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An Integrated Two-Dimension Linguistic Intuitionistic Fuzzy Decision-Making Approach for Unmanned Aerial Vehicle Supplier Selection

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Abstract: With the rapid development of unmanned aerial vehicles (UAVs) and their applications in problems such as power line inspection, selecting the appropriate UAV supplier according to several sustainable attributes has attracted many interests. In this regard, an integrated multiattribