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An Interactive Decision-Making Method for Third-Party Logistics Provider Selection under Hybrid Multi-Criteria

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Abstract: Due to the complexity and uncertainty of third-party logistics (3PL) provider selection circumstances, the research on the hybrid multi-criteria decision-making (HMCDM) method with fuzzy hesitation information is becoming more and more important. Based on symmetry principles, both the objectivity of the decision information and the subjectivity of decision makers' (DMs) preferences should be considered in the HMCDM method. In this paper, a novel interactive decision-making method to deal with the 3PL provider selection problem of hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers is developed. We first investigate the positive and negative ideal solutions of the alternative and the satisfaction degree of the DMs under hybrid multi-criteria circumstances. Then, the interactive HMCDM models based on satisfaction degrees are established, which can use objective decision information to rank alternatives and, symmetrically, the preference information of the DMs is also taken into account. DMs can modify their preference information using the models and thus make the most reasonable selection of 3PL provider. Finally, the case analysis and sensitivity analysis show that the change of parameter and the setting of the satisfaction lower limit will not affect the optimal rank of alternatives, and the feasibility of the proposed method is confirmed.

Keywords: hybrid multi-criteria decision-making; interactive method; third-party logistics provider; hesitant fuzzy set; intuitionistic fuzzy set

1. Introduction

With the rapid development of logistics management and practice, logistics outsourcing has already become an important way to reduce cost and improve service level for most manufacturing enterprises [1,2]. Third-party logistics (3PL) providers are the main undertakers of logistics outsourcing activities, as they provide comprehensive logistics services for manufacturers and professional logistics providers [3]. Selecting the right 3PL provider as a business partner is the premise of logistics outsourcing for manufacturing enterprises [4].

In general, 3PL provider selection is a multi-criteria decision-making (MCDM) problem. Many of the main MCDM methods have been used in 3PL provider selection, including Delphi [5,6], analytic hierarchy process (AHP) [7,8], fuzzy analytic hierarchy process (FAHP) [9,10], grey relational analysis (GRA) [11,12], data envelopment analysis (DEA) [13,14], technique for order preference by similarity to an ideal solution (TOPSIS) [15–17], entropy weight-TOPSIS [18], and multi-criteria optimization and compromise solution (VIKOR) [19,20]. In addition, other methods including quality function deployment (QFD) [21,22], back-propagation neural network [23,24] and support vector machine (SVM) [25,26] have been applied to solve the 3PL provider selection problem. The existing approaches can only be used to deal with the problem insofar as multiple criteria of 3PL provider selection have the same types of decision information, such as real numbers [5–7,9–16,18,19,25], interval numbers [27], triangular fuzzy numbers [28], intuitionistic fuzzy sets [29] and fuzzy language [30,31]. However, due to the complexity of the 3PL provider selection problem, the criterion type cannot be limited to one, but should rather be a mixture of two or more types [32]. It is a challenge to choose a 3PL provider under hybrid multi-criteria.

As 3PL provider selection issues become more complex, they essentially become a hybrid multi-criteria decision-making (HMCDM) problem [33]. Recently, a large number of HMCDM problems have appeared in the fields of social management, economic activities and large-scale engineering projects etc. [34–40]. However, there has been no application of such methods on the issue of 3PL provider selection. At present, the research on HMCDM has mainly focused on several hybrid types of decision information, such as real numbers, interval numbers, fuzzy numbers, intuitionistic fuzzy sets and linguistic variables etc. Wei [41] investigated the hybrid multi-criteria problems of real numbers, interval numbers and triangular fuzzy numbers, which obtained the ideal alternatives based on GRA. For the hybrid multi-criteria problem of real numbers and fuzzy linguistics, Ko [42] constructed a decision matrix by converting different information types into real numbers and used the QFD method to sort the alternatives. Zhao [43] et al. analyzed the hybrid decision information types of intuitionistic fuzzy sets, interval intuitionistic fuzzy sets and linguistic variables, and obtained the decision results by converting the linguistic variable information into triangular fuzzy numbers. Herrera [44] et al. converted numerical and linguistic variables into 2-tuple fuzzy linguistics and studied the HMCDM problem. Yucesan [45] et al. proposed a method for transforming fuzzy sets into real numbers, and used the TOPSIS method to rank the decision alternatives. Wang [46] et al. investigated the MCDM problem under the hybrid types of real numbers and fuzzy linguistics, and used Bonferroni mean operators to sort the decision alternatives. Deveci [47] designed a HMCDM approach combining the hybrid criterion types of hesitant and interval type 2 fuzzy sets to assess the service quality of airline companies. In view of the uncertainty in the decision-making process, Deveci [48] integrated the PCA and QFD methods with interval-valued intuitionistic fuzzy sets, aiming to evaluate service quality in public bus transportation. In recent years, the research on MCDM problems with hesitant fuzzy sets has become a hot topic [49–53]. However, the approach of HMCDM with hesitant fuzzy information has not yet been seen.

Because of the uncertainty of the evaluation circumstances and the incompleteness of the decision information in MCDM process, the subjective preference of DMs is often inconsistent with the evaluation results [54]. Interactive decision-making methods can build the model according to objective decision information and the subjective preference of DMs. By using the feedback, the difference between evaluation results and the preference of DMs can be reduced and, finally, an optimal alternative satisfying the requirements of the DMs can be obtained. Sakawa [55] first designed an interactive multi-objective 0–1 program with fuzzy numbers to reflect the preferences of the DMs. The interactive decision-making method has attracted more and more scholars' attention recently, whose main results have focused on a single type of decision information, such as real numbers [56], triangular fuzzy numbers [57], linguistic variables [58,59], intuitionistic fuzzy sets [60], hesitant fuzzy sets [61] and probability hesitant fuzzy sets [62]. There has been little research on interactive decision-making methods under hybrid multi-criteria.

