Evaluation and selection of green suppliers for papermaking enterprises using the interval basic probability assignment-based intuitionistic fuzzy set

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Abstract
With the vigorous development of the global economy, modern enterprises have agreed to implement green supply chain management. The evaluation and selection of green suppliers plays a vital role in successful green supply chain management. As a multi-attribute group decision-making green supplier selection problem, it is difficult to fully describe the evaluation factors using precise numerical values and classical fuzzy sets, so it cannot assist enterprise managers in making completely reasonable decisions. Therefore, this paper proposes a green supplier evaluation and selection method based on interval BPA-based intuitionistic fuzzy sets. First, build a green supplier evaluation index system based on the characteristics of the papermaking enterprise’s suppliers. Then, the intuitionistic fuzzy number is used to express the indicators of the evaluator for each supplier, and the intuitionistic fuzzy information is integrated through the organic combination of the IIFWA integration operator and the structural entropy weight to obtain the comprehensive evaluation value of the evaluator. Finally, the interval BPA-based intuitionistic fuzzy set method ranks the candidate suppliers and determines the best green supplier. Applying this method to the field of green supplier evaluation and selection can provide an effective method for enterprises to select suppliers scientifically and reasonably, which has practical reference value and practical significance.

Keywords Interval evidence theory · Interval-valued intuitionistic fuzzy set · Structural entropy method · IIFWA operator · Green supplier selection

Introduction
As an important global light manufacturing industry, the paper industry is closely related to many fields, such as packaging, logistics, printing, and residents’ lives. Take China as an example. In the first half of 2021, the operating income of national paper companies reached 714.20 billion yuan, and the total profit exceeded 48.43 billion yuan. In recent years, under the trend of stricter environmental protection, the state has increased its efforts to strictly control the pollutant emission standards of the papermaking industry. The “Industrial Green Development Plan” promulgated by the Ministry of Industry and Information Technology clearly states that the concept of green development will become a universal requirement in the entire industry. China’s paper industry urgently needs to accelerate the green transformation to promote industrial development. The green development of the paper industry should strengthen the application of a low-carbon circular economy and the attributes of green plants. Relying on green technological innovation to break through the constraints of resources and the environment, incorporating environmental awareness into the traditional supply chain management model with the characteristics of “high investment, high consumption, and high pollution”, Form a green supply chain management model led by environmental protection concepts to promote the sustainable development of the paper industry.
In recent years, scholars have conducted much research on supplier evaluation and selection in two aspects. On the one hand, it is the evaluation criteria of green suppliers. For example, Hashemi et al. [14] considers economic and environmental standards and proposes a green supplier selection model combining network analysis and improved gray relational analysis. Based on relevant standards of environmental management activities, Kuo et al. [19] established a hybrid multi-objective decision-making model integrating DANP and VIKOR methods. Almalki et al. [3] adopted green innovation standards to develop a green supplier selection model that combined fuzzy AHP and TOPSIS gray. Xu et al. [36] constructed a green supplier selection model based on the fuzzy C-means-VIKOR model of genetic search weights.

On the other hand, is the selection method of green suppliers. For example, Guo et al. [13] used the method of combining ANP and TOPSIS to select the best supplier through calculation with the help of Super Decision and MATLAB software. You et al. [39] used an extended interval binary language variable group decision VIKOR method to deal with the supplier selection problem in an incompletely determined information environment. Fallahpour et al. [11] combined the KA method of the DEA robust model with genetic programming to the problem of green supplier selection. Zhang et al. [43] proposed a three-stage ensemble MCDM method called PL-SSS model, which combines the Delphi method with fuzzy entropy VIKOR for selecting sustainable private label product manufacturing suppliers. The above scholars have carried out more comprehensive research on supplier evaluation, which provides a useful reference for selecting green suppliers. Through literature analysis, it is found that the existing traditional methods of green supplier selection generally have limitations. For example, the fuzzy C-means method does not consider the difference in the impact of the data’s various dimensional attributes on the clustering contribution. The application-based ANP model has obvious loopholes in the analysis of qualitative indicators. Although the traditional TOPSIS method is convenient to calculate and has strong applicability, the lack of information usually leads to deviations in the results. The genetic algorithm is redundant in the calculation process, which easily leads to the loss of original data information, and the evaluation results are not objective enough. These methods rely on the precise assignment of indicators to achieve the selection of green suppliers. However, in the actual process of multi-attribute group decision-making, it is usually difficult to use accurate data to evaluate multi-attribute objective things due to the limitations of ideological cognition and the complexity of the decision-making environment. The same applies to the selection of green suppliers. Some of the selected indicators that are difficult to quantify usually do not have accurate statistical data and can only be vaguely evaluated based on the experience of relevant experts and scholars and existing research results.

As an important part of modern decision-making science, multi-attribute group decision-making theory has been widely used in many social fields, such as investment decision-making, project evaluation, economic benefit evaluation, and personnel assessment [9, 15, 16, 31, 40]. The method of representing fuzzy information with membership degree has played an important role in multi-attribute group decision-making problems. Zadeh [41] was the first to apply fuzzy set theory, which characterizes evaluation information with membership degree, to fuzzy information processing. Atanassov [1] first proposed the concept of an intuitionistic fuzzy set based on the opposite information of membership degree, using a membership function, non-membership function, and hesitancy function to comprehensively and deliberately describe the uncertainty of evaluation information. Subsequently, some scholars have introduced the concept of interval intuitionistic fuzzy sets considering the difficulty of the accurate assignment. Because of its significant advantages in fuzzy information processing, scholars have valued and recognized it at home and abroad [17, 18, 25, 42, 45]. Different decision-makers have different degrees of support for each plan in the multi-attribute group decision-making problem, making it more difficult to gather all expert opinions and form a definite conclusion. Dempster [7] and Shafer [28] established and perfected the DS evidence theory, introduced the accurate BPA in the form of real numbers to represent the basic probability distribution function (BPA) focusing on the basic probability quality (BPM) of all focal elements, and tried to model the evidence theory and obtain sufficient and effective information before making the final decision. However, in the actual decision fusion problem, it is difficult to centralize the uncertain opinions formed by the subjective judgments of all decision-makers. As a result, it is impossible to obtain accurate BPA as evaluation data [32]. In recent years, the use of interval BPA in the form of interval numbers to accurately model fuzzy information has been recognized by many scholars [8, 23, 29, 37]. A general trend is to extend D-S evidence theory to interval evidence theory. In the existing research results, the upper and lower bounds of the results of interval evidence fusion are mostly determined by optimization models. The algorithm has high complexity and cannot merge multiple interval evidence in sequence. It cannot effectively avoid the serious loss of information and cannot solve the problem of fusion of time-domain information [22].

Therefore, given the selection of green suppliers in a fuzzy environment, this paper considers papermaking enterprises’ green suppliers as the research object, draws on relevant research results and practical experience, and proposes a green supplier evaluation and selection method based on
interval BPA-based intuitionistic fuzzy sets. First, the questionnaire survey and the Delphi method evaluated the 7 key standards and 14 sub-standards. Then, the structural entropy method is used to obtain the weight of the indicators, and intuitionistic fuzzy information is integrated based on the Interval Intuitionistic Fuzzy Number Weighted Average (IIFWA) operator. Finally, the interval BPA-based intuitionistic fuzzy set method evaluates green suppliers and determines their priority. The research contribution of this paper is that the multi-attribute group decision-making method based on intuitionistic fuzzy sets and evidence theory can overcome shortcomings and defects of existing research methods. It can deal with the problem of information loss in the decision-making process, improve decision-making effectiveness, and greatly shorten decision-making time. To provide strong theoretical and methodological support for enterprise supply chain managers to make efficient and accurate evaluations.

