Research Article

Supplier Selection Group Decision Making in Logistics Service Value Cocreation Based on Intuitionistic Fuzzy Sets

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Intuitionistic fuzzy information aggregation plays an important role in intuitionistic fuzzy set theory and is widely used in group decision making. In this paper, an induced intuitionistic fuzzy Einstein hybrid aggregation operator (I-IFEHA) is investigated for supplier selection group decision making in logistics service value cocreation based on fuzzy measures. We first introduce some aggregation operators and Einstein operations on intuitionistic fuzzy sets and develop a new induced intuitionistic fuzzy Einstein hybrid aggregation operator to accommodate the environment in which the given arguments are intuitionistic fuzzy values. Then, we study the supplier selection group decision model in logistics service value cocreation based on intuitionistic fuzzy sets with the I-IFEHA operator. Finally, an example of 3PL supplier selection in logistics service value cocreation environment is given to verify the developed approach and to demonstrate the effectiveness of the developed approach.

1. Introduction

In today's business world, more and more companies rely on outsourcing their logistics services to 3PL to reduce costs, improve business performance, and focus on their core business. Supplier selection has received considerable attention for its significant effect towards successful logistics and supply chain management [1]. The 3PL supplier selection issue is a typical multiple attribute decision making problem in complex business environment. The study of 3PL supplier selection mainly includes the following two main issues; one is the selection criteria of 3PL supplier [2–7] and the other is the selection models and approaches of 3PL supplier [8–16]. In many decision making scenarios, most decision information provided by the decision maker is often imprecise or uncertain due to the complex decision making environment, lack of data, or the decision maker's limited knowledge. The accuracy of 3PL supplier selection decision making process is based on the correct information from fuzzy data. To calculate the fuzzy data, Atanassov introduced the concept of intuitionistic fuzzy set (IFS) characterized by a membership function and nonmembership function, which is more suitable for dealing with fuzziness and uncertainty

than the ordinary fuzzy set developed by Atanassov et al. [17–20]. Since its appearance, IFS has received more and more attention in the field of multiple attribute decision making [20–35]. Xu [36] developed the intuitionistic fuzzy weighted averaging (IFWA) operator, the intuitionistic fuzzy ordered weighted averaging (IFOWA) operator, and the intuitionistic fuzzy hybrid aggregation (IFHA) operator. Xu and Yager [37] proposed some intuitionistic fuzzy geometric aggregation operators and applied them to multiattribute decision making problems. Merigó [38] presented a new operator that unifies the OWA operator with the WA when we assess the information with induced aggregation operators called the induced ordered weighted averaging-weighted average (IOWAWA) operator. Wei [39] proposed the dynamic intuitionistic fuzzy weighted geometric (DIFWG) and induced intuitionistic fuzzy ordered weighted geometric (I-IFOWG) operator [40]. Xu and Wang [41] developed the induced generalized intuitionistic fuzzy ordered weighted averaging (I-GIFOWA) operator.

It is clear that the above operators are based on the algebraic operational laws of IFSs for carrying the combination process and are not consistent with the limiting case of ordinary fuzzy sets [20]. For an intersection, a good alternative

to the algebraic operational laws is Einstein operation laws for fuzzy sets. Wang and Liu [42, 43] developed intuitionistic fuzzy aggregation operators based on Einstein operators. Zhao and Wei [20] developed the intuitionistic fuzzy Einstein hybrid averaging (IFEHA) operator and intuitionistic fuzzy Einstein hybrid geometric (IFEHG) operator and applied the intuitionistic fuzzy Einstein hybrid averaging (IFEHA) operator and intuitionistic fuzzy Einstein hybrid geometric (IFEHG) operator to deal with multiple attribute decision making under intuitionistic fuzzy environments. Xu et al. [44] developed an I-IFOWA$^\varepsilon$ operator which generalizes some of the intuitionistic fuzzy Einstein aggregation operators and apply the I-IFOWA$^\varepsilon$ operator and the IFWA$^\varepsilon$ operator to multiple attribute group decision making with intuitionistic fuzzy information. Yet it is worthy of pointing out that there is little investigation on aggregation technologies using the Einstein operations on IFS and the induced intuitionistic fuzzy aggregation operator is more suitable for aggregation individual intuitionistic fuzzy values into collective intuitionistic fuzzy value. Therefore, this paper focuses on developing an induced intuitionistic fuzzy aggregation operator based on Einstein operators considering both the weights of positions and attributes.

In order to do so, the remainder of the paper is organized as follows. Section 2 briefly introduces some basic concepts related to intuitionistic fuzzy sets and some existing intuitionistic fuzzy aggregating operators. In Section 3, based on the induction of Einstein operation laws, we develop an induced intuitionistic fuzzy Einstein hybrid aggregation operator (I-IFEHA) and study some desired properties of the operator. In Section 4, we study the supplier selection group decision model in logistics service value cocreation and apply I-IFEHA operator to deal with supplier selection group decision making problems. In Section 5, an illustrative example for 3PL supplier selection in logistics service value cocreation environment is given to illustrate the concrete application of the approach. Section 6 concludes the paper and gives some remarks.

2. Preliminaries

In the following, we will first briefly introduce some basic concepts, aggregation operators related to intuitionistic fuzzy sets (IFSs) to facilitate future discussions.

2.1. Intuitionistic Fuzzy Set. Intuitionistic fuzzy set (IFS) introduced by Atanassov [17] is an extension of the classical fuzzy set, which is a suitable way to deal with vagueness. It can be defined as follows.

Definition 1. Let X be a universe of discourse. An IFS in X is given by

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in X\}, \tag{1}$$

where $\mu_A(x), \nu_A(x) \in [0, 1]$, with the condition $0 \le \mu_A(x) + \nu_A(x) \le 1$, $\forall x \in X$. The numbers $\mu_A(x)$ and $\nu_A(x)$ represent, respectively, the degree of membership and the degree of nonmembership of the element x to the set A [17, 18].