For the complexity and uncertainty of the 3PL provider selection problem, the criterion types are usually more than two and come with hesitant fuzziness. However, the existing interactive decision-making methods are limited to a single criterion type and the lack of hesitant fuzzy information. In this paper, which considers hesitant fuzzy sets, intuitionistic fuzzy sets and exact numerical values as hybrid multi-criteria, a novel interactive HMCDM method is proposed.

The main contributions of this work are as follows. Firstly, the proposed interactive method can solve the HMCDM problem under hybrid multi-criteria with hesitant fuzzy sets. Secondly, this method can directly use the original decision information to determine the weight and rank of the alternatives, so as to avoid the information loss caused by different criterion type conversions. Thirdly, in the interactive HMCDM method, the satisfaction function reflecting the DMs' preference is introduced to solve the problem where the evaluation results may be inconsistent with the DMs' subjective preference.

The rest of this paper is organized as follows. The selection criteria for 3PL providers and some related definitions are given in the next section. In Section 3, the satisfaction function of DMs for alternatives under hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers is introduced. The interactive HMCDM method and its implementation procedure are developed based on the satisfaction function. In Section 4, a practical case of a Chinese airport company for 3PL provider selection is presented to illustrate the application of our models. Section 5 provides the sensitivity analysis to demonstrate the feasibility of the proposed approach. Some suggestions for future research are discussed in Section 6.

2. Preliminaries

2.1. Selection Criteria for 3PL Providers

For the selection criteria of 3PL providers, most of the research has mainly focused on cost, delivery, service quality, the ability to provide relevant information, financial condition, and so on. A brief list of the most critical criteria of 3PL provider selection is shown in Table 1.

Generally, the total assets, transport cost, delivery time, transport equipment and employee structure can be represented by real numbers, as shown in Table 1. However, the process of 3PL provider selection is characterized by the inaccuracy and uncertainty of practical criteria, as well as the appearance of confusion in human thinking. Since linguistic terms are preferred in 3PL provider selection, intuitionistic fuzzy sets are used for the linguistic ratings, such as customer satisfaction and user compatibility in Table 1. Not only the membership and non-membership but also the hesitation is used to characterize the vagueness and uncertainty in 3PL provider selection, where the evaluations of personalized service and technology level in Table 1 are represented by hesitant fuzzy sets.

Table 1. Key criteria for 3PL provider selection.

Variable	Criterion	Definition	Authors
Y_1	Total assets	All assets owned by a logistics enterprise	Wang et al. [14], Prakash and Barua [16], Huang et al. [18], Guarnieri et al. [63], Aguezzoul and Aicha [64]
Y_2	Transport cost	Costs related to logistics activities	Stefan et al. [9], Yu et al. [12], Patricija and Suban [13], Sremac et al. [15], Guarnieri et al. [63], Zarbakhshnia et al. [65]
Y_3	On time rate	Logistics delivery on time rate	Stefan et al. [9], Patricija and Suban [13], Sremac et al. [15], Guarnieri et al. [63], Zarbakhshnia et al. [65], Li et al. [66]
Y_4	Customer satisfaction	Matching degree of customer expectation and customer experience	Patricija and Suban et al. [13], Guarnieri et al. [63], Aguezzoul and Aicha [64], Zarbakhshnia et al. [65], Li et al. [66] Senthil et al. [67], Zouggari and Benyoucef [68]
Y_5	Personalized service	Diversification degree of logistics products and services	Prakash and Barua [20], Guarnieri et al. [63], Aguezzoul and Aicha [64], Zarbakhshnia et al. [65], Li et al. [66], Senthil et al. [67], Zouggari and Benyoucef [68]
Y_6	User compatibility	Degree of information sharing with user	Shan [29], Feng et al. [69]
Y_7	Transport equipment	Number of transportation equipment	Shan [29], Feng et al. [69]
Y_8	Employee structure	Proportion of employees with bachelor degree or above in the total number of employees	Sremac et al. [15], Huang et al. [18], Guarnieri et al. [63], Zarbakhshnia [65], Li et al. [66], Senthil [67]
Y_9	Technology level	Technical development ability to monitor and implement logistics activities	Stefan et al. [9], Sremac et al. [15], Prakash and Barua et al. [20], Guarnieri et al. [63], Aguezzoul and Aicha [64], Arpachshad et al. [65]

2.2. Related Definitions

Hesitant fuzzy sets are very useful in dealing with situations where DMs have hesitancy in determining their preference of criteria for 3PL provider selection. Considering that some of the criteria for 3PL provider selection are in linguistic form, intuitionistic fuzzy sets are more comprehensively applied to the linguistic ratings.