The chapters of this article are arranged as follows: In the first part, we briefly review the related theories of interval evidence and interval intuitionistic fuzzy sets and the interval BPA-based intuitionistic fuzzy sets method. In the second part, a green supplier evaluation index system is constructed, and a green supplier selection model is proposed. In the third part, taking specific data as an example, the above model is applied to the evaluation and selection process of green suppliers of papermaking enterprises. In the fourth part, by comparing the existing fuzzy multi-attribute group decision-making methods in the literature, the rationality and effectiveness of applying the interval BPA-based intuitionistic fuzzy set method are further verified. In the fifth part, the research conclusions of this article are described.

**Preliminary**

**Interval evidence theory**

D-S evidence theory is based on the identification framework \( \Theta = \{\theta_1, \theta_2 \cdots, \theta_n\} \) to express the support of the evidence to all propositions in the form of a set. Through the correspondence between propositions and collections, the conversion between abstract logical concepts and image collection concepts is carried out.

**Definition 1** Let \( 2^\Theta \) be the power set composed of all the subsets \( F_1, F_2, \cdots, F_N \) on the identification frame \( \Theta = \{\theta_1, \theta_2 \cdots, \theta_n\} \). If the conditions \( m(\phi) = 0 \) and \( \sum m(A) = 1 (\forall A \subseteq \Theta) \) are satisfied, then the function \( m : 2^\Theta \rightarrow [0, 1] \) is called the BPA, and when \( m(A) > 0 \), \( A \) is the focal element of \( \Theta \) [21].

Interval evidence theory achieves full acquisition of decision information through accurate modeling of uncertain information. Due to the substantial expansion of the D-S evidence theory, the construction interval BPA is usually used to replace the precise BPA to make the final decision in solving the actual group decision-making problem.

**Definition 2** Set the BPM interval number of all subsets \( F_1, F_2, \cdots, F_N \) in the identification framework \( \Theta = \{\theta_1, \theta_2 \cdots, \theta_n\} \) as \( [a_1, b_1], [a_2, b_2], \cdots, [a_N, b_N] \) if the following conditions are satisfied [21]:

\[
\begin{align*}
& a_i \leq m(F_i) \leq b_i \\
& \sum_{i=1}^{N} a_i \leq 1 \quad \text{and} \quad \sum_{i=1}^{N} b_i \geq 1 \\
& m(H) = 0, \forall H \notin \{F_1, F_2, \cdots F_N\}
\end{align*}
\]

Then, \( m \) is called the interval BPA.

If all focal elements on identification frame \( \Theta \) are single-element subsets, it can be expressed as the interval Bayesian BPA:

\[
\text{Bet } P_m\left([\theta_j]\right) = \left[\text{Bet } P^-_m\left([\theta_j]\right), \text{ Bet } P^+_m\left([\theta_j]\right)\right] = \left[\sum_{\theta_j \in F_i} a_i, \min 1, \sum_{\theta_j \in F_i} b_i \right]
\]

where \( 0 \leq a_i \leq b_i \leq 1, i = 1, 2, \cdots N, j = 1, 2, \cdots n \).

**Definition 3** Let \( m \) be the interval BPA where all focal elements on the identification frame \( \Theta = \{\theta_1, \theta_2 \cdots, \theta_n\} \) are \( F_1, F_2, \ldots, F_N \) if \( a_j \) and \( b_j \) satisfy the following conditions [33]:

\[
\sum_{j=1}^{N} b_j - (b_k - a_k) \geq 1 \\
\sum_{j=1}^{N} a_j + (b_k - a_k) \leq 1
\]

Then, \( m \) is called the normalized interval BPA, where \( j = 1, 2, \ldots, N, \forall k \in \{1, 2, \ldots, N\} \).

Furthermore, the interval BPA that does not satisfy the normalization condition is called the non-normalized interval BPA. It is divided into two categories. If \( \sum_{j=1}^{N} a_j \leq 1 \) and \( \sum_{j=1}^{N} b_j \geq 1 \) are not satisfied, it is called the first type of non-normalized interval BPA. Its normalization formula is as follows:
\[ \hat{a}_i = \frac{a_i}{a_i + \sum_{j=1, j\neq i}^{N} b_j}, \quad i = 1, 2, \ldots N \]  
(1)

\[ \hat{b}_i = \frac{b_i}{b_i + \sum_{j=1, j\neq i}^{N} a_j}, \quad i = 1, 2, \ldots N \]  
(2)

If the above normalization conditions are satisfied but the conditions \( \sum_{j=1}^{N} b_j - (b_k - a_k) \geq 1 \) and \( \sum_{j=1}^{N} a_j + (b_k - a_k) \leq 1 \) are not satisfied, it is called the second type of non-normalized interval BPA. Its normalization formula is as follows:

\[ \hat{a}_i = \max \left\{ a_i, 1 - \sum_{j=1, j\neq i}^{N} b_j \right\}, \quad i = 1, 2, \ldots N \]

\[ \hat{b}_i = \min \left\{ b_i, 1 - \sum_{j=1, j\neq i}^{N} a_j \right\}, \quad i = 1, 2, \ldots N \]

**Interval intuitionistic fuzzy sets**

Atanassov [1] was the first to use intuitionistic fuzzy sets to describe the ambiguity in random phenomena, proposes the concepts of membership function, non-membership function, and hesitation function, and uses this to finely describe fuzzy information.

**Definition 4** Set domain \( X = \{x_1, x_2, \ldots, x_n\} \) as a non-empty set; then, the intuitionistic fuzzy set \( A \) in domain \( X \) can be defined as [10]:

\[ A = \{(x, \mu_A(x), \nu_A(x))| x \in X \} \]

where \( \mu_A(x) : X \rightarrow [0, 1] \) and \( \nu_A(x) : X \rightarrow [0, 1] \) represent the membership function and the non-membership function, respectively, satisfying the conditions \( 0 \leq \mu_A(x) + \nu_A(x) \leq 1 \). The expression of the hesitation function \( \pi_A(x) : X \rightarrow [0, 1] \) is \( \pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \).

Subsequently, Atanassov et al. [2] found that it is usually difficult to obtain an accurate value of the intuitionistic fuzzy number \( \alpha = (\mu_A(x), \nu_A(x)) \) in actual group decision-making problems. The ordered interval is composed of the membership interval and the non-membership interval to express the interval intuitionistic fuzzy number \( \alpha = ([\mu_L^A(x), \mu_R^A(x)], [\nu_L^A(x), \nu_R^A(x)]) \). This can perfectly avoid such problems. Therefore, the concept of interval intuitionistic fuzzy sets was proposed.

**Definition 5** Set domain \( X = \{x_1, x_2, \ldots, x_n\} \) as a non-empty set; then, the interval intuitionistic fuzzy set \( A \) in domain \( X \) can be defined as [5]:

\[ A = \{\langle x, [\mu_A^L(x), \mu_A^R(x)], [\nu_A^L(x), \nu_A^R(x)]\rangle| x \in X \} \]

where \( [\mu_A^L(x), \mu_A^R(x)] \) and \( [\nu_A^L(x), \nu_A^R(x)] \) represent the membership degree interval and the non-membership degree interval, respectively. Then, the hesitation degree interval is expressed as \( \pi_A(x) = [1 - \mu_A^R(x) - \nu_A^R(x), 1 - \mu_A^L(x) - \nu_A^L(x)] \).

