, h_n) = \mathop{\oplus}_{j=1}^{n}(\frac{1}{n}h_j) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n}\{1-\prod_{j=1}^{n}(1-\gamma_j)^{1/n}\}. \tag{3}$$

Definition 5 [18]. Let $h_j (j = 1, 2, \ldots, n)$ be a collection of HFSs. A hesitant fuzzy weighted geometric (HFWG) operator is a mapping $H^n \rightarrow H$ such that

$$\mathrm{HFWG}(h_1, h_2, \ldots, h_n) = \mathop{\oplus}_{j=1}^{n}(h_j^{w_j}) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n}\{\prod_{j=1}^{n}\gamma_j^{w_j}\}, \tag{4}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $h_j (j = 1, 2, \ldots, n)$ with $0 \le w_j \le 1$ $(j = 1, 2, \ldots, n)$ and $\sum_{i=1}^{n} w_j = 1$.

When $w = (1/n, 1/n, \ldots, 1/n)^T$, the HFWG operator reduces to the hesitant fuzzy geometric (HFG) operator:

$$\mathrm{HFG}(h_1, h_2, \ldots, h_n) = \mathop{\oplus}_{j=1}^{n}(h_j^{1/n}) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n}\{\prod_{j=1}^{n}\gamma_j^{1/n}\}. \tag{5}$$

Definition 6. Let $h_j (j = 1, 2, \ldots, n)$ be a collection of HFSs. A generalized hesitant fuzzy weighted averaging (GHFWA) operator is a mapping $H^n \rightarrow H$ such that

$$\mathrm{GHFWA}(h_1, h_2, \ldots, h_n) = \mathop{\oplus}_{j=1}^{n}(w_j h_j) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n}\{\left(1-\prod_{j=1}^{n}(1-\gamma_j^{\lambda})^{w_j}\right)^{1/\lambda}\}, \tag{6}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $h_j (j = 1, 2, \ldots, n)$ with $0 \le w_j \le 1$ $(j = 1, 2, \ldots, n)$ and $\sum_{i=1}^{n} w_j = 1$. Especially, if $\lambda = 1$, then the GHFWA operator reduces to the HFWA operator.

Definition 7. Let $h_j (j = 1, 2, \ldots, n)$ be a collection of HFSs. A hesitant fuzzy weighted geometric (HFWG) operator is a mapping $H^n \rightarrow H$ such that

$$\mathrm{GHFWG}(h_1, h_2, \ldots, h_n) = \overset{n}{\underset{j=1}{\oplus}} (h_j^{w_j}) = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2, \cdots, \gamma_n \in h_n} \{1 - \left(1 - \prod_{j=1}^{n} (1 - (1 - \gamma_j)^{\lambda})^{w_j}\right)^{1/\lambda}\}, \quad (7)$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $h_j (j = 1, 2, \ldots, n)$ with $0 \le w_j \le 1$ $(j = 1, 2, \ldots, n)$ and $\sum_{i=1}^{n} w_j = 1$. Especially, if $\lambda = 1$, then the GHFWG operator reduces to the HFWG operator.

Definition 8 Let h be a HFN. The score function of h can be obtained as follow:

$$S(h) = \frac{1}{l_h} \sum_{\gamma \in h} \gamma, \quad (8)$$

where l_h denotes the number of the elements in h.

Definition 9. For two HFN h_1 and h_2, we have

if $S(h_1) > S(h_2)$, then h_1 is better than or preferred to h_2, denoted by $h_1 \succ h_2$;

if $S(h_1) = S(h_2)$, then h_1 is indifferent to h_2, denoted by $h_1 \sqcup h_2$;

if $S(h_1) < S(h_2)$, then h_1 is worse than or less preferred to h_2, denoted by $h_1 \prec h_2$.

3.3. A New Assessment Framework

As mentioned in Section 1, it is significant to construct a new assessment framework with hesitant fuzzy multiple attribute decision making methods to help select a supplier more scientific and reasonable. Firstly, we development an assessment model based on the existing studies illustrated in Figure 1. We can propose a new method with hesitant fuzzy sets to form a MADM procedure via this assessment model.