Definition 1. [70] *Let T be a given finite set; a hesitant fuzzy set on T is in terms of a function that, when applied to T, returns a subset of* $[0,1]$*, which can be represented as the following mathematical symbol:*

$$H = \{< t, h_H(t) > \big| t \in T\} \tag{1}$$

where $h_H(t)$ *is a set of values of* $[0,1]$*, denoting the possible membership degree of the element* $t \in T$ *to the set H. A hesitant fuzzy element* $h_H(t)$ *can be expressed as h for short.*

Definition 2. *Let* H_1 *and* H_2 *be two hesitant fuzzy sets, and l be denoted the number of hesitant fuzzy elements of* H_1 *and* H_2*. For illustration purposes, we show it with the same number of hesitant fuzzy elements. Then, the distance measured between* H_1 *and* H_2 *is defined as*

$$d(H_1, H_2) = \frac{1}{l}\sum_{\lambda=1}^{l}\left|h_1^{\lambda} - h_2^{\lambda}\right| \tag{2}$$

Definition 3. *Let* H_1 *and* H_2 *be two hesitant fuzzy sets; then, the distance measure* $d(H_1, H_2)$ *between* H_1 *and* H_2 *should satisfy the following properties:*

(1) $d(H_1, H_2) \geq 0$;
(2) $d(H_1, H_2) = 0$ *if and only if* $H_1 = H_2$;
(3) $d(H_1, H_2) = d(H_2, H_1)$.

Definition 4. [71] *Let T be a given finite set; an intuitionistic fuzzy set on T can be defined as:*

$$\mathrm{I} = \{< t, \mu_I(t), \nu_I(t) > \big| t \in T\} \tag{3}$$

where $0 \leq \mu_I(t) \leq 1$ *and* $0 \leq \nu_I(t) \leq 1$ *represent the membership function and the non-membership function respectively, and* $0 \leq \mu_I(t) + \nu_I(t) \leq 1$*. For convenience,* $\mu_I(t)$ *and* $\nu_I(t)$ *are denoted by* μ *and* ν *respectively.*

Definition 5. *Let* I_1 *and* I_2 *be two intuitionistic fuzzy sets; then, the distance measure between* I_1 *and* I_2 *is defined as*

$$d(I_1, I_2) = \frac{1}{2}(|\mu_1 - \mu_2| + |\nu_1 - \nu_2|) \tag{4}$$

Definition 6. *The distance measure* $d(I_1, I_2)$ *between* I_1 *and* I_2 *should satisfy the following properties:*

(1) $d(I_1, I_2) \geq 0$;
(2) $d(I_1, I_2) = 0$ *if and only if* $I_1 = I_2$;
(3) $d(I_1, I_2) = d(I_2, I_1)$.

Definition 7. *Let* E_1 *and* E_2 *be two real numbers; the distance measure* $d(E_1, E_2)$ *between* E_1 *and* E_2 *is represented as*

$$d(E_1, E_2) = \left|E_1 - E_2\right| \tag{5}$$

3. Interactive HMCDM Method

3.1. Description of a HMCDM Problem

For a HMCDM problem, there is a discrete set of m alternatives $X = \{X_1, X_2, \cdots, X_m\}(\mathrm{m} \geq 2)$ and a finite set of n criteria $Y = \{Y_1, Y_2, \cdots, Y_n\}(n \geq 3)$. For the alternative $X_i(i = 1, 2, \cdots, m)$ under the criteria $Y_j(j = 1, 2, \cdots, n)$, the evaluation results of the DMs can be known as $A_{ij}(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$. The weight vector of criteria Y_j can be represented by $w = (w_1, w_2, \cdots, w_n)^T$, where $0 \leq w_j \leq 1(j = 1, 2, \cdots, n; n \geq 3)$ and $\sum_{j=1}^{n} w_j = 1$.

If the set of all possible evaluations for the alternative X_i under the criteria Y_j can be considered as a hesitating fuzzy set $H_{ij}(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$, then let $A_{ij} = H_{ij} = \left\{{h_{ij}}^1, {h_{ij}}^2, \cdots, {h_{ij}}^{l_{H_{ij}}}\right\}$, where $l_{H_{ij}}$ is the number of hesitant fuzzy elements in H_{ij}. In general, the numbers of elements in two hesitant fuzzy sets H_1 and H_2 are different, so it is hard to compare different alternatives under the same criterion. For the hesitant fuzzy set with the lower elements number, the method [72] was used in this paper to add the largest hesitant fuzzy element into it until the number of elements in the two hesitant fuzzy sets is the same. For example, if $H_1 = \{0.1, 0.2, 0.3\}$ and $H_2 = \{0.4, 0.5\}$, H_2 can be extended to $H_2 = \{0.4, 0.5, 0.5\}$.

If the set of all possible evaluations for the alternative X_i under the criteria Y_j can be considered as an intuitionistic fuzzy set $I_{ij}(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$, then let $A_{ij} = I_{ij} = (\mu_{ij}, \nu_{ij})$, where μ_{ij} and ν_{ij} indicate the membership and non-membership degree of the alternative X_i under the criteria Y_j respectively.

If the evaluation results of the alternative X_i under the criteria Y_j are real numbers $E_{ij}(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$, then let $A_{ij} = E_{ij}$. In order to eliminate the dimension difference between real numbers, a normalization transformation [73] was introduced to make $0 \leq E_{ij} \leq 1$.

By using the above normalized hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers, an initial decision matrix under hybrid multi-criteria can be written as

$$A = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix} \tag{6}$$

where A_{ij} can be hesitant fuzzy set H_{ij}, intuitionistic fuzzy set I_{ij} and real number E_{ij}.

3.2. Setting the Ideal Solution of Hybrid Multi-Criteria

In order to describe the satisfaction of the DMs for the alternative X_i under the criteria Y_j, the positive ideal solution ${A_{ij}}^+(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$ and negative ideal solution ${A_{ij}}^-(i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3)$ should be set.