**Interval BPA-based intuitionistic fuzzy set method**

Regarding the BPA \( m \) in the identification framework \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_n\} \) from the perspective of set theory as the intuitionistic fuzzy set \( M \) in the universe of discourse \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_n\} \), \( \mu(\theta_i) \) corresponds to the membership function of \( \theta_i \) relative to the intuitionistic fuzzy set \( M \), and \( \nu(\theta_i) \) corresponds to the non-membership of \( \theta_i \) relative to the intuitionistic fuzzy set \( M \) function. The intuitionistic blur number \( \langle \mu(\theta_i), \nu(\theta_i) \rangle \) represents the trust degree of each focal element in BPA \( m \), where all focal elements are gathered in a single-element focal element.

**Definition 6** Set \( m \) as the interval Bayesian BPA on the identification framework \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_n\} \), and the support of each single-element subset in \( m \) is \( m(\{\theta_i\}) = [a_i, b_i] \). Then, the intuitionistic fuzzy set \( M \) on the universe \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_n\} \) corresponding to \( m \) can be expressed as [22]:

\[ M_i = \{\langle \theta_i, \mu(\theta_i), \nu(\theta_i) \rangle| i = 1, 2, \ldots n \} \]  
(3)

Moreover, there is the following correspondence:

\[ \mu(\theta_i) = a_i \]  
(4)

\[ \nu(\theta_i) = 1 - b_i \]  
(5)

\[ \pi(\theta_i) = b_i - a_i \]  
(6)

If \( M_1 = \{\langle \theta_i, \mu_1(\theta_i), \nu_1(\theta_i)\rangle| \theta_i \in \Theta \} \) and \( M_2 = \{\langle \theta_i, \mu_2(\theta_i), \nu_2(\theta_i)\rangle| \theta_i \in \Theta \} \) are two intuitionistic fuzzy sets on the universe \( \Theta = \{\theta_1, \theta_2, \ldots, \theta_n\} \), the orthogonal sum operation result \( M_1 \oplus M_2 \) of the intuitionistic fuzzy sets \( M_1 \) and \( M_2 \) can be expressed as:

\[ M_1 \oplus M_2 = \{\langle \theta_i, \frac{\mu_1(\theta_i)(1 - \nu_2(\theta_i)) + \mu_2(\theta_i)\pi_1(\theta_i)}{1 - \mu_1(\theta_i)\nu_2(\theta_i) - \mu_2(\theta_i)\nu_1(\theta_i)}, \frac{\nu_1(\theta_i)(1 - \mu_2(\theta_i)) + \nu_2(\theta_i)\pi_1(\theta_i)}{1 - \mu_1(\theta_i)\nu_2(\theta_i) - \mu_2(\theta_i)\nu_1(\theta_i)}\rangle| i = 1, 2, \ldots n \} \]
Definition 7 Set \( m \) as the interval Bayesian BPA on the identification frame \( \Theta = \{\theta_1, \theta_2, \cdots, \theta_n\} \), and the intuitionistic fuzzification form of the support \( m(\{\theta_i\}) = [a_i, b_i] \) of each single element subset in \( m \) is \( (a_i, 1 - b_i)(i = 1, 2, \cdots, n) \). Then, the intuitionistic fuzzy set \( M \) on the universe \( \Theta = \{\theta_1, \theta_2, \cdots, \theta_n\} \) corresponding to \( m \) can be expressed as [22]:
\[
M_i = \{(\theta_i, a_i, 1 - b_i)|i = 1, 2, \cdots n\}
\]

If \( m_1 \) and \( m_2 \) are the normalized interval BPA on the identification frame \( \Theta = \{\theta_1, \theta_2, \cdots, \theta_n\} \), the support for the single-element subsets of \( m_1 \) and \( m_2 \) are \( m_1(\{\theta_i\}) = [a_{1i}, b_{1i}] \) and \( m_2(\{\theta_i\}) = [a_{2i}, b_{2i}] \), then the intuitionistic fuzzy sets on the universe \( \Theta = \{\theta_1, \theta_2, \cdots, \theta_n\} \) corresponding to \( m_1 \) and \( m_2 \) are denoted as \( M_1 = \{(\theta_i, a_{1i}, 1 - b_{1i})|i = 1, 2, \cdots n\} \) and \( M_2 = \{(\theta_i, a_{2i}, 1 - b_{2i})|i = 1, 2, \cdots n\} \). Therefore, the orthodox sum operation \( M_1 \oplus M_2 \) of the intuitionistic fuzzy set \( M_1 \) and \( M_2 \) can be further expressed as:
\[
M_1 \oplus M_2 = \left\{\left(\theta_i, \frac{a_{1i}b_{2i} + a_{2i}(b_{1i} - a_{1i})}{1 - a_{1i} - a_{2i} + a_{1i}b_{2i} + a_{2i}b_{1i}}, \frac{b_{1i}(1 - a_{2i}) + (1 - b_{2i})(b_{1i} - a_{1i})}{1 - a_{1i} - a_{2i} + a_{1i}b_{2i} + a_{2i}b_{1i}}\right)|i = 1, 2, \cdots n\right\} \tag{7}
\]

The orthogonal sum operation of multiple intuitionistic fuzzy sets satisfies the commutative and associative laws \( M_1 \oplus M_2 \oplus M_3 = (M_1 \oplus M_2) \oplus M_3 = M_1 \oplus (M_2 \oplus M_3) \).

Based on the corresponding relationship between evidence theory and the intuitionistic fuzzy set in the, the combined result \( M_1 \oplus M_2 \) of \( m_1 \) and \( m_2 \) can be expressed as:
\[
m_1 \oplus m_2(\{\theta_i\}) = \left[\begin{array}{c}
\frac{a_{1i}b_{2i} + a_{2i}(b_{1i} - a_{1i})}{1 - a_{1i} - a_{2i} + a_{1i}b_{2i} + a_{2i}b_{1i}} \\
1 - b_{1i}(1 - a_{2i}) + (1 - b_{2i})(b_{1i} - a_{1i}) \end{array}\right] \quad (i = 1, 2, \cdots n) \tag{8}
\]

The combined operation \( \oplus_{j=1}^{N} m_j \) of multiple intervals BPA also satisfies the commutative and associative laws \( m_1 \oplus m_2 \oplus m_3 = (m_1 \oplus m_2) \oplus m_3 = m_1 \oplus (m_2 \oplus m_3) \).

It should be noted that when the combined result is a non-normalized interval BPA, it needs to be normalized.

Green supplier selection model

Green supplier evaluation index system

Green supplier evaluation indicators are the key factors that affect the selection of green suppliers. Most scholars only consider economic benefits when selecting indicators while ignoring environmental benefits. Only a few documents have conducted a comprehensive study on this, such as Pourjavad and Shahin [26] divided the factors that affect the evaluation of GSDPs green suppliers into supplier operational performance and supplier environmental performance; Gao et al. [12] divided the green supplier evaluation and selection index system with four indicators: environmental protection capability, product quality, technical capability, and product cost based on the group consensus decision-making framework; Rahimi et al. [27] identified five factors of price, quality, delivery, technical capability and pay off as important criteria for selecting the best suppliers. This paper summarizes the research data through literature reading and analysis, follows the scientific and guiding principles of indicator selection, and builds a green supplier evaluation index system based on the two dimensions of suppliers’ operational performance and environmental performance. The three primary indicators of supplier operation capability, supplier cooperation ability, and supplier green ability are subdivided into several secondary and tertiary indicators. The evaluation information is comprehensively and delicately described through the layer-by-layer screening of the indicators with typical characteristic attributes in the evaluation index system. This index system can comprehensively and objectively analyze the evaluation problems of green suppliers of papermaking enterprises, as shown in Table 1.