Definition 2. For each IFS A in X, if

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x), \quad \forall x \in X, \tag{2}$$

then $\pi_A(x)$ is called the indeterminacy degree of x to set A [17, 18].

For computational convenience, the pair $(\mu_A(x), \nu_A(x))$ is called an intuitionistic fuzzy value (IFV) [31], which is simply denoted as $\alpha = (\mu_A, \nu_A)$ such that $\mu_A(x), \nu_A(x) \in [0, 1]$ and $0 \le \mu_A(x) + \nu_A(x) \le 1$.

Definition 3. Let $\alpha = (\mu_\alpha, \nu_\alpha)$ be an IFV; a score function S of an intuitionistic fuzzy value can be represented as follows [21]:

$$S(\alpha) = \mu_\alpha - \nu_\alpha, \quad \text{where } S(\alpha) \in [-1, 1]. \tag{3}$$

The function S is used to measure the score of an IFV. The bigger the score of α, the larger the IFV α.

Definition 4. Let $\alpha = (\mu_\alpha, \nu_\alpha)$ be an IFV; an accuracy function H of an intuitionistic fuzzy value can be represented as follows [22]:

$$H(\alpha) = \mu_\alpha + \nu_\alpha, \quad \text{where } H(\alpha) \in [0, 1]. \tag{4}$$

The function H is used to evaluate the accuracy of an IFV. The larger the value of $H(\alpha)$, the higher the degree of accuracy of the IFV α.

Definition 5 (see [37]). Let $\alpha = (\mu_\alpha, \nu_\alpha)$ and $\beta = (\mu_\beta, \nu_\beta)$ be two IFVs, let $S(\alpha) = \mu_\alpha - \nu_\alpha$ and $S(\beta) = \mu_\beta - \nu_\beta$ be the score of α and β, respectively, and let $H(\alpha) = \mu_\alpha + \nu_\alpha$ and $H(\beta) = \mu_\beta + \nu_\beta$ be the accuracy degree of α and β, respectively; then one gets the following:

(1) If $S(\alpha) < S(\beta)$, then $\alpha < \beta$.

(2) If $S(\alpha) = S(\beta)$, then one gets the following:

    (a) If $H(\alpha) < H(\beta)$, then $\alpha < \beta$.
    (b) If $H(\alpha) = H(\beta)$, then $\alpha = \beta$.

2.2. The Intuitionistic Fuzzy Aggregation Operator. Intuitionistic fuzzy information aggregation plays an important role in intuitionistic fuzzy set theory. Xu [36] proposed some intuitionistic fuzzy aggregation operators to aggregate the intuitionistic fuzzy information.

Definition 6 (see [36]). Let $\alpha_j = (\mu_j, \nu_j)$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and an intuitionistic fuzzy weighted averaging operator of dimension n is a mapping IFWA: $\Omega^n \to \Omega$, if

$$\text{IFWA}_w(\alpha_1, \alpha_2, \ldots, \alpha_n) = \sum_{j=1}^{n} w_j \alpha_j$$

$$= \left(1 - \prod_{j=1}^{n}(1 - \mu_j)^{w_j}, \prod_{j=1}^{n}(\nu_j)^{w_j}\right), \tag{5}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weighting vector of α_j $(j = 1, 2, \ldots, n)$ with $w_j \in [0, 1]$, $\sum_{j=1}^{n} w_j = 1$.

Definition 7 (see [36]). Let $\alpha_j = (\mu_j, \nu_j)$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and an intuitionistic fuzzy ordered weighted averaging operator of dimension n is a mapping IFOWA: $\Omega^n \to \Omega$, if

$$
\begin{aligned}
\text{IFOWA}_w(\alpha_1, \alpha_2, \ldots, \alpha_n) &= \sum_{j=1}^{n} w_j \alpha_{\sigma(j)} \\
&= \left(1 - \prod_{j=1}^{n} \left(1 - \mu_{\sigma(j)} \right)^{w_j}, \prod_{j=1}^{n} \left(\nu_{\sigma(j)} \right)^{w_j} \right),
\end{aligned}
\tag{6}
$$

where $\alpha_{\sigma(j)}$ is jth largest of α_j $(j = 1, 2, \ldots, n)$ and $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector with $w_j \in [0, 1]$, $\sum_{j=1}^{n} w_j = 1$.

The intuitionistic fuzzy hybrid aggregation operator (IFHA) was introduced by Xu [36]. It is an extension of the IFWA operator and IFOWA operator for uncertain situations where the available information can be assessed with IFVs. Let Ω be the set of all IFVs; it can be defined as follows.

Definition 8. Let $\alpha_j = (\mu_j, \nu_j)$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and an intuitionistic fuzzy hybrid aggregation operator of dimension n is a mapping IFHA: $\Omega^n \to \Omega$, if

$$
\begin{aligned}
\text{IFHA}_{w,\omega}(\alpha_1, \alpha_2, \ldots, \alpha_n) &= \sum_{j=1}^{n} w_j \dot{\alpha}_{\sigma(j)} \\
&= \left(1 - \prod_{j=1}^{n} \left(1 - \dot{\mu}_{\sigma(j)} \right)^{w_j}, \prod_{j=1}^{n} \left(\dot{\nu}_{\sigma(j)} \right)^{w_j} \right),
\end{aligned}
\tag{7}
$$

where $\dot{\alpha}_{\sigma(j)}$ is jth largest of the weighted intuitionistic fuzzy values $\dot{\alpha}_j$ $(\dot{\alpha}_j = n\omega_j \alpha_j, \ j = 1, 2, \ldots, n)$, $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weighting vector of α_j $(j = 1, 2, \ldots, n)$ with $\omega_j \geq 0$, $\sum_{j=1}^{n} \omega_j = 1$, and n is the balancing coefficient. $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector with $w_j \in [0, 1]$, $\sum_{j=1}^{n} w_j = 1$.