When A_{ij} is a hesitant fuzzy set, if the DMs are very satisfied with the alternative X_i under the criteria Y_j, they will not hesitate to give their evaluation results "1". At this time, the hesitant fuzzy element is 1. When all of the hesitant fuzzy elements are 1 in the hesitant fuzzy set A_{ij}, ${A_{ij}}^+ = \{1, 1, \cdots, 1\}$ is the positive ideal solution of the alternative X_i under the criteria Y_j. If DMs are very dissatisfied with the alternative X_i under the criteria Y_j, they will not hesitate to give their evaluation result "0" directly. When all of the hesitant fuzzy elements in the hesitant fuzzy set are 0, ${A_{ij}}^- = \{0, 0, \cdots, 0\}$ is the negative ideal solution of the alternative X_i under the criteria Y_j.

When A_{ij} is an intuitionistic fuzzy set, if DMs believe that the alternative X_i completely meets their requirements for criteria Y_j and they have no objection, the intuitionistic fuzzy set is $(1, 0)$. Therefore, the positive ideal solution of the alternative X_i under the criteria Y_j can be denoted by ${A_{ij}}^+ = (1, 0)$. If DMs think that the alternative X_i does not meet the requirements of DMs under criteria Y_j at all and they give the negative evaluation results, the intuitionistic fuzzy set is $(0,1)$. Therefore, the negative ideal solution of the alternative X_i under the criteria Y_j can be represented as $A_{ij}{}^{-} = (0,1)$.

When A_{ij} is a real number, if the alternative X_i fully meets the requirements of DMs under the criteria Y_j, the evaluation result of DMs is usually 1. Therefore, the positive ideal solution of the alternative X_i under the criteria Y_j can be set to $A_{ij}{}^{+} = 1$. If an alternative X_i does not meet DMs' requirements for the criteria Y_j at all, the evaluation result is 0. Therefore, the negative ideal solution of the alternative X_i under the criteria Y_j can be represented as $A_{ij}{}^{-} = 0$.

In a HMCDM process with hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers, in order to describe the DMs' preference for the alternative under a different criterion, the satisfaction function can be constructed by using the weighted distance measures between the evaluation results, which are represented by positive and negative ideal solutions. The satisfaction function $S_i(w)(i = 1,2,\cdots,m; m \geq 2)$ for the given alternative X_i under the criteria Y_j with the weight vector $w = (w_1, w_2, \cdots, w_n)^T$ is defined as

$$S_i(w) = \frac{(1-\theta)\sum\limits_{j=1}^{n} w_j d(A_{ij}, A_{ij}{}^{-})}{\theta \sum\limits_{j=1}^{n} w_j d(A_{ij}, A_{ij}{}^{+}) + (1-\theta)\sum\limits_{j=1}^{n} w_j d(A_{ij}, A_{ij}{}^{-})} \tag{7}$$

where the parameter θ represents the DMs' preference, $0 \leq w_j \leq 1$, and $\sum\limits_{j=1}^{n} w_j = 1$. For an alternative X_i, when the evaluation results are of hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers, $d(A_{ij}, A_{ij}^{+})$ and $d(A_{ij}, A_{ij}^{-})$ are distance measures between the positive and negative ideal solution of the evaluation results A_{ij}. The value of $d(A_{ij}, A_{ij}^{+})$ and $d(A_{ij}, A_{ij}^{-})$ can be calculated by the corresponding Equations (2), (4) and (5) respectively.

Usually the value of θ can be given by DMs in advance: $0 < \theta < 1$. θ can be adjusted according to the DMs' preference. When $\theta > 0.5$, it indicates that the DMs are pessimists. Under the same conditions, the higher the value of θ, the lower the satisfaction. When $\theta < 0.5$, it means that the DMs are optimistic. Satisfaction increases as the value of θ decreases under the same conditions.

3.3. Interactive Decision-Making Process

In a HMCDM process, DMs have their own subjective preferences for different alternatives, which leads to their satisfaction degree with some alternatives being too high and simultaneously too low with others. As our purpose is to select the alternative with the optimal satisfaction degree, several interactive HMCDM models, based on the satisfaction function, should be established to facilitate DMs to provide a new satisfaction degree or modify the previous satisfaction degree.

An initial interactive HMCDM model is constructed to obtain the initial satisfaction degree of DMs for the alternatives. Then, the first interactive HMCDM model is developed according to the limit of the initial satisfaction degree. The weights can be obtained by solving this model, and the satisfaction degree for the alternatives can be determined. If the satisfaction degree cannot be accepted by DMs, they have to adjust the limit of the satisfaction degree and reestablish a new interactive HMCDM model until the acceptable satisfaction is achieved. Through several interactions of the DMs' preference information in the models, the limit of the satisfaction degree can be modified and gradually improved until the acceptable satisfaction degree is finally obtained.

In order to obtain the initial satisfaction degree of the DMs, an initial interactive HMCDM model based on the satisfaction function $S_i(w)$ for the alternative X_i is constructed, as shown in Equation (8):

$$\max \zeta$$
$$s.t.\begin{cases} S_i(w) \geq \zeta \\ w = (w_1, w_2, \cdots, w_n)^T \in W \\ \sum\limits_{j=1}^{n} w_j = 1 \\ w_j \geq 0; i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3 \end{cases} \tag{8}$$

where $w = (w_1, w_2, \cdots, w_n)^T \in W$, W is a collection of weight vectors. Generally, there are five different representations of a weight vector [74], as follows:

(1) $\{w_{j_1} \geq w_{j_2}\}(j_1 \neq j_2)$;
(2) $\{w_{j_1} - w_{j_2} \geq \alpha\}(j_1 \neq j_2; \alpha > 0)$;
(3) $\{w_{j_1} - w_{j_2} \geq w_{j_3} - w_{j_4}\}(j_1 \neq j_2 \neq j_3 \neq j_4)$;
(4) $\{w_{j_1} \geq \alpha w_{j_2}\}(j_1 \neq j_2; 0 \leq \alpha \leq 1)$;
(5) $\{\alpha \leq w_j \leq \alpha + \beta\}(0 \leq \alpha \leq \alpha + \beta \leq 1)$

where α and β are parameters of a weight vector. The appropriate weight representation in Equation (8) will be selected.