**Green supplier selection model**

This paper regards the selection of green suppliers as a fuzzy evaluation problem. First, the questionnaire survey method and the Delphi method were used to obtain the interval fuzzy number measurement of the indicators. Then, the weighted indicator is comprehensively evaluated by the organic combination of the IIFWA integration operator and structural entropy weight method. Furthermore, the interval BPA is used to express the comprehensive evaluation value of each indicator. Finally, based on the correspondence between the interval evidence and the intuitionistic fuzzy set, the orthogonal sum calculation result of the intuitionistic fuzzy set formed by the normalized interval BPA is converted. The result of the obtained interval evidence combination is compared, and the optimal green supplier is determined. Suppose that a company has \( n \) candidate green suppliers, the plan set is \( V = \{v_1, v_2, \cdots v_n\} \), and \( V_j(j = 1, 2, \cdots n) \) represents the \( j \)th evaluation unit of the evaluation matrix. The evaluation indicator attribute set of each green supplier is \( U = \{u_1, u_2, \cdots u_m\} \), where \( U_i(i = 1, 2, \cdots, m) \) represents the \( i \)th attribute of the evaluation indicator. The evaluation indicator ranking opinion data corresponding to the evaluation indicator attribute
### Table 1: Evaluation index system of green suppliers of papermaking enterprises

| Purpose | First-level indicators | Second-level indicators | Third-level indicators |
|---------|------------------------|-------------------------|------------------------|
| Evaluation index system of green suppliers of papermaking enterprises | Supplier operational capability A₁ | Product quality B₁ | Product quality qualification rate C₁₁ |
| | | Product cost B₂ | Quality control ability C₁₂ |
| | Supplier cooperation capability A₂ | Cooperation service capability B₃ | Transportation transaction cost C₂₁ |
| | | Order response delivery capability C₃₁ | Environmental governance cost C₂₂ |
| | Supplier green capability A₃ | Green environmental capability B₅ | Green recycling and utilization capacity C₅₂ |
| | | Green development capability B₆ | Green product development rate C₆₁ |
| | Green competitiveness B₇ | Green technology transformation success rate C₆₂ | Green customer share C₇₂ |

set \( U = (a₁, a₂, \cdots, aₘ) \), the weight vector of each evaluation indicator attribute is \( \omega = (\omega₁, \omega₂, \cdots, \omegaₘ)ᵀ \), and its weight \( \omegaᵢ \) satisfies \( \sum_{i=1}^{m} \omegaᵢ = 1 (\omegaᵢ \in (0, 1)) \). The selection process of the green supplier based on the interval BPA-based intuitionistic fuzzy set is as follows:

1. Obtain the measurement of the evaluation indicators

A questionnaire survey method was used to select several internal employees of the enterprise, make them choose among the two attribute options of each three-level indicator, and summarize and organize employee feedback. The first evaluation of the three-level indicators is shown in Table 2.

To increase the authenticity of the questionnaire survey results, authoritative experts were invited to conduct a second evaluation of the above results. The five grades of “Very Poor”, “Poor”, “Medium”, “Good”, and “Very Good” are used as the evaluation indicator attribute evaluation terms of each green supplier. Calculate the hesitation interval \( \widetilde{\pi}_A(x) \) of each evaluation term according to formula (6), and obtain the final data in the form of intuitionistic fuzzy numbers for each evaluation indicator evaluation term interval, as shown in Table 3.

2. Determine the weight of the evaluation indicators

This paper is based on the hierarchical structure of the green supplier index system for papermaking enterprises and gradually assigns corresponding weights to the indicators based on the importance of the indicators. After referring to many indicator weight determination methods \([4, 6, 20, 24, 30]\), this paper decided to adopt the structural entropy weight method to determine the evaluation indicator weights.

**Step 1** Form a "typical ranking" of experts.

The Delphi method was used to collect \( K \) experts’ ranking opinions on the relative importance of indicators at different levels. Consider \( A = (aₖₘ)_{K \times M} (k = 1, 2, \cdots, K, m = 1, 2, \cdots, M) \) as the expert ranking opinion matrix formed by the feedback opinions of \( K \) experts on the \( M \) indicators at the same level, that is, the expert "typical ranking" matrix. Among them, \( aₖₘ \in \{1, 2, \cdots, n\} \) represents the expert’s "1st choice, 2nd choice, \cdots, nth choice", and the importance of the indicator is inversely proportional to its value.

**Step 2** Obtain overall awareness.

In the "typical ranking" of experts, the membership function value of the indicator qualitative ranking number \( I \) is represented by \( \chi(I) (I = 1, 2, \cdots, m) \), the
Step 3 Acquire the evaluation indicator weights.

Normalize the overall awareness \(x_m\) and calculate the weight coefficient \(\omega_m = x_m / \sum_{m=1}^{M} x_m\) of the \(m\) th indicator at the same level. Then, the weight vector of the indicator set \(U = \{u_1, u_2, \ldots, u_m\}\) is \(W = \{\omega_1, \omega_2, \ldots, \omega_m\}\).

3. Comprehensive evaluation of the indicator attributes

Use the IIFWA Operator to Integrate Interval Intuitionistic Fuzzy Information. Through the organic combination of the second-level and third-level indicators interval intuitionistic fuzzy numbers and the corresponding weight coefficients, the comprehensive evaluation of the upper indicators is realized, forming a gathering of different expert opinions, thereby improving the authenticity of the evaluation results [35]. The interval intuitionistic fuzzy set integrated by the IIFWA operator is

\[
f_{\omega}(\alpha_1, \alpha_2, \ldots, \alpha_m) = \left(\sum_{i=1}^{m} c_{ij}^\omega, \sum_{i=1}^{m} d_{ij}^\omega\right)
\]

Step 1 Establish the interval intuitionistic fuzzy number \(\alpha_{ij}\) of the evaluation unit \(Z_j\) based on the evaluation indicator attribute \(U_i\).

\[
\alpha_{ij} = ([a_{ij}, b_{ij}], [c_{ij}, d_{ij}]) (i = 1, 2, \ldots, m, j = 1, 2 \ldots n)
\]

Step 2 Use the IIFWA operator to integrate the comprehensive interval intuitionistic fuzzy number \(\beta_{ij}\) of the evaluation unit \(Z_j\).

\[
\beta_{ij} = ([e_{ij}, f_{ij}], [g_{ij}, h_{ij}]) (i = 1, 2, \ldots, m, j = 1, 2 \ldots n)
\]

4. Fusion of the comprehensive evaluation results
Convert the first-level indicator interval BPA integrated by the IIFWA operator into an intuitionistic fuzzy set and perform the orthogonal sum operation. Based on the conversion relationship between interval BPA and intuitionistic fuzzy sets, the orthogonal sum operation result is transformed into the result of interval evidence combination. Finally, the optimal combination result is determined.

Analysis of example

A papermaking enterprise intends to select an optimal supplier as a component of its green supply chain management system based on the green economic environment. After preliminary screening, the existing four green suppliers \( V_1, V_2, V_3 \) and \( V_4 \) can be used as alternatives for enterprises. To facilitate the evaluation, this article uses the first-level indicators in Table 1 as the evaluation criteria, and the second-level and third-level indicators are used as references for the first-level indicators.

Green supplier evaluation indicators measurement

Through the evaluation team composed of authoritative experts in the papermaking field to evaluate the results of the internal employee questionnaire survey, the three-level indicator interval intuitive fuzzy numbers of the four green suppliers \( V_1, V_2, V_3 \) and \( V_4 \) were obtained. Taking green supplier \( V_1 \) as an example, the interval intuitionistic fuzzy number of its three-level indicators is shown in Table 4.

Then, we determine the interval intuitionistic fuzzy numbers of the three-level indicators of green suppliers \( V_2, V_3 \) and \( V_4 \), as shown in Table 5.