The induced intuitionistic fuzzy hybrid aggregation operator (I-IFHA) is the extension of the IFHA operator. The main difference is that the reordering step in I-IFHA is not carried out with the values of the argument $\dot{\alpha}_j$. In this case, the reordering step is developed with order-inducing variables that reflect a more complex reordering process.

Definition 9 (see [45]). An I-IFHA operator of dimension n is a mapping I-IFHA: $\Omega^n \to \Omega$, if

$$
\begin{aligned}
&\text{I-IFHA}_{w,\omega}\left(\langle u_1, \alpha_1 \rangle, \langle u_2, \alpha_2 \rangle, \ldots, \langle u_n, \alpha_n \rangle \right) \\
&= \sum_{j=1}^{n} w_j \dot{\alpha}_{\sigma(j)} \\
&= \left(1 - \prod_{j=1}^{n} \left(1 - \dot{\mu}_{\sigma(j)} \right)^{w_j}, \prod_{j=1}^{n} \left(\dot{\nu}_{\sigma(j)} \right)^{w_j} \right),
\end{aligned}
\tag{8}
$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector such that $w_j \in [0, 1]$, $\sum_{j=1}^{n} w_j = 1$. $\dot{\alpha}_{\sigma(j)}$

is $\dot{\alpha}_j$ $(\dot{\alpha}_j = n\omega_j \alpha_j, \ j = 1, 2, \ldots, n)$ value of the pair $\langle u_j, \dot{\alpha}_j \rangle$ having jth largest u_j which is the order-inducing variable and $\dot{\alpha}_j$ is the argument variable, and $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weighting vector of α_j $(j = 1, 2, \ldots, n)$ with $\omega_j \geq 0$, $\sum_{j=1}^{n} \omega_j = 1$, and n is the balancing coefficient.

3. The Induced Intuitionistic Fuzzy Einstein Hybrid Aggregation Operator

Besides the algebra operations for IFVs, there are various t-norms and t-conorms can satisfy the requirements of the conjunction and disjunction operators. Einstein operations include the Einstein product which is a t-norm and Einstein sum which is t-conorms can be used to perform the corresponding intersections and unions of IFVs. Wang and Liu [42] extended the Einstein operations to the IFVs. Let A and B be two IFSs; then the Einstein operators are as follows:

(1)

$$
\begin{aligned}
A \bigoplus_{\varepsilon} B = \Bigg\{ \Bigg\langle x, \ & \frac{\mu_A(x) + \mu_B(x)}{1 + \mu_A(x) \cdot \mu_B(x)}, \\
& \frac{\nu_A(x) \cdot \nu_B(x)}{1 + (1 - \nu_A(x)) \cdot (1 - \nu_B(x))} \Bigg\rangle \mid x \in X \Bigg\}.
\end{aligned}
\tag{9}
$$

(2)

$$
\begin{aligned}
A \bigotimes_{\varepsilon} B = \Bigg\{ \Bigg\langle x, \ & \frac{\mu_A(x) \cdot \mu_B(x)}{1 + (1 - \mu_A(x)) \cdot (1 - \mu_B(x))}, \\
& \frac{\nu_A(x) + \nu_B(x)}{1 + \nu_A(x) \cdot \nu_B(x)} \Bigg\rangle \mid x \in X \Bigg\}.
\end{aligned}
\tag{10}
$$

(3)

$$
\begin{aligned}
A^{\wedge_\varepsilon \lambda} = \Bigg\{ \Bigg\langle x, \ & \frac{2 \left(\mu_A(x) \right)^\lambda}{\left(2 - \mu_A(x) \right)^\lambda + \left(\mu_A(x) \right)^\lambda}, \\
& \frac{\left(1 + \nu_A(x) \right)^\lambda - \left(1 - \nu_A(x) \right)^\lambda}{\left(1 + \nu_A(x) \right)^\lambda + \left(1 - \nu_A(x) \right)^\lambda} \Bigg\rangle \mid x \in X \Bigg\}.
\end{aligned}
\tag{11}
$$

(4)

$$
\begin{aligned}
\lambda_\varepsilon A = \Bigg\{ \Bigg\langle x, \ & \frac{\left(1 + \mu_A(x) \right)^\lambda - \left(1 - \mu_A(x) \right)^\lambda}{\left(1 + \mu_A(x) \right)^\lambda + \left(1 - \mu_A(x) \right)^\lambda}, \\
& \frac{2 \left(\nu_A(x) \right)^\lambda}{\left(2 - \nu_A(x) \right)^\lambda + \left(\nu_A(x) \right)^\lambda} \Bigg\rangle \mid x \in X \Bigg\}.
\end{aligned}
\tag{12}
$$

Based upon the definition of Einstein operations for IFVs and intuitionistic fuzzy aggregation operator proposed by Xu [36], Wang and Liu [42] proposed the intuitionistic fuzzy Einstein weighted averaging operator (IFEWA) and intuitionistic fuzzy Einstein ordered weighted averaging operator (IFEOWA).