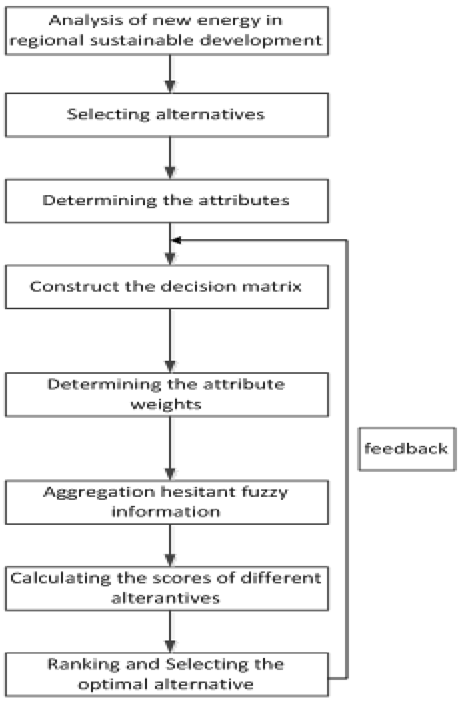

Figure 1. An Assessment Model of Selecting An Optimal Supplier

3.4. Procedure of the Proposed Method

According to this assessment model, we can propose a procedure to solve this MADM problem, where attribute values take the form of hesitant fuzzy elements. The procedure includes the following steps:

Step1. For a MADM problem, we construct the decision matrix $D = [\tilde{h}_{ij}]_{m \cdot n}$, where all the arguments $\tilde{h}_{ij}$ (i = 1, 2, ...,m; j = 1, 2, ..., n)are HFNs, given by the decision maker. As for every alternative A_i (i = 1, 2, ..., m), the decision maker is invited to express evaluation or preference according to each attribute C_j (j = 1, 2, ..., n) by a hesitant fuzzy number h_{ij} (i = 1, 2, ..., m; j = 1, 2, ..., n) and specifies the relative weights of the n attributes denoted as $w = (w_1, w_2, \ldots, w_n)^T$ with $0 \le w_j \le 1$ (j = 1, 2, ..., n)and $\sum_{i=1}^{n} w_j = 1$.Then we can obtain a decision making matrix as follow:

$$D_{m \times n} = \begin{bmatrix} \tilde{h}_{11} & \tilde{h}_{12} & \cdots & \tilde{h}_{1n} \\ \tilde{h}_{21} & \tilde{h}_{22} & \cdots & \tilde{h}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{h}_{m1} & \tilde{h}_{m2} & \cdots & \tilde{h}_{mn} \end{bmatrix} \tag{9}$$

Step 2. The generalized hesitant fuzzy weighted averaging (GHFWA) operator denoted as Eq.(6) or the generalized hesitant fuzzy weighted geometric (GHFWG) operator denoted as Eq.(7) are introduced to aggregate the hesitant fuzzy assessments. Then, the aggregated hesitant fuzzy numbers represent every alternative in MADM.
Step 3. The score function proposed in Definition 8 is used to compare every alternative in decision making matrix. The scores of the aggregated hesitant fuzzy numbers can be calculated.
Step 4. Through different scores of alternative, the rank-order can be obtained using the rule in Definition 9. Then, we can select the optimal alternative by the largest score.
Step 5. End.

4. Case Study

In this section, we shall utilize the proposed method to evaluate this assessment framework with hesitant fuzzy information. To select the optimal supplier to help company obtain more effective, the manager from the company as the decision maker chooses four supplier as the alternatives including A_1, A_2, A_3, A_4 from China. By existing studies, he identifies four attributes denoted as C_1, C_2, C_3, C_4 as discussed in Table 1.

Then, the four experts are invited to express their preferences to help the decision maker make decision. Firstly, they give the weight vector of these four attributes denoted as $w = (0.2, 0.3, 0.35, 0.15)^T$. Secondly, they give their preferences of every supplier on each attribute, respectively. Therefore, the decision maker combines the opinions of these experts to provide a hesitant fuzzy decision matrix $D = [\tilde{h}_{ij}]_{4 \cdot 4}$ illustrated in Table 2.