Green supplier evaluation indicator weights

Combined with the actual situation of the supply chain management of papermaking enterprises, authoritative experts in the papermaking field \( D_1-D_{10} (K = 10) \) are invited to provide the ranking opinions of the second-level and third-level indicators and the structural entropy weight method is used to obtain the weight coefficients of the corresponding indicators. The process of determining the weight coefficients of the second-level indicators “green environmental capability \( B_5 \)”, “green development capability \( B_6 \)”, and “green competitiveness \( B_7 \)” is as follows:

**Step 1** Form a “typical ranking” of experts.

According to each expert’s ranking of the importance of the above evaluation indicators based on their own cognitive experience, the weighted survey of the second-level indicators “green environmental capability \( B_5 \)”, “green development capability \( B_6 \)”, and “green competitiveness \( B_7 \)” was obtained. As shown in Table 6.

Based on the ranking opinions of experts, the “typical ranking” matrix is formed as:

\[
A = \begin{bmatrix}
1 & 1 & 2 & 1 & 3 & 2 & 1 & 2 & 2 & 1 \\
2 & 2 & 2 & 2 & 1 & 1 & 3 & 1 & 3 & 2 \\
3 & 3 & 1 & 3 & 2 & 2 & 3 & 3 & 1 & 3 
\end{bmatrix}
\]

**Step 2** Obtain overall awareness.

In the “typical sorting” matrix \( AA_{km} \in \{1, 2, 3\} \), the maximum sequence number \( m \) of the indicators is 3, that is, \( y = m + 2 = 5 \). According to formula \( \chi (dkm) = \frac{\ln (y-a_{km})}{\ln (y-1)} \), we know \( b_{km} \in \{0.7925, 0.5000, 0.5000\} \), and its membership matrix \( B \) is:

\[
B = (b_{km})_{K \times M} = \begin{bmatrix}
1 & 1 & 0.7925 & 1 & 0.5000 & 0.7925 & 1 & 0.7925 & 0.7925 & 1 \\
0.7925 & 0.7925 & 0.5000 & 0.7925 & 1 & 1 & 0.5000 & 0.5000 & 1 & 0.7925 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
0.5000 & 0.5000 & 1 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 0.5000 & 0.7925 & 1 \\
\end{bmatrix}
\]

Obtain the average degree of awareness \( b_{km} \in \{0.8670, 0.7670, 0.6585\} \) of the second-level indicators \( B_1, B_2 \) and \( B_3 \) through the average awareness formula. Use the awareness blindness formula to calculate the corresponding blindness \( Q_{km} \in \{0.1170, 0.0170, 0.0915\} \). According to the overall awareness formula, we can know its overall awareness \( x_{km} \in \{0.7656, 0.7540, 0.5982\} \). Then, the evaluation vector \( X = \{0.7656, 0.7540, 0.5982\} \) of the second-level indicators \( B_1, B_2 \) and \( B_3 \).

**Step 3** Acquire the evaluation indicator weights.

Use formula \( \omega_m = x_m / \sum_{m=1}^{M} x_m \) to calculate the weight coefficient \( \omega_m \in \{0.3615, 0.3560, 0.2825\} \) of the second-level indicators \( B_1, B_2 \) and \( B_3 \), and the corresponding weight vector is \( W = \{0.3615, 0.3560, 0.2825\} \). Then, the weight coefficients of the second and third levels in the green supplier evaluation index system of papermaking enterprises are determined, and the results are shown in Table 7.
Table 4 Papermaking enterprises $v_1$ green supplier third-level indicators interval intuitionistic fuzzy number survey table

| Indicators | High or strong | Low or weak | Not evaluated | Interval intuitionistic fuzzy number $\tilde{a}$ | Evaluation term | Interval intuitionistic fuzzy number $\alpha$ |
|------------|----------------|-------------|---------------|-----------------------------------------------|----------------|---------------------------------------------|
|            | Sure           | Hesitate    | Sure          | [0.412, 0.470], [0.386, 0.428] >               | M              | [0.361, 0.369], [0.437, 0.529] >             |
| $C_{11}$   | 206            | 29          | 193           | 21                                          |                |                                              |
| $C_{12}$   | 257            | 45          | 133           | 16                                          |                |                                              |
| $C_{21}$   | 135            | 19          | 266           | 37                                          |                |                                              |
| $C_{22}$   | 211            | 30          | 192           | 28                                          |                |                                              |
| $C_{31}$   | 262            | 43          | 132           | 15                                          |                |                                              |
| $C_{32}$   | 184            | 47          | 186           | 44                                          |                |                                              |
| $C_{41}$   | 260            | 42          | 136           | 14                                          |                |                                              |
| $C_{42}$   | 285            | 98          | 85            | 10                                          |                |                                              |
| $C_{51}$   | 145            | 21          | 263           | 36                                          |                |                                              |
| $C_{52}$   | 191            | 39          | 197           | 32                                          |                |                                              |
| $C_{61}$   | 260            | 37          | 152           | 12                                          |                |                                              |
| $C_{62}$   | 261            | 44          | 132           | 16                                          |                |                                              |
| $C_{71}$   | 198            | 45          | 183           | 36                                          |                |                                              |
| $C_{72}$   | 257            | 48          | 146           | 10                                          |                |                                              |

Green suppliers indicator attributes comprehensive evaluation

The IIFWA operator and structural entropy weight method are combined to integrate the interval intuitionistic fuzzy information of the second-level and third-level indicators. The three-level indicators “product quality qualification rate $C_{11}$” and “quality control ability $C_{12}$”, “transportation transaction cost $C_{21}$” and “environmental governance cost $C_{22}$” are sequentially integrated into the second-level indicators “product quality $B_{1}$” and “product cost $B_{2}$” to form the first-level indicators. The comprehensive evaluation process of “supplier operational capability $A_1$” is as follows:

**Step 1** Establish the interval intuitionistic fuzzy number $\alpha_{ij}(i = 1, j = 1, 2)$ between the three-level indicators $C_{11}$ and $C_{12}$.

$$\alpha_{11} = \{ [0.361, 0.369], [0.437, 0.529] \},$$

$$\alpha_{12} = \{ [0.456, 0.460], [0.292, 0.360] \},$$

**Step 2** Use the IIFWA operator to integrate the comprehensive interval intuitionistic fuzzy number $\beta_{ij}(i = 1, j = 1, 2, 3, 4)$ of the second-level indicator $B_{1}$. 

\[ \beta_{ij} = \]
Table 5 Summary table of interval intuitionistic fuzzy numbers for the third-level indicators of papermaking enterprises green suppliers

| Indicators | $V_1$ | $V_2$ | $V_3$ | $V_4$ |
|------------|-------|-------|-------|-------|
| $C_{11}$   | $< [0.361, 0.369], [0.437, 0.529]$ | $< [0.456, 0.460], [0.445, 0.535]$ | $< [0.361, 0.367], [0.445, 0.535]$ | $< [0.450, 0.451], [0.320, 0.373]$ |
| $C_{12}$   | $< [0.445, 0.450], [0.295, 0.364]$ | $< [0.321, 0.346], [0.415, 0.572]$ | $< [0.337, 0.338], [0.431, 0.572]$ | $< [0.335, 0.336], [0.437, 0.582]$ |
| $C_{13}$   | $< [0.244, 0.249], [0.592, 0.745]$ | $< [0.260, 0.265], [0.582, 0.731]$ | $< [0.256, 0.272], [0.568, 0.736]$ | $< [0.449, 0.450], [0.299, 0.384]$ |
| $C_{21}$   | $< [0.383, 0.385], [0.423, 0.537]$ | $< [0.449, 0.450], [0.297, 0.378]$ | $< [0.457, 0.464], [0.297, 0.356]$ | $< [0.249, 0.261], [0.583, 0.743]$ |
| $C_{22}$   | $< [0.457, 0.462], [0.293, 0.358]$ | $< [0.329, 0.332], [0.411, 0.590]$ | $< [0.368, 0.369], [0.458, 0.547]$ | $< [0.383, 0.386], [0.389, 0.556]$ |
| $C_{23}$   | $< [0.329, 0.332], [0.411, 0.590]$ | $< [0.450, 0.452], [0.340, 0.386]$ | $< [0.449, 0.450], [0.299, 0.384]$ | $< [0.487, 0.489], [0.297, 0.343]$ |
| $C_{41}$   | $< [0.453, 0.458], [0.301, 0.362]$ | $< [0.459, 0.462], [0.315, 0.366]$ | $< [0.509, 0.511], [0.187, 0.221]$ | $< [0.359, 0.373], [0.439, 0.529]$ |
| $C_{42}$   | $< [0.530, 0.532], [0.174, 0.216]$ | $< [0.348, 0.350], [0.428, 0.574]$ | $< [0.459, 0.474], [0.315, 0.370]$ | $< [0.321, 0.323], [0.425, 0.579]$ |
| $C_{51}$   | $< [0.269, 0.277], [0.575, 0.727]$ | $< [0.454, 0.455], [0.308, 0.373]$ | $< [0.367, 0.371], [0.435, 0.531]$ | $< [0.230, 0.242], [0.580, 0.756]$ |
| $C_{52}$   | $< [0.341, 0.348], [0.435, 0.570]$ | $< [0.349, 0.350], [0.415, 0.556]$ | $< [0.455, 0.456], [0.301, 0.366]$ | $< [0.342, 0.348], [0.434, 0.572]$ |
| $C_{61}$   | $< [0.465, 0.471], [0.327, 0.381]$ | $< [0.451, 0.457], [0.275, 0.353]$ | $< [0.347, 0.349], [0.399, 0.593]$ | $< [0.366, 0.373], [0.436, 0.523]$ |
| $C_{62}$   | $< [0.456, 0.460], [0.292, 0.360]$ | $< [0.244, 0.245], [0.584, 0.769]$ | $< [0.323, 0.324], [0.457, 0.586]$ | $< [0.438, 0.446], [0.282, 0.346]$ |
| $C_{71}$   | $< [0.358, 0.367], [0.404, 0.557]$ | $< [0.335, 0.336], [0.397, 0.578]$ | $< [0.449, 0.456], [0.299, 0.362]$ | $< [0.248, 0.261], [0.582, 0.747]$ |
| $C_{72}$   | $< [0.459, 0.474], [0.315, 0.370]$ | $< [0.236, 0.242], [0.614, 0.740]$ | $< [0.437, 0.441], [0.311, 0.371]$ | $< [0.334, 0.341], [0.428, 0.575]$ |

Table 6 Survey of the weights of green supplier evaluation indicators for papermaking enterprises

| Expert indicators | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|-------------------|----|----|----|----|----|----|----|----|----|-----|
| B5                | 1  | 1  | 2  | 1  | 3  | 2  | 1  | 2  | 2   | 1   |
| B6                | 2  | 2  | 3  | 2  | 2  | 1  | 1  | 3  | 1   | 2   |
| B7                | 3  | 3  | 1  | 3  | 2  | 3  | 2  | 3  | 1   | 3   |

\[
\beta_{11} = \left( \left[ 1 - \left( 1 - 0.361 \right)^{0.5226} \right] \left( 1 - 0.445 \right)^{0.4774}, \left( 1 - 0.369 \right)^{0.5226} \left( 1 - 0.450 \right)^{0.4774} \right), \left( 0.437^{0.5226} \times 0.2950^{0.4774}, 0.529^{0.5226} \times 0.364^{0.4774} \right] \\
= \left( [0.403, 0.409], [0.362, 0.443] \right)
\]

\[
\beta_{12} = \left( \left[ 1 - \left( 1 - 0.456 \right)^{0.5226} \right] \left( 1 - 0.321 \right)^{0.4774}, \left( 1 - 0.460 \right)^{0.5226} \left( 1 - 0.346 \right)^{0.4774} \right), \left( 0.292^{0.5226} \times 0.415^{0.4774}, 0.360^{0.5226} \times 0.572^{0.4774} \right] \\
= \left( [0.395, 0.408], [0.345, 0.449] \right)
\]
shown in Table 8.

| Purpose | First-level indicators | Second-level indicators | Weights | Third-level indicators | Weights |
|---------|------------------------|-------------------------|---------|------------------------|---------|
| Green supplier evaluation indicator weight | A1 B1 | 0.5453 C11 | 0.5226 C12 | | |
| | | 0.4547 C21 | 0.4774 C22 | | |
| | A2 B3 | 0.5226 C31 | 0.5679 C32 | | |
| | | 0.4774 C41 | 0.4547 C42 | | |
| | A3 B5 | 0.3615 C51 | 0.4774 C52 | | |
| | | 0.3560 C61 | 0.5226 C62 | | |
| | | 0.2825 C71 | 0.5000 C72 | | |

\[
\beta_{13} = \left\{ \begin{array}{l}
1 - (1 - 0.361)0.5226(1 - 0.337)0.4774, 1 - (1 - 0.367)0.5226(1 - 0.338)0.4774 \\
0.4450.5226 \times 0.4310.4774, 0.5350.5226 \times 0.5720.4774
\end{array} \right\} = \left\{ \begin{array}{l}
[0.350, 0.353], [0.438, 0.552]
\end{array} \right\}
\]

\[
\beta_{14} = \left\{ \begin{array}{l}
1 - (1 - 0.450)0.5226(1 - 0.335)0.4774, 1 - (1 - 0.451)0.5226(1 - 0.336)0.4774 \\
0.3200.5226 \times 0.4370.4774, 0.3730.5226 \times 0.5820.4774
\end{array} \right\} = \left\{ \begin{array}{l}
[0.398, 0.399], [0.371, 0.461]
\end{array} \right\}
\]

Comprehensive interval intuitionistic fuzzy numbers integrate each second-level indicator in turn, and the results are shown in Table 8.

**Step 3** Establish the interval intuitionistic fuzzy number \(\gamma_{ij}(i = 1, j = 1, 2)\) between the second-level indicators “product quality \(B_1\)” and “product cost \(B_2\)”.

\[
\gamma_{11} = \left\{ \begin{array}{l}
[0.403, 0.409], [0.362, 0.443], \\
[0.395, 0.408], [0.345, 0.449], \\
[0.350, 0.353], [0.438, 0.552], \\
[0.398, 0.399], [0.371, 0.461]
\end{array} \right\}
\]

\[
\gamma_{12} = \left\{ \begin{array}{l}
[0.320, 0.323], [0.497, 0.628], \\
[0.366, 0.368], [0.410, 0.518], \\
[0.369, 0.380], [0.405, 0.504], \\
[0.353, 0.358], [0.424, 0.542]
\end{array} \right\}
\]

**Step 4** Use the IIFWA operator to integrate the comprehensive interval intuitionistic fuzzy number \(\vartheta_{ij}(i = 1, j = 1, 2, 3, 4)\) of the first-level indicator \(A_1\).

\[
\vartheta_{11} = \left\{ \begin{array}{l}
1 - (1 - 0.403)0.5453(1 - 0.320)0.4547, 1 - (1 - 0.409)0.5453(1 - 0.323)0.4547 \\
0.3620.5453 \times 0.4970.4547, 0.4430.5453 \times 0.6280.4547
\end{array} \right\} = \left\{ \begin{array}{l}
[0.367, 0.371], [0.418, 0.519]
\end{array} \right\}
\]

\[
\vartheta_{12} = \left\{ \begin{array}{l}
1 - (1 - 0.403)0.5453(1 - 0.320)0.4547, 1 - (1 - 0.409)0.5453(1 - 0.323)0.4547 \\
0.3620.5453 \times 0.4970.4547, 0.4430.5453 \times 0.6280.4547
\end{array} \right\} = \left\{ \begin{array}{l}
[0.367, 0.371], [0.418, 0.519]
\end{array} \right\}
\]
Table 8: Summary table of interval intuitionistic fuzzy numbers for the second-level indicators of papermaking enterprises green suppliers

| Indicators | V1 | V2 | V3 | V4 |
|------------|----|----|----|----|
| B1         | < [0.403, 0.409], [0.362, 0.443] > | < [0.395, 0.408], [0.345, 0.449] > | < [0.350, 0.353], [0.438, 0.552] > | < [0.398, 0.399], [0.371, 0.461] > |
| B2         | < [0.320, 0.332], [0.497, 0.628] > | < [0.366, 0.368], [0.410, 0.518] > | < [0.389, 0.390], [0.405, 0.504] > | < [0.424, 0.542], [0.430, 0.543] > |
| B3         | < [0.405, 0.409], [0.339, 0.444] > | < [0.384, 0.387], [0.379, 0.491] > | < [0.405, 0.406], [0.381, 0.469] > | < [0.430, 0.533], [0.346, 0.451] > |
| B4         | < [0.497, 0.500], [0.223, 0.273] > | < [0.450, 0.454], [0.286, 0.367] > | < [0.482, 0.491], [0.249, 0.293] > | < [0.339, 0.346], [0.431, 0.456] > |
| B5         | < [0.308, 0.315], [0.497, 0.640] > | < [0.401, 0.402], [0.360, 0.459] > | < [0.415, 0.417], [0.359, 0.437] > | < [0.291, 0.299], [0.498, 0.653] > |
| B6         | < [0.461, 0.466], [0.310, 0.371] > | < [0.360, 0.364], [0.394, 0.512] > | < [0.336, 0.337], [0.426, 0.590] > | < [0.402, 0.409], [0.354, 0.430] > |
| B7         | < [0.411, 0.423], [0.357, 0.454] > | < [0.287, 0.291], [0.494, 0.654] > | < [0.443, 0.448], [0.305, 0.366] > | < [0.292, 0.302], [0.499, 0.655] > |

\[ \vartheta_{12} = \left\{ \begin{array}{l} 1 - (1 - 0.395)^{0.5453}(1 - 0.366)^{0.4547}, 1 - (1 - 0.408)^{0.5453}(1 - 0.368)^{0.4547} \end{array} \right\} \]

\[ = ([0.382, 0.391], [0.373, 0.479]) \]

\[ \vartheta_{13} = \left\{ \begin{array}{l} 1 - (1 - 0.350)^{0.5453}(1 - 0.369)^{0.4547}, 1 - (1 - 0.353)^{0.5453}(1 - 0.380)^{0.4547} \end{array} \right\} \]

\[ = ([0.358, 0.366], [0.423, 0.530]) \]

\[ \vartheta_{14} = \left\{ \begin{array}{l} 1 - (1 - 0.398)^{0.5453}(1 - 0.353)^{0.4547}, 1 - (1 - 0.399)^{0.5453}(1 - 0.358)^{0.4547} \end{array} \right\} \]

\[ = ([0.378, 0.381], [0.395, 0.496]) \]

Comprehensive interval intuitionistic fuzzy numbers integrate each first-level indicator in turn, and the results are shown in Table 9.

**Green suppliers comprehensive evaluation results fusion**

This paper uses the interval BPA-based intuitionistic fuzzy set method to fuse the comprehensive evaluation results of the first-level indicators. Evaluate alternatives and determine their priority by comparing the results of the fusion.

**Step 1** The interval Bayesian BPA formed by the first-level indicators interval intuitionistic fuzzy number is normalized.

Obtain the corresponding interval Bayesian BPA based on the interval intuitionistic fuzzy number of the first-level indicator A1:

\[ m_1(\{\vartheta_1\}) = [a_{11}, b_{11}] = \left[ \frac{0.367+0.371}{2}, 1 - \frac{0.418+0.519}{2} \right] = [0.369, 0.531] \]

\[ m_1(\{\vartheta_2\}) = [a_{12}, b_{12}] = \left[ \frac{0.382+0.391}{2}, 1 - \frac{0.373+0.479}{2} \right] = [0.386, 0.574] \]

\[ m_1(\{\vartheta_3\}) = [a_{13}, b_{13}] = \left[ \frac{0.382+0.391}{2}, 1 - \frac{0.423+0.530}{2} \right] = [0.362, 0.524] \]
Table 9 Summary table of interval intuitionistic fuzzy numbers for the first-level indicators of papermaking enterprises green suppliers

| Indicators | $V_1$ | $V_2$ | $V_3$ | $V_4$ |
|------------|-------|-------|-------|-------|
| A<sub>1</sub> | $<0.367, 0.371, \ [0.418, 0.519]$ | $<0.382, 0.391, \ [0.423, 0.530]$ | $<0.358, 0.366, \ [0.395, 0.496]$ | $<0.378, 0.381, \ [0.395, 0.496]$ |
| A<sub>2</sub> | $<0.377, 0.380, \ [0.366, 0.447]$ | $<0.349, 0.352, \ [0.417, 0.513]$ | $<0.372, 0.375, \ [0.401, 0.469]$ | $<0.340, 0.344, \ [0.449, 0.555]$ |
| A<sub>3</sub> | $<0.418, 0.426, \ [0.355, 0.451]$ | $<0.372, 0.375, \ [0.386, 0.430]$ | $<0.422, 0.425, \ [0.334, 0.430]$ | $<0.350, 0.358, \ [0.420, 0.546]$ |

Obtain the corresponding interval BPA of the first-level indicators $A_2$ and $A_3$ in turn. The results are as follows:

$m_1(\{\theta_4\}) = [a_{14}, b_{14}] = \left[\frac{0.378+0.381}{2}, 1 - \frac{0.395+0.496}{2}\right] = [0.379, 0.555]$

From Definition 3, we know that $m_1, m_2$ and $m_3$ are all Bayesian BPs of the first type of non-normalized interval. According to formulas (1) and (2), $m_1$ can be normalized as follows:

$$Bet P^*_m(\{\theta_4\}) = a_{14}, b_{14}$$

$$= \left[\frac{a_{14}}{a_{14}+\sum_{j=1, j \neq 1}^{4} b_{1j}}, \frac{b_{14}}{b_{14}+\sum_{j=1, j \neq 1}^{4} a_{1j}}\right]$$

$$= \left[0.369+0.531+0.369+0.369, 0.531+0.369+0.369+0.369\right]$$

$$= [0.183, 0.320]$$

$$Bet P^*_m(\{\theta_2\}) = a_{12}, b_{12}$$

$$= \left[\frac{a_{12}}{a_{12}+\sum_{j=1, j \neq 1}^{4} b_{2j}}, \frac{b_{12}}{b_{12}+\sum_{j=1, j \neq 1}^{4} a_{1j}}\right]$$

$$= \left[0.386+0.574+0.574+0.574, 0.574+0.574+0.574+0.574\right]$$

$$= [0.194, 0.341]$$

$$Bet P^*_m(\{\theta_3\}) = a_{13}, b_{13}$$

$$= \left[\frac{a_{13}}{a_{13}+\sum_{j=1, j \neq 1}^{4} b_{3j}}, \frac{b_{13}}{b_{13}+\sum_{j=1, j \neq 1}^{4} a_{1j}}\right]$$

$$= \left[0.362+0.531+0.531+0.531, 0.531+0.531+0.531+0.531\right]$$

$$= [0.179, 0.316]$$

Step 2 Perform the orthogonal sum operation on the intuitionistic fuzzy set $M$ formed by the normalized interval Bayesian BPA.