Definition 10 (see [42]). Let $\alpha_j = (\mu_j, \nu_j)$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and an intuitionistic fuzzy Einstein weighted averaging operator of dimension n is a mapping IFEWA: $\Omega^n \rightarrow \Omega$, if

$$\text{IFEWA}_w \left(\alpha_1, \alpha_2, \ldots, \alpha_n\right)$$

$$= \left(\frac{\prod_{j=1}^n \left(1 + \mu_j\right)^{w_j} - \prod_{j=1}^n \left(1 - \mu_j\right)^{w_j}}{\prod_{j=1}^n \left(1 + \mu_j\right)^{w_j} + \prod_{j=1}^n \left(1 - \mu_j\right)^{w_j}}, \right. \tag{13}$$

$$\left. \frac{2\prod_{j=1}^n \left(\nu_j\right)^{w_j}}{\prod_{j=1}^n \left(2 - \nu_j\right)^{w_j} + \prod_{j=1}^n \left(\nu_j\right)^{w_j}} \right),$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weighting vector of α_j $(j = 1, 2, \ldots, n)$ with $w_j \in [0, 1]$, $\sum_{j=1}^n w_j = 1$.

Based on the OWA operator and the IFEWA operator, an IFEOWA operator is defined as follows.

Definition 11 (see [42]). Let $\alpha_j = (\mu_j, \nu_j)$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and an intuitionistic fuzzy Einstein ordered weighted averaging operator of dimension n is a mapping IFEOWA: $\Omega^n \rightarrow \Omega$, if

$$\text{IFEOWA}_w \left(\alpha_1, \alpha_2, \ldots, \alpha_n\right)$$

$$= \left(\frac{\prod_{j=1}^n \left(1 + \mu_{\sigma(j)}\right)^{w_j} - \prod_{j=1}^n \left(1 - \mu_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(1 + \mu_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(1 - \mu_{\sigma(j)}\right)^{w_j}}, \right. \tag{14}$$

$$\left. \frac{2\prod_{j=1}^n \left(\nu_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(2 - \nu_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(\nu_{\sigma(j)}\right)^{w_j}} \right),$$

where $\alpha_{\sigma(j)}$ is jth largest of α_j $(j = 1, 2, \ldots, n)$ and $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector with $w_j \in [0, 1]$, $\sum_{j=1}^n w_j = 1$.

From Definitions 10 and 11, we know that the IFEWA operator weights only represent the intuitionistic fuzzy values, while the IFWOWA operator weights only represent the ordered positions of the intuitionistic fuzzy values. To solve this drawback and reflect the importance degrees of both given arguments and their ordered positions, Zhao and Wei [20] proposed an intuitionistic fuzzy Einstein hybrid aggregation operator (IFEHA), which is defined as follows.

Definition 12 (see [20]). An IFEHA operator of dimension n is a mapping IFEHA: $\Omega^n \rightarrow \Omega$, if

$$\text{IFEHA}_{w,\omega} \left(\alpha_1, \alpha_2, \ldots, \alpha_n\right) = \bigoplus_{j=1}^n {}_{\varepsilon} w_j \dot{\alpha}_{\sigma(j)}$$

$$= \left(\frac{\prod_{j=1}^n \left(1 + \dot{\mu}_{\sigma(j)}\right)^{w_j} - \prod_{j=1}^n \left(1 - \dot{\mu}_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(1 + \dot{\mu}_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(1 - \dot{\mu}_{\sigma(j)}\right)^{w_j}}, \right. \tag{15}$$

$$\left. \frac{2\prod_{j=1}^n \left(\dot{\nu}_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(2 - \dot{\nu}_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(\dot{\nu}_{\sigma(j)}\right)^{w_j}} \right),$$

where $\dot{\alpha}_{\sigma(j)}$ is jth largest of the weighted intuitionistic fuzzy values $\dot{\alpha}_j$ $(\dot{\alpha}_j = n\omega_j\alpha_j, \ j = 1, 2, \ldots, n)$, $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weighting vector of α_j $(j = 1, 2, \ldots, n)$ with $\omega_j \geq 0$, $\sum_{j=1}^n \omega_j = 1$, and n is the balancing coefficient. $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector with $w_j \in [0, 1]$, $\sum_{j=1}^n w_j = 1$.

Based on the idea of IFEHA operator and I-IFHA operator, we develop the induced intuitionistic fuzzy Einstein hybrid aggregation operator as follows.

Definition 13. An I-IFEHA operator of dimension n is a mapping I-IFEHA: $\Omega^n \rightarrow \Omega$, if

$$\text{I-IFEHA}_{w,\omega} \left(\langle u_1, \alpha_1 \rangle, \langle u_2, \alpha_2 \rangle, \ldots, \langle u_n, \alpha_n \rangle\right)$$

$$= \bigoplus_{j=1}^n {}_{\varepsilon} w_j \dot{\alpha}_{\sigma(j)}$$

$$= \left(\frac{\prod_{j=1}^n \left(1 + \dot{\mu}_{\sigma(j)}\right)^{w_j} - \prod_{j=1}^n \left(1 - \dot{\mu}_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(1 + \dot{\mu}_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(1 - \dot{\mu}_{\sigma(j)}\right)^{w_j}}, \right. \tag{16}$$

$$\left. \frac{2\prod_{j=1}^n \left(\dot{\nu}_{\sigma(j)}\right)^{w_j}}{\prod_{j=1}^n \left(2 - \dot{\nu}_{\sigma(j)}\right)^{w_j} + \prod_{j=1}^n \left(\dot{\nu}_{\sigma(j)}\right)^{w_j}} \right),$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the aggregation-associated weighting vector such that $w_j \in [0, 1]$, $\sum_{j=1}^n w_j = 1$. $\dot{\alpha}_{\sigma(j)}$ is $\dot{\alpha}_j$ $(\dot{\alpha}_j = n\omega_j\alpha_j, \ j = 1, 2, \ldots, n)$ value of the pair $\langle u_j, \dot{\alpha}_j \rangle$ having jth largest u_j which is the order-inducing variable and $\dot{\alpha}_j$ is the argument variable, and $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weight vector of α_j $(j = 1, 2, \ldots, n)$, with $\omega_j \geq 0$, $\sum_{j=1}^n \omega_j = 1$, and n is the balancing coefficient.

Example 14. Assume the following collection of arguments with their respective order-inducing variables $\langle u_j, \alpha_j \rangle$:

$$\langle u_1, \alpha_1 \rangle = \langle 0.2, (0.5, 0.4) \rangle,$$

$$\langle u_2, \alpha_2 \rangle = \langle 0.4, (0.7, 0.2) \rangle,$$

$$\langle u_3, \alpha_3 \rangle = \langle 0.6, (0.8, 0.1) \rangle, \tag{17}$$

$$\langle u_4, \alpha_4 \rangle = \langle 0.3, (0.6, 0.3) \rangle.$$

We assume that the aggregation-associated weighting vector $w = (0.3, 0.4, 0.1, 0.2)^T$ and the weight vector of α_j $(j = 1, 2, 3, 4)$, $\omega = (0.3, 0.4, 0.2, 0.1)^T$; then

$$\langle \mu_{\sigma(1)}, \alpha_{\sigma(1)} \rangle = \langle 0.6, (0.706, 0.173) \rangle,$$

$$\langle \mu_{\sigma(2)}, \alpha_{\sigma(2)} \rangle = \langle 0.4, (0.883, 0.058) \rangle,$$

$$\langle \mu_{\sigma(3)}, \alpha_{\sigma(3)} \rangle = \langle 0.3, (0.270, 0.666) \rangle, \tag{18}$$

$$\langle \mu_{\sigma(4)}, \alpha_{\sigma(4)} \rangle = \langle 0.2, (0.578, 0.319) \rangle.$$

And then with (16) we can get the aggregated value:

$$
\begin{aligned}
&\text{I-IFEHA}_{w,\omega}\left(\langle\mu_1,\alpha_1\rangle,\langle\mu_2,\alpha_2\rangle,\langle\mu_3,\alpha_3\rangle,\langle\mu_4,\alpha_4\rangle\right)\\
&\quad = (0.753, 0.150).
\end{aligned}
\tag{19}
$$

I-IFEHA operator has the following properties, including commutativity, idempotency, boundedness, and monotonicity. Note that the proofs of these theorems are straightforward and thus are omitted.

Theorem 15 (commutativity). *Let $\alpha_j = (\mu_{\alpha_j}, \nu_{\alpha_j})$ $(j = 1, 2, \ldots, n)$ and $\alpha'_j = (\mu_{\alpha'_j}, \nu_{\alpha'_j})$ $(j = 1, 2, \ldots, n)$ be two collections of IFVs; then*

$$
\begin{aligned}
&\text{I-IFEHA}_{w,\omega}\left(\langle u_1,\alpha_1\rangle,\langle u_2,\alpha_2\rangle,\ldots,\langle u_n,\alpha_n\rangle\right)\\
&\quad = \text{I-IFEHA}_{w,\omega}\left(\langle u'_1,\alpha'_1\rangle,\langle u'_2,\alpha'_2\rangle,\ldots,\langle u'_n,\alpha'_n\rangle\right),
\end{aligned}
\tag{20}
$$

where $(\langle u_1,\alpha_1\rangle,\langle u_2,\alpha_2\rangle,\ldots,\langle u_n,\alpha_n\rangle)$ is any permutation of $(\langle u'_1,\alpha'_1\rangle,\langle u'_2,\alpha'_2\rangle,\ldots,\langle u'_n,\alpha'_n\rangle)$.

Theorem 16 (idempotency). *Let $\alpha_j = (\mu_{\alpha_j}, \nu_{\alpha_j})$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs. If all α_j $(j = 1, 2, \ldots, n)$ are equal, that is, $\alpha_j = \alpha$ for all j, then*

$$
\text{I-IFEHA}_{w,\omega}\left(\langle u_1,\alpha_1\rangle,\langle u_2,\alpha_2\rangle,\ldots,\langle u_n,\alpha_n\rangle\right) = \alpha.
\tag{21}
$$

Theorem 17 (boundedness). *Let $\alpha_j = (\mu_{\alpha_j}, \nu_{\alpha_j})$ $(j = 1, 2, \ldots, n)$ be a collection of IFVs and let $\alpha^- = \min_j \alpha_j$, $\alpha^+ = \max_j \alpha_j$; then*

$$
\begin{aligned}
\alpha^- &\leq \text{I-IFEHA}_{w,\omega}\left(\langle u_1,\alpha_1\rangle,\langle u_2,\alpha_2\rangle,\ldots,\langle u_n,\alpha_n\rangle\right)\\
&\leq \alpha^+.
\end{aligned}
\tag{22}
$$

Theorem 18 (monotonicity). *Let $\alpha_j = (\mu_{\alpha_j}, \nu_{\alpha_j})$ $(j = 1, 2, \ldots, n)$ and $\beta_j = (\mu_{\beta_j}, \nu_{\beta_j})$ $(j = 1, 2, \ldots, n)$ be two collections of IFVs; if $\alpha_j \leq \beta_j$ for all j, then*

$$
\begin{aligned}
&\text{I-IFEHA}_{w,\omega}\left(\langle u_1,\alpha_1\rangle,\langle u_2,\alpha_2\rangle,\ldots,\langle u_n,\alpha_n\rangle\right)\\
&\quad \leq \text{I-IFEHA}_{w,\omega}\left(\langle u_1,\beta_1\rangle,\langle u_2,\beta_2\rangle,\ldots,\langle u_n,\beta_n\rangle\right).
\end{aligned}
\tag{23}
$$

4. Supplier Selection Group Decision Model in Logistics Service Value Cocreation Based on Intuitionistic Fuzzy Sets

4.1. Supplier Selection Group Decision Model in Logistics Service Value Cocreation. Logistics supplier selection is a multicriteria problem and it requires taking into account a large number of attributes. Spencer et al. listed 23 potential selection attributes [2], and Govindan et al. identified 35 selection factors in their studies [9]. With the review of 67 3PL selection articles published within 1994–2013 period, Aicha revealed 11 key 3PL selection criteria, and each one is defined by a set of attributes; the study revealed cost was

the widely adopted criteria, followed by relationship, service, and quality [7]. Although the abovementioned selection criteria are widely used in 3PL selection, the selection criteria are operational-oriented, while supply chain strategic and service value creation factors were seldom considered in logistics supplier selection in previous studies. It is necessary to reconsider the selection criteria in logistics service value cocreation scenario.