Table 2. Original Hesitant Fuzzy Decision Matrix

	A_1	A_2	A_3	A_4
C_1	{03,0.4,0.5}	{0.2,0.3}	{0.3,0.5,0.6}	{0.4,0.5}
C_2	{0.1,0.3}	{0.4,0.5,0.6}	{0.2,0.3,0.4}	{0.6,0.7}
C_3	{0.2,0.5,0.8}	{0.3,0.4}	{0.5,0.6}	{0.4,0.5,0.6}
C_4	{0.3,0.5}	{0.5,0.7,0.8}	{0.1,0.2,0.4}	{0.1,0.2}

Based on Section 2, we get the decision maker is risk-seeking by interviewing with him. Then, it can be derived that $\eta = 1$. Then, the normal decision matrix can be obtained. Because of the limited length of the article, it is omitted.

As mentioned in Definition 6 and Definition 7, suppose $\lambda = 1$, the hesitant fuzzy assessments can be aggregated through the generalized hesitant fuzzy weighted averaging (GHFWA) operator illustrated in Figures.2.

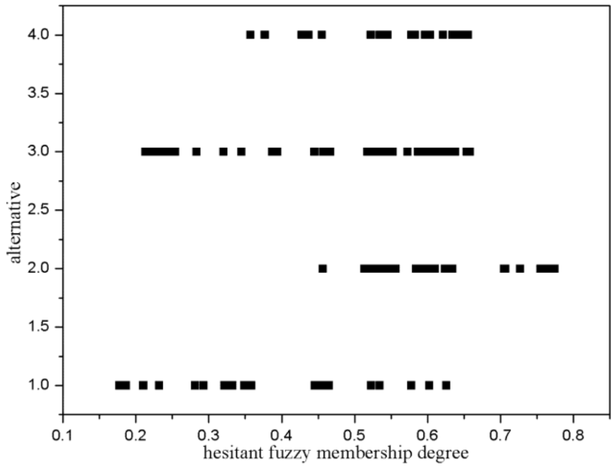

Figure 2. Hesitant Fuzzy Elements of Alternatives by GHFWA

Based on Definitions 8 and 9, it can be generated the scores of each alternative illustrated in Table 3.

Table 3. Scores and Rank-Order

	score	rank
A_1	0.3157	4
A_2	0.5825	1
A_3	0.5019	2
A_4	0.3946	3

From Table 3, the rank-order is demonstrated as $A_2 \succ A_3 \succ A_4 \succ A_1$. It is obvious to select that A_2 is the optimal region that the supplier is better to help company obtain more benefits than others. Therefore, the case study demonstrate that this assessment framework can better express the decision maker's preference more accurately and can be applied in more multiple decision making problems.

5. Conclusion and Further Study

The supplier selection is related to the product quality. So, the proper assessment of supplier is very necessary. In this paper, we evaluate the supplier though the new multiple attribute decision making method based on generalized hesitant fuzzy aggregation operator. Because of the inherent vagueness of human preferences as well as the objects being fuzzy and uncertain, the attributes involved in decision making problems are not always expressed in real numbers, and some are better suited to be denoted by fuzzy values, such as hesitant fuzzy values. Then, we introduce hesitant fuzzy sets to solve the assessment issue of selecting optimal supplier. In this paper, we introduce generalized hesitant fuzzy weighted averaging (GHFWA) operator and generalized hesitant fuzzy weighted geometric (GHFWG) operator as well as construct an assessment framework to solve this multiple attribute decision making problems. Finally, a case study is demonstrated to verify the reliability and practicability of the proposed method.

Although the method is useful to evaluate this issue, it cannot solve the problems with many experts. In the further study, we will research it.

Acknowledgments

This work is supported by Fujian Province Department of Education social science research project (project number: 2014R0048) of the initial results.

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