The initial weight vector $w^0 = (w_1{}^0, w_2{}^0, \cdots, w_n{}^0)^T$ can be obtained by solving the above HMCDM model. Using the initial weight, the initial satisfaction degree of DMs for the alternative X_i can be calculated according to Equation (7), denoted as $S_i(w^0)$. If the initial satisfaction degree of each alternative meets the expectation of the DMs, the optimal rank of alternatives satisfying DMs can be obtained. Otherwise, the limit of the satisfaction degree for the alternatives $\zeta_i^t(i = 1, 2, \cdots, m; m \geq 2)$ can be set by means of the initial satisfaction function $S_i(w^0)$. Based on the limit, the t^{th} interactive HMCDM model can be constructed, as shown in Equation (9):

$$\max \sum_{i=1}^{n} S_i(w^t)$$
$$s.t.\begin{cases} S_i(w^t) \geq \zeta_i{}^t \\ w = (w_1{}^t, w_2{}^t, \cdots, w_n{}^t)^T \in W \\ \sum\limits_{j=1}^{n} w_j{}^t = 1 \\ w_j{}^t \geq 0; i = 1, 2, \cdots, m; m \geq 2; j = 1, 2, \cdots, n; n \geq 3 \end{cases} \tag{9}$$

where $t(t \geq 1)$ is the number of the interactive process. The weight vector $w^t = (w_1{}^t, w_2{}^t, \cdots, w_n{}^t)^T$ can be obtained by solving the interactive HMCDM Equation (9). If the model has no optimal solution, it means that some limits should be less than the current satisfaction degree of DMs. Thus, a new limit of satisfaction should be set and the interactive HMCDM model should be reestablished until the optimal weights can be solved by the model, and the ideal satisfaction degree for the alternative X_i under the criteria Y_j can then be obtained. Once the decision makers achieve their expected satisfaction, the iterative process of the Equation (9) can be completed.

Based on the above interactive HMCDM method, the process of 3PL provider selection can be divided into three phases. In phase I, it aims to collect and normalize the information of 3PL provider selection. Based on the decision matrix of hybrid multi-criteria in phase I, an initial interactive HMCDM model is constructed and used to obtain the initial satisfaction degree of DMs for the alternatives in phase II. The goal in phase III is to obtain the optimal weight vector and satisfaction degree by solving the interactive HMCDM models. The steps of the proposed interactive HMCDM method are shown in Figure 1.

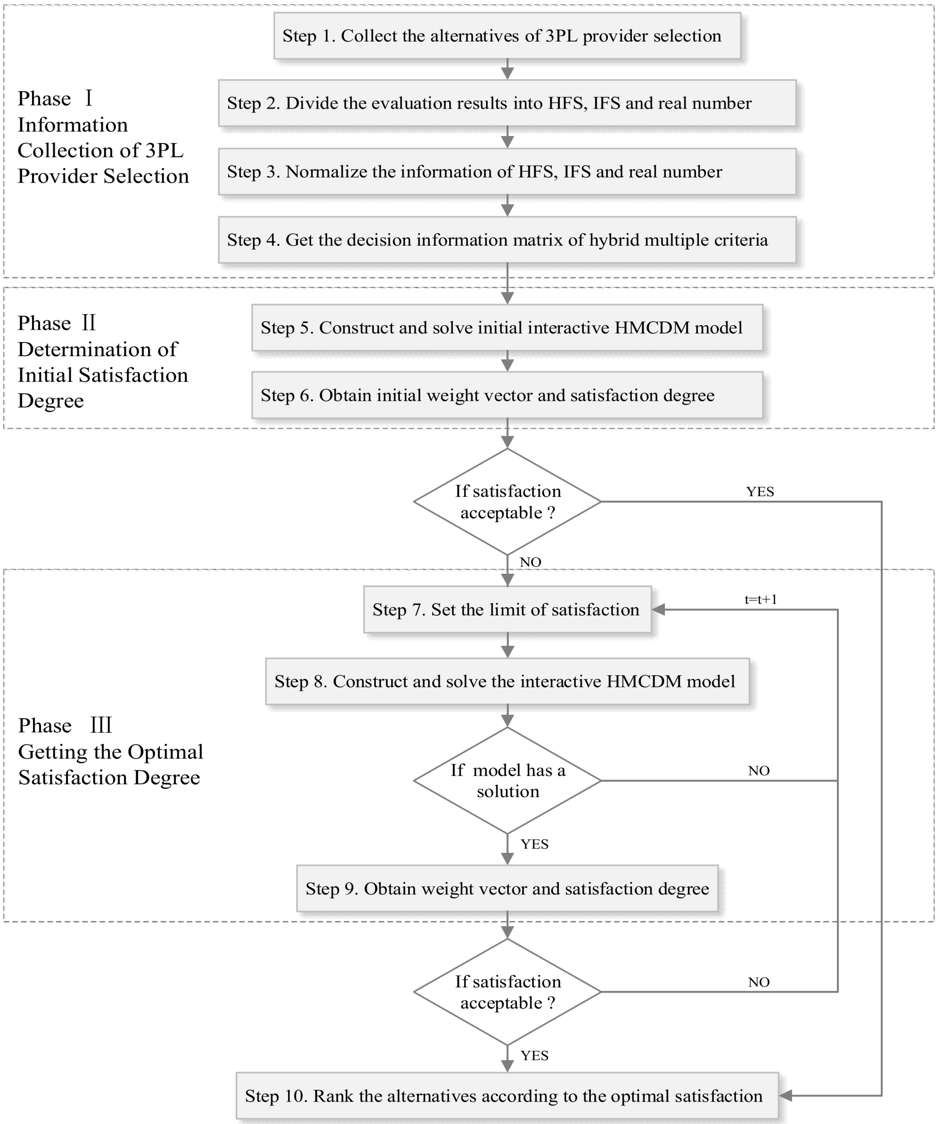

Figure 1. The steps of the proposed interactive HMCDM method.