The creation of value is the core premise of establishing and maintaining the customer relationship and is the core purpose and central process of economic exchange [46]. In supply chain management environment, more and more companies realize the importance of logistics service value cocreation with partners. Logistics service value cocreation has become the new way for the 3PL to find an innovative mode to achieve competitive advantage and for the customers to achieve more customized product and service offerings [47]. The supplier selection is one of the most important issues for logistics service value cocreation in SCM environment. The emerging trend in 3PL supplier selection is the integration of traditional selection attributes, such as cost, response time, quality, and location, with the new factors in service value cocreation, such as new value creation, knowledge management, and service innovation. We integrate the traditional operational-oriented selection attributes and value cocreation oriented SCM strategic selection attributes to establish a comprehensive selection attributes for supplier selection in logistics service value cocreation scenario. The attributes of supplier selection in logistics service value cocreation are shown in Table 1.

4.2. An Approach to Supplier Selection Group Decision Making in Logistics Service Value Cocreation with Intuitionistic Fuzzy Information. In this section, we apply I-IFEHA operator and IFEWA operator to multiple attribute group decision making for supplier selection in logistics service value cocreation based on intuitionistic fuzzy information.

We suppose $A = \{A_1, A_2, \ldots, A_n\}$ is a discrete set of alternatives of logistics service provider and $P = \{P_1, P_2, \ldots, P_m\}$ is a set of attributes, whose weight vector is $\omega = \{\omega_1, \omega_2, \ldots, \omega_m\}^T$, where $\omega_j \in [0, 1]$, $\sum_{j=1}^{m} \omega_j = 1$. Let $D = \{D_1, D_2, \ldots, D_k\}$ be a set of decision makers (DMs) with the weight vector $u = \{u_1, u_2, \ldots, u_k\}^T$, where $u_j \in [0, 1]$, $\sum_{j=1}^{k} u_j = 1$. Suppose that $R^{(l)} = (r_{ij}^{(l)})_{m \times n}$ is an intuitionistic fuzzy decision matrix, where $r_{ij}^{(l)} = (\mu_{ij}^{(l)}, \nu_{ij}^{(l)})$ is an IFV provided by the DMs $D^l \in D$ for the alternative $A_i \in A$ with respect to the attribute $P_j \in P$. $\mu_{ij}^{(l)}$ indicates the degree that the alternative A_i should satisfy the attribute P_j, and $\nu_{ij}^{(l)}$ indicates the degree that the alternative A_i should not satisfy the attribute P_j, such that $\mu_{ij}^{(l)} \in [0, 1]$, $\nu_{ij}^{(l)} \in [0, 1]$, and $\mu_{ij}^{(l)} + \nu_{ij}^{(l)} \leq 1$.

The method for solving the above logistics service value cocreation multiattribute group decision making problem with the intuitionistic fuzzy information involves the following steps.

TABLE 1: The attributes of supplier selection in logistics service value cocreation.

Attribute	Attribute elements	Attribute element description
Value collaboration	Strategic collaboration Business objectives collaboration Market collaboration	Value collaboration is the basis of value cocreation, which should be presented from the aspects of strategic, business objective, and market.
Knowledge matching	Knowledge heterogeneous Knowledge complementary Knowledge creation Knowledge transfer and sharing	Knowledge plays an important role in logistics service value cocreation; knowledge management is integrated in the process of value cocreation.
Service innovation ability	Service concept innovation Service process innovation Service technology innovation Service delivery mode innovation	Service innovation presents the abilities for the 3PL to fulfill the service value cocreation in logistics service solutions.
Quality of service	Response time Service price Service reliability Logistics service network Information sharing	Quality of service is the traditional evaluation factors for 3PL selection, which also presents the quality of service value cocreation.
Resource interaction	Resource heterogeneous Resource complementary Resource dependency Resource integration	Logistics resource is the material basis for service value cocreation. The logistics service is fulfilled with the integration and interaction of different logistics resource from the participated 3PLs.

Step 1. Choose the attributes for logistics supplier selection based on the logistics service value cocreation decision making model.

Step 2. Utilize the weighting vector $\omega = \{\omega_1, \omega_2, \ldots, \omega_m\}^T$ for the logistics supplier selection attribute and utilize the intuitionistic fuzzy decision matrix $R^{(k)} = (r_{ij}^{(k)})_{m \times n}$ with weight vector $u = \{u_1, u_2, \ldots, u_k\}^T$ for decision makers.

Step 3. Utilize all the individual intuitionistic fuzzy decision matrices $R^{(l)} = (r_{ij}^{(l)})_{m \times n}$ for logistics supplier selection into a collective intuitionistic fuzzy decision matrix $R = (r_{ij})_{m \times n}$ with the I-IFEHA operator which has the associated weighting vector $w = (w_1, w_2, \ldots, w_k)^T$:

$$r_{ij} = \text{I-IFEHA}_{w,\omega}\left(\left\langle u_1, r_{ij}^{(1)}\right\rangle, \left\langle u_2, r_{ij}^{(2)}\right\rangle, \ldots, \left\langle u_k, r_{ij}^{(k)}\right\rangle\right). \tag{24}$$

Step 4. According to the collective intuitionistic fuzzy decision matrix $R = (r_{ij})_{m \times n}$, then use the IFEWA operator to derive the overall intuitionistic fuzzy preference values r_i of the alternative.