Given the conversion relationship between interval evidence and the intuitionistic fuzzy set shown in Definition 6, the interval Bayesian BPA$_m$ is converted into an intuitionistic fuzzy set $M_1$ according to formulas (3)–(5):

$$M_1 = \{\{\theta_1, a_{1i}, 1 - b_{1i}\} | i = 1, 2, 3, 4\}$$

$$= \{\{\theta_1, a_{11}, 1 - b_{11}\}, \{\theta_2, a_{12}, 1 - b_{12}\}\}$$

$$= \{\{\theta_1, a_{13}, 1 - b_{13}\}, \{\theta_4, a_{14}, 1 - b_{14}\}\}$$

$$= \{\{\theta_1, 0.183, 1 - 0.320\}, \{\theta_2, 0.194, 1 - 0.341\}\}$$

$$= \{\{\theta_3, 0.179, 1 - 0.316\}, \{\theta_4, 0.189, 1 - 0.332\}\}$$

$$= \{\{\theta_1, 0.183, 0.680\}, \{\theta_2, 0.194, 0.659\}\}$$

$$= \{\{\theta_3, 0.179, 0.684\}, \{\theta_4, 0.189, 0.668\}\}$$

The intuitionistic fuzzy sets $M_2$ and $M_3$ are formed in turn:

$$M_2 = \{\{\theta_i, a_{2i}, 1 - b_{2i}\} | i = 1, 2, 3, 4\}$$

$$= \{\{\theta_1, 0.192, 0.642\}, \{\theta_2, 0.175, 0.672\}, \{\theta_3, 0.187, 0.655\}, \{\theta_4, 0.168, 0.689\}\}$$
\( M_3 = \{(\theta_i, a_{i}^x, 1 - b_{i}^x)| i = 1, 2, 3, 4\} \\
= \{(\theta_1, 0.209, 0.641), (\theta_2, 0.184, 0.673), \\
(\theta_3, 0.205, 0.648), (\theta_4, 0.167, 0.702)\} \\
\)

According to formula (7), the orthogonal sum operation is performed on intuitionistic fuzzy sets \( M_1 \) and \( M_2 \):

\[
M_1 \oplus M_2 = \left\{ \begin{array}{l}
\left( \theta_i, \frac{a_{i_1}^x b_{i_2}^x + a_{i_2}^x (b_{i_1}^x - a_{i_1}^x)}{1 - a_{i_1}^x - a_{i_2}^x + a_{i_1}^x b_{i_2}^x + a_{i_2}^x b_{i_1}^x}, \frac{b_{i_1}^x (1 - a_{i_2}^x) + (1 - b_{i_2}^x) (b_{i_1}^x - a_{i_1}^x)}{1 - a_{i_1}^x - a_{i_2}^x + a_{i_1}^x b_{i_2}^x + a_{i_2}^x b_{i_1}^x}) \right) \end{array} \right\} i = 1, 2, 3, 4
\]

\[
= \left\{ \begin{array}{l}
\left( \theta_1, \frac{0.183 \times 0.358 + 0.192(0.320 - 0.183)}{0.320 - 0.183}) \right) \end{array} \right\} \}
\]

From Definition 3, it can be seen that the interval evidence combination result \( m_1 \oplus m_2 \oplus m_3 (\{\theta_i\}) (i = 1, 2, 3, 4) \) is the first type of non-normalized interval BPA, so it needs to be normalized according to formulas (1) and (2). The normalized combination result is:

M_{123}(\{\theta_1\}) = [0.177, 0.421]

M_{123}(\{\theta_2\}) = [0.150, 0.328]

M_{123}(\{\theta_3\}) = [0.171, 0.417]

M_{123}(\{\theta_4\}) = [0.133, 0.314]

**Step 4** Compare and prioritize the results of interval evidence combinations.

\[
m_{123}(\{\theta_1\}) = (0.177 + 0.421)/2 = 0.299
\]

\[
m_{123}(\{\theta_2\}) = (0.150 + 0.328)/2 = 0.239
\]

\[
m_{123}(\{\theta_3\}) = (0.171 + 0.417)/2 = 0.294
\]
\[ m_{123}(\{\theta_4\}) = (0.133 + 0.314) / 2 = 0.223 \]

The priority of the above combination result is \( m_{123}(\{\theta_1\}) > m_{123}(\{\theta_3\}) > m_{123}(\{\theta_2\}) > m_{123}(\{\theta_4\}) \), so the optimal green supplier of the papermaking enterprise is \( V_4 \).

**Discussion**

Many fuzzy multi-attribute group decision-making methods based on intuitionistic fuzzy sets have been continuously proposed in recent years. For example, Xu [34] proposed a fuzzy multi-attribute group decision-making method based on deviation measures and information theory. Yue [38] created a TOPSIS fuzzy group decision-making method based on intuitionistic fuzzy sets. Zeng and Su [44] developed a fuzzy multi-attribute group decision-making method based on an intuitionistic fuzzy ordered weighted distance operator. This paper further verifies the effectiveness and superiority of the interval BPA-based intuitionistic fuzzy set method by analyzing the shortcomings of the existing fuzzy multi-attribute group decision-making methods.

In Xu’s method, when there is an evaluation value with a degree of non-membership equal to 0, since the intuitionistic fuzzy decision matrix of all individual decision-makers regarding the attributes of the alternatives is not clearly defined, an erroneous intuitionistic fuzzy decision matrix will be formed. Therefore, a reasonable preference order of alternatives cannot be obtained. In Yue’s method, there is an evaluation value with a degree of non-membership equal to 0 or a degree of membership equal to 1 since all individual decision-makers positive ideal decision matrix regarding the attributes of the alternatives is not clearly defined. It is also impossible to obtain a reasonable order of preference for alternatives. Xu’s method and Yue’s method will obtain unreasonable priority orders of alternatives in some cases. In addition, Zeng and Su’s method cannot assign different weights assigned by different experts to the attributes of alternatives.

In some cases, an unreasonable preference order of alternatives will be obtained. The interval BPA-based intuitionistic fuzzy set method adopted in this paper can overcome the shortcomings and deficiencies of the Xu method, Yue method, and Zeng and Su methods in solving the multi-attribute group decision-making problem in an intuitionistic fuzzy environment. A low-complexity algorithm meets the needs of time-domain evidence combination and realizes the flexible combination of multiple interval evidence, ensuring reasonable fusion results while considering fusion efficiency.

**Conclusions**

The evaluation and selection of green suppliers is an important milestone in the transition of enterprises to green supply chain management based on the concept of sustainable development. This paper proposes a green supplier evaluation index system for papermaking enterprises from the two dimensions of suppliers’ operational performance and environmental performance. It uses the interval BPA-based intuitionistic fuzzy set method to study the evaluation and selection of green suppliers in an environment with incomplete and uncertain information. Since differences in the professional background of evaluators may cause collisions of different opinions, the evaluation information obtained is usually incomplete. Based on intuitionistic fuzzy information, the evaluation indicator measurement is expressed in the form of uncertain intuitionistic fuzzy numbers, which is helpful to deal with and eliminate uncertainty in the decision-making process. Combined with examples, it is shown that the calculation process of this method is simple and convenient, and the decision-making effectiveness is relatively high. The comparative analysis with the existing fuzzy multi-attribute group decision-making method further verifies the rationality of applying the interval BPA-based intuitionistic fuzzy set method, which is beneficial to the effective development of enterprise green supplier selection and has an important reference value and practical significance.

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