4. Case Study

With the expansion of the airport and the increase in air cargo business, the existing 3PL providers have been unable to meet the needs of the airport's transportation. In this section, we consider an illustrative case in which a Chinese airport company wants to evaluate and select five potential 3PL providers, denoted as $\{X_1, X_2, X_3, X_4, X_5\}$. X_1, X_2, X_3, X_4 and X_5 are CS, CE, AC, H and S airline companies, respectively. The five companies are both passenger and cargo airlines, and they account for a major share of China's air logistics market. For convenience, total assets Y_1, transport cost Y_2, customer satisfaction Y_3, personalized service Y_4 and technology level Y_5 are taken as the criteria for 3PL provider selection.

As mentioned above, total assets Y_1 and transport cost Y_2 are usually expressed in real numbers that can be collected from the annual reports of the logistics company. For customer satisfaction Y_3, DMs prefer to give their evaluations in linguistic terms of belonging or non-belonging. For two criteria, personalized service Y_4 and technical level Y_5, the DMs are hesitant. It is hard to give a definite result and the DMs often give multiple evaluation values. Therefore, for the alternatives $X_i (i = 1, 2, 3, 4, 5)$, the evaluations A_{i1} and A_{i2} are real numbers under criterion Y_1 and Y_2 respectively,

A_{i3} is an intuitionistic fuzzy set under criterion Y_3, and A_{i4} and A_{i5} are hesitant fuzzy sets under criteria Y_4 and Y_5 respectively.

In order to solve the 3PL provider selection problem under hybrid multi-criteria, the decision-making information is collected and normalized, for which the decision matrix $A = (A_{ij})_{5*5}$ is shown in Table 2.

Table 2. The decision information under hybrid multi-criteria.

Alternative	Criteria				
	Y1	**Y2**	**Y3**	**Y4**	**Y5**
X1	0.57	0.45	(0.8, 0.2)	(0.7, 0.75, 0.8, 0.9)	(0.5, 0.7, 0.9, 0.9)
X2	0.48	0.47	(0.6, 0.4)	(0.6, 0.7, 0.7, 0.7)	(0.3, 0.5, 0.5, 0.5)
X3	0.66	0.46	(0.6, 0.4)	(0.7, 0.75, 0.8, 0.8)	(0.5, 0.7, 0.9, 0.9)
X4	0.08	0.33	(0.8, 0.2)	(0.6, 0.7, 0.8, 0.8)	(0.5, 0.7, 0.9, 0.9)
X5	0.01	0.51	(0.6, 0.4)	(0.1, 0.2, 0.2, 0.2)	(0.5, 0.7, 0.9, 0.9)

In the process of the five 3PL provider selections, the importance of the criteria is investigated. It is found that the criterion 'total assets' was the most important, and that personalized service takes precedence over technology level. Customer satisfaction is more important than transport cost and personalized service. Transport cost is greater than average 0.2. Therefore, the relationship between the weights can be obtained as follows:

$$w_1 > w_3 > w_2; w_3 > w_4 > w_5; w_2 > 0.2$$

Since the satisfaction degree of the DMs for each alternative in actual 3PL provider selection is relatively low, $\theta = 0.7$ can be taken in Equation (7). In order to obtain the initial satisfaction degree of the DMs for the alternatives, an initial interactive HMCDM model for 3PL provider selection can be constructed, as shown in Equation (10).

$$\max \zeta$$
$$s.t.\begin{cases} \frac{0.1722w_1+0.135w_2+0.21w_3+0.2363w_4+0.225w_5}{0.4704w_1+0.52w_2+0.42w_3+0.385w_4+0.4w_5} \geq \zeta \\ \frac{0.1424w_1+0.141w_2+0.18w_3+0.225w_4+0.135w_5}{0.5101w_1+0.5120w_2+0.46w_3+0.43w_4+0.52w_5} \geq \zeta \\ \frac{0.1988w_1+0.138w_2+0.15w_3+0.2288w_4+0.225w_5}{0.4349w_1+0.516w_2+0.5w_3+0.395w_4+0.4w_5} \geq \zeta \\ \frac{0.0228w_1+0.099w_2+0.24w_3+0.2175w_4+0.225w_5}{0.6696w_1+0.568w_2+0.38w_3+0.41w_4+0.4w_5} \geq \zeta \\ \frac{0.004w_1+0.153w_2+0.18w_3+0.0525w_4+0.225w_5}{0.6947w_1+0.496w_2+0.46w_3+0.63w_4+0.4w_5} \geq \zeta \\ w_1 > w_3 > w_2; w_3 > w_4 > w_5; w_2 > 0.2; \sum_{j=1}^{5} w_j = 1 \\ w_j \geq 0; i = 1,2,3,4,5; j = 1,2,3,4,5 \end{cases} \tag{10}$$