Step 5. By using (3) and (4), calculate the scores $S(r_i)$ ($i = 1, 2, \ldots, m$) and the accuracies $H(r_i)$ ($i = 1, 2, \ldots, m$) of all the overall values r_i ($i = 1, 2, \ldots, m$).

Step 6. Rank the alternatives A_i ($i = 1, 2, \ldots, m$) and then select the best one.

5. Illustrative Example and Discussion

In this section, we discuss a group of decision making problems in the logistics supply chain environment, which are concerned with a 4PL solution provider searching the best 3PL supplier for service value cocreation with its customer (an international manufacturing company group). Now suppose that there are five global 3PL suppliers x_i ($i = 1, 2, 3, 4, 5$) and three decision makers (whose weighting vector $u = (0.4, 0.25, 0.35)^T$) from different professional fields are involved in the decision making. In the following, we utilize the procedure to find the decision result.

Step 1. Determine the attributes for 3PL supplier selection in service value cocreation environment. The attributes which are considered here in selection for the best 3PL supplier are as follows; (1) P_1 is value collaboration ability with each other; (2) P_2 is knowledge matching ability; (3) P_3 is service innovation ability; (4) P_4 is quality of service; (5) P_5 is resource interaction ability.

Step 2. Utilize the weighting vector $\omega = (0.2, 0.15, 0.15, 0.3, 0.2)^T$ for 3PL supplier selection attributes and utilize the intuitionistic fuzzy decision matrix $R^{(k)} = (r_{ij}^{(k)})_{m \times n}$ ($k = 1, 2, 3, 4$) as listed in Tables 2–4.

Step 3. Give the associated vector $w = (0.3, 0.45, 0.25)^T$ of the I-IFEHA$_{w,\omega}$ operator. Then we utilize the I-IFEHA$_{w,\omega}$ operator to aggregate all the intuitionistic fuzzy decision matrices into a collective decision matrix $R = (r_{ij})_{m \times n}$ (as listed in Table 5).

Table 2: Intuitionistic fuzzy decision matrix $R^{(1)}$.

	P_1	P_2	P_3	P_4	P_5
x_1	(0.7, 0.1)	(0.6, 0.2)	(0.9, 0.1)	(0.5, 0.3)	(0.8, 0.1)
x_2	(0.8, 0.1)	(0.7, 0.1)	(0.6, 0.3)	(0.7, 0.1)	(0.8, 0.1)
x_3	(0.9, 0.1)	(0.5, 0.2)	(0.7, 0.1)	(0.8, 0.1)	(0.7, 0.2)
x_4	(0.7, 0.2)	(0.7, 0.2)	(0.5, 0.3)	(0.5, 0.4)	(0.6, 0.3)
x_5	(0.8, 0.1)	(0.8, 0.1)	(0.7, 0.1)	(0.5, 0.2)	(0.5, 0.4)

Table 3: Intuitionistic fuzzy decision matrix $R^{(2)}$.

	P_1	P_2	P_3	P_4	P_5
x_1	(0.9, 0.1)	(0.7, 0.2)	(0.5, 0.3)	(0.7, 0.2)	(0.7, 0.1)
x_2	(0.7, 0.2)	(0.8, 0.1)	(0.5, 0.4)	(0.6, 0.2)	(0.8, 0.1)
x_3	(0.8, 0.1)	(0.6, 0.2)	(0.7, 0.1)	(0.8, 0.1)	(0.6, 0.2)
x_4	(0.6, 0.3)	(0.7, 0.1)	(0.6, 0.3)	(0.5, 0.2)	(0.7, 0.2)
x_5	(0.8, 0.2)	(0.5, 0.1)	(0.8, 0.1)	(0.6, 0.3)	(0.5, 0.2)

Table 4: Intuitionistic fuzzy decision matrix $R^{(3)}$.

	P_1	P_2	P_3	P_4	P_5
x_1	(0.6, 0.3)	(0.8, 0.1)	(0.8, 0.1)	(0.4, 0.3)	(0.7, 0.2)
x_2	(0.8, 0.2)	(0.6, 0.3)	(0.5, 0.3)	(0.6, 0.2)	(0.6, 0.2)
x_3	(0.6, 0.3)	(0.7, 0.2)	(0.6, 0.2)	(0.8, 0.1)	(0.8, 0.1)
x_4	(0.6, 0.2)	(0.5, 0.4)	(0.7, 0.1)	(0.6, 0.2)	(0.6, 0.3)
x_5	(0.7, 0.2)	(0.6, 0.2)	(0.8, 0.1)	(0.4, 0.4)	(0.6, 0.3)

Step 4. Utilize the IFEWA operator to get the collective overall values r_i ($i = 1, 2, 3, 4, 5$) of the alternatives x_i ($i = 1, 2, 3, 4, 5$):

$$r_1 = (0.707, 0.169),$$
$$r_2 = (0.691, 0.167),$$
$$r_3 = (0.739, 0.134), \qquad (25)$$
$$r_4 = (0.605, 0.233),$$
$$r_5 = (0.645, 0.192).$$

Step 5. Calculate the scores $S(r_i)$ ($i = 1, 2, 3, 4, 5$) of all the overall values r_i ($i = 1, 2, 3, 4, 5$):

$$S(r_1) = 0.538,$$
$$S(r_2) = 0.524,$$
$$S(r_3) = 0.605, \qquad (26)$$
$$S(r_4) = 0.372,$$
$$S(r_5) = 0.453.$$

Step 6. Rank all the alternatives x_i ($i = 1, 2, 3, 4, 5$) in accordance with the scores $S(r_i)$ ($i = 1, 2, 3, 4, 5$); we get $x_3 \succ x_1 \succ x_2 \succ x_5 \succ x_4$, and thus the most desirable alternative 3PL provider is x_3.