The initial weight vector $w^0 = (w_1{}^0, w_2{}^0, w_3{}^0, w_4{}^0, w_5{}^0)^T = (0.24, 0.22, 0.23, 0.16, 0.15)^T$ and the initial satisfaction degree $S_i(w^0) = \left(S_1(w^0), S_2(w^0), S_3(w^0), S_4(w^0), S_5(w^0)\right)^T = (0.4284, 0.3331, 0.4011, 0.3028, 0.2178)^T$ can be obtained by solving the Equation (10). Since the DMs are not yet satisfied with the initial satisfaction, they modify the limit of the satisfaction degree. Suppose that the modified limit is $\zeta_i{}^1 = (\zeta_1^1, \zeta_2^1, \zeta_3^1, \zeta_4^1, \zeta_5^1)^T = (0.43, 0.33, 0.4, 0.3, 0.2)^T$; the first interactive HMCDM model can be set up as follows:

$$\max \sum_{i=1}^{5} S_i\left(w^1\right)$$
$$s.t.\begin{cases} \frac{0.1722w_1{}^1+0.135w_2{}^1+0.21w_3{}^1+0.2363w_4{}^1+0.225w_5{}^1}{0.4704w_1{}^1+w_2{}^1+0.42w_3{}^1+0.385w_4{}^1+0.4w_5{}^1} \geq 0.43 \\ \frac{0.1424w_1{}^1+0.141w_2{}^1+0.18w_3{}^1+0.225w_4{}^1+0.135w_5{}^1}{0.5101w_1{}^1+0.5120w_2{}^1+0.46w_3{}^1+0.43w_4{}^1+0.52w_5{}^1} \geq 0.33 \\ \frac{0.1988w_1{}^1+0.138w_2{}^1+0.15w_3{}^1+0.2288w_4{}^1+0.225w_5{}^1}{0.4349w_1{}^1+0.516w_2{}^1+0.5w_3{}^1+0.395w_4{}^1+0.4w_5{}^1} \geq 0.4 \\ \frac{0.0228w_1{}^1+0.099w_2{}^1+0.24w_3{}^1+0.2175w_4{}^1+0.225w_5{}^1}{0.6696w_1{}^1+0.568w_2{}^1+0.38w_3{}^1+0.41w_4{}^1+0.4w_5{}^1} \geq 0.3 \\ \frac{0.004w_1{}^1+0.153w_2{}^1+0.18w_3{}^1+0.0525w_4{}^1+0.225w_5{}^1}{0.6947w_1{}^1+0.496w_2{}^1+0.46w_3{}^1+0.63w_4{}^1+0.4w_5{}^1} \geq 0.2 \\ w_1{}^1 > w_3{}^1 > w_2{}^1; w_3{}^1 > w_4{}^1 > w_5{}^1; w_2{}^1 > 0.2; \sum_{j=1}^{5} w_j{}^1 = 1 \\ w_j{}^1 \geq 0; i = 1,2,3,4,5; j = 1,2,3,4,5 \end{cases} \tag{11}$$

The weight vector $w^1 = (w_1{}^1, w_2{}^1, w_3{}^1, w_4{}^1, w_5{}^1)^T = (0.23, 0.21, 0.22, 0.18, 0.16)^T$ and the satisfaction degree $S_i(w^1) = \left(S_1(w^1), S_2(w^1), S_3(w^1), S_4(w^1), S_5(w^1)\right)^T = (0.4348, 0.3351, 0.4077, 0.3113, 0.2177)^T$ can be obtained respectively by solving the Equation (11). If this satisfaction degree can be accepted by the DMs, it means the optimal satisfaction degree for five 3PL providers is obtained by the Equation (11). According to the priority relationship $S_1(w^1) > S_3(w^1) > S_2(w^1) > S_4(w^1) > S_5(w^1)$, X_1 is the best among five 3PL providers, which is the right selection for the Chinese airport company.

5. Sensitivity Analysis

In this section, sensitivity analysis is carried out to show the performance of the proposed method, which can be divided into two parts. One part relates to the change of parameter θ and the other to the setting of the limit of satisfaction.

The cases of $\theta = 0.1$,$\theta = 0.2$,$\theta = 0.8$ and $\theta = 0.9$ are too extreme, therefore, we're not going to discuss them. Five scenarios are formed by parameter θ being increased by 0.1 in each scenario from 0.3–0.7. The sensitivity analysis of parameter θ can be shown in Table 3.

Table 3. Sensitivity analysis of parameter θ.

Parameter	Satisfaction					Ranking Order
	$S_1(w^0)$	$S_2(w^0)$	$S_3(w^0)$	$S_4(w^0)$	$S_5(w^0)$	
$\theta = 0.3$	0.8032	0.712	0.7848	0.7028	0.6026	$X_1 > X_3 > X_2 > X_4 > X_5$
$\theta = 0.4$	0.7292	0.626	0.7067	0.6127	0.4933	$X_1 > X_3 > X_2 > X_4 > X_5$
$\theta = 0.5$	0.6422	0.5334	0.6163	0.5133	0.3936	$X_1 > X_3 > X_2 > X_4 > X_5$
$\theta = 0.6$	0.5448	0.4365	0.5171	0.4128	0.3021	$X_1 > X_3 > X_2 > X_4 > X_5$
$\theta = 0.7$	0.4284	0.3331	0.4011	0.3028	0.2178	$X_1 > X_3 > X_2 > X_4 > X_5$

It can be seen from Table 3 that although the initial satisfaction degree is different for θ within a range of 0.3–0.7, the ranking orders of five 3PL providers according to the satisfaction degree are the same; that is, $X_1 > X_3 > X_2 > X_4 > X_5$. It can also be seen that the smaller the value of θ, the higher the satisfaction $S_i(w)$, and that the two values show the opposite trend. Figure 2 shows that a change in parameter θ does not affect the rank of the alternatives.