Now, we use the I-IFHA operator and IFWA operator proposed in [45] to aggregate the individual intuitionistic

fuzzy information into a collective one to select the suitable 3PL provider.

Step 1. Firstly, we utilize the I-IFHA operator to aggregate all the intuitionistic fuzzy decision matrices into a collective decision matrix $R' = (r'_{ij})_{m \times n}$ (as listed in Table 6).

Step 2. Utilize the IFWA operator to get the collective overall values r'_i ($i = 1, 2, 3, 4, 5$) of the alternatives x_i ($i = 1, 2, 3, 4, 5$):

$$r'_1 = (0.702, 0.160),$$
$$r'_2 = (0.694, 0.160),$$
$$r'_3 = (0.746, 0.136), \qquad (27)$$
$$r'_4 = (0.605, 0.239),$$
$$r'_5 = (0.647, 0.192).$$

Step 3. Calculate the scores $S(r'_i)$ ($i = 1, 2, 3, 4, 5$) of all the overall values r'_i ($i = 1, 2, 3, 4, 5$):

$$S(r'_1) = 0.542,$$
$$S(r'_2) = 0.534,$$
$$S(r'_3) = 0.610, \qquad (28)$$
$$S(r'_4) = 0.366,$$
$$S(r'_5) = 0.455.$$

Step 4. Rank all the alternatives x_i ($i = 1, 2, 3, 4, 5$) in accordance with the scores $S(r'_i)$ ($i = 1, 2, 3, 4, 5$); we get $x_3 \succ x_1 \succ x_2 \succ x_5 \succ x_4$, and thus the most desirable alternative 3PL provider is x_3.

We can see that the results of the two induced intuitionistic fuzzy hybrid aggregation operators based on either the algebraic operational laws of IFSs or the Einstein operational laws are the same. Therefore, the approach proposed in this paper is effective and valid. And we also can see that the overall values of r_i ($i = 1, 2, 3, 4, 5$) using I-IFEHA operator are smaller than that of r'_i ($i = 1, 2, 3, 4, 5$) using the I-IFHA operator with respect to the partial order, respectively. That is to say, the proposed I-IFEHA operator shows more pessimistic attitude of the decision makers than the I-IFHA operator in aggregation process, which reveals the same result of the operator pair of I-IFOWA and I-IFEOWA proposed by Xu et al. [44]. Therefore, the I-IFEHA operator is also an effective approach for decision making information aggregation.

6. Conclusion

In this paper, we investigate the supplier selection multiple attribute decision making problems with intuitionistic fuzzy numbers. Firstly, we introduced some operational laws

Table 5: Intuitionistic fuzzy decision matrix R.

	P_1	P_2	P_3	P_4	P_5
x_1	(0.799, 0.133)	(0.703, 0.169)	(0.746, 0.166)	(0.579, 0.251)	(0.734, 0.119)
x_2	(0.759, 0.163)	(0.730, 0.133)	(0.532, 0.342)	(0.632, 0.163)	(0.760, 0.119)
x_3	(0.804, 0.133)	(0.600, 0.200)	(0.677, 0.119)	(0.800, 0.100)	(0.689, 0.169)
x_4	(0.632, 0.241)	(0.657, 0.177)	(0.600, 0.231)	(0.527, 0.248)	(0.648, 0.251)
x_5	(0.778, 0.163)	(0.635, 0.119)	(0.774, 0.100)	(0.525, 0.287)	(0.527, 0.275)

Table 6: Intuitionistic fuzzy decision matrix R'.

	P_1	P_2	P_3	P_4	P_5
x_1	(0.748, 0.147)	(0.708, 0.157)	(0.809, 0.132)	(0.531, 0.271)	(0.745, 0.127)
x_2	(0.779, 0.152)	(0.700, 0.147)	(0.543, 0.322)	(0.644, 0.152)	(0.745, 0.128)
x_3	(0.807, 0.147)	(0.605, 0.200)	(0.668, 0.128)	(0.800, 0.100)	(0.720, 0.157)
x_4	(0.644, 0.221)	(0.641, 0.214)	(0.605, 0.204)	(0.538, 0.264)	(0.628, 0.271)
x_5	(0.770, 0.152)	(0.680, 0.128)	(0.765, 0.100)	(0.496, 0.282)	(0.538, 0.304)

and aggregation operators of IFVs; moreover, the paper introduces the Einstein product and Einstein sum which are good alternatives to the algebraic product and algebraic sum. Secondly, the paper developed the induced intuitionistic fuzzy Einstein hybrid aggregation operator and studied its desirable properties, such as commutativity, idempotency, boundedness, and monotonicity. By using the I-IFEHA, we are able to deal with complex decision making issues in which the given arguments are intuitionistic fuzzy values. Thirdly, we have also studied the supplier selection decision model for logistics service value cocreation; the evaluation attributes for supplier selection have extended from traditional quality of service to a complex evaluation indicator system, including value collaboration, knowledge matching, service innovation ability, quality of service, and resource interaction. We have also developed an approach to supplier selection group decision making in logistics service value cocreation with intuitionistic fuzzy information and I-IFEHA operator. Finally, an illustrative example in 3PL supplier selection domains is given to verify the developed approach and to demonstrate its practicality and effectiveness. In the future, we will continue working in the extension and application of the developed operator to other actual fields.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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