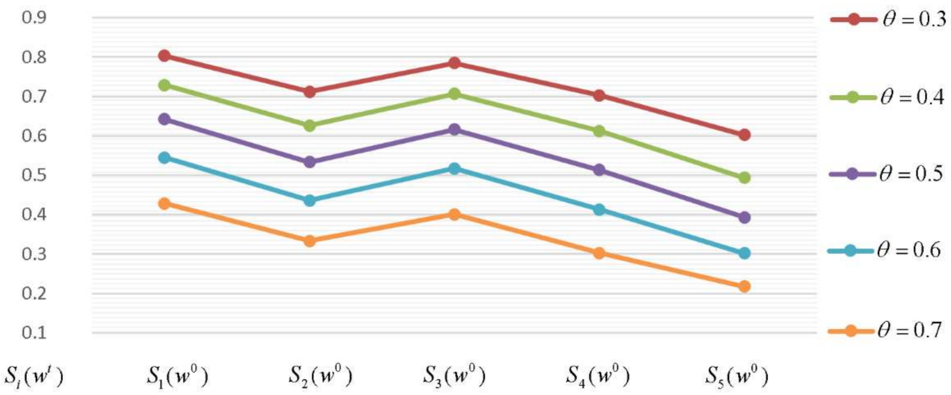

Figure 2. Sensitivity analysis of parameter θ.

The second part of the sensitivity analysis is to investigate the influence of different limits of satisfaction on the optimal solution of the proposed model. In the above case study, for the initial satisfaction degree obtained by the Equation (10), according to the subjective preference of the DMs, two limits of the satisfaction degree are set to $\zeta_i{}^1 = (0.43, 0.33, 0.4, 0.3, 0.2)$ and $\zeta_i{}^2 = (0.42, 0.34, 0.4, 0.3, 0.2)$ respectively. When $\theta = 0.7$, the satisfaction degree corresponding to the above limits is calculated by Equation (11), which are shown in Table 4.

Table 4. Sensitivity analysis of the setting of the limit.

Limit	**Satisfaction**					**Ranking Order**
$\zeta_i{}^1$	$S_1(w^1)$ 0.4348	$S_2(w^1)$ 0.3351	$S_3(w^1)$ 0.4077	$S_4(w^1)$ 0.3113	$S_5(w^1)$ 0.2177	$X_1 > X_3 > X_2 > X_4 > X_5$
$\zeta_i{}^2$	$S_1(w^2)$ 0.4360	$S_2(w^2)$ 0.3413	$S_3(w^2)$ 0.4081	$S_4(w^2)$ 0.3106	$S_5(w^2)$ 0.2055	$X_1 > X_3 > X_2 > X_4 > X_5$

As can be seen from Table 4, although the limits of the satisfaction degree are different, the ranking order of the five 3PL providers remains the same; that is, $X_1 > X_3 > X_2 > X_4 > X_5$. This means that the different settings of the limit of satisfaction degree will not affect the optimal rank of alternatives.

6. Conclusions

Due to the lack of hesitant fuzzy information in the previous HMCDM methods and the limitation of the single criterion type in the interactive decision-making research, this paper proposes a novel interactive HMCDM approach to deal with a 3PL provider selection problem for which the types of criterion evaluation results are hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers. First, the critical criteria for 3PL provider selection are set up. Then, it focuses on the issue of how to reduce the loss of decision information and express the subjective preference of DMs. For this reason, the positive and negative ideal solutions of the alternatives under hesitant fuzzy sets, intuitionistic fuzzy sets and real numbers are introduced respectively, and the satisfaction degrees of the DMs under hybrid multi-criteria circumstances are presented. In order to make the more reasonable decision, the proposed interactive HMCDM models for 3PL provider selection were developed. By using the interactive HMCDM approach, DMs can modify their preference information and make the most reasonable decision. Finally, an illustrative example of a Chinese airport company for 3PL provider selection was given, and the feasibility and practicality of the interactive HMCDM approach was demonstrated by sensitivity analysis.

The proposed method can directly use the original decision information to determine the weight and rank of the alternatives, which can avoid the information loss caused by different criterion type conversions. At the same time, the satisfaction degree limit can reflect the subjective preference of DMs, so as to solve the MCDM problem where the evaluation results are inconsistent with the subjective preference of the DMs.

In this paper, the importance of the DMs is considered to be the same in the proposed interactive HMCDM approach, and it can be applied to the hybrid multi-criteria group decision-making with the same importance under hesitation fuzzy sets, intuitionistic fuzzy sets and exact numerical value circumstances. However, in the actual group decision-making process, due to the different knowledge backgrounds and experience of DMs, as well as their understanding of the evaluation object, the DMs' importance in the evaluation process is different. In this paper, hesitant fuzzy sets, intuitionistic fuzzy sets and exact values were taken as hybrid multi-criteria. Other criteria, such as triangular fuzzy numbers, linguistic variables and probabilistic hesitant fuzzy sets, should be considered in the future HMCDM method under hybrid multi-criteria.

Therefore, this will also be our future direction of work. In further research, the interactive approach in this paper can be extended to hybrid multi-criteria group decision-making incorporating the different importance of DMs under hesitation fuzzy sets, intuitionistic fuzzy sets and real numbers. In this situation, the importance of each DM will also be reflected in the decision information. At the same time, whether the decision information can be expressed in more diverse ways is also a subject for future research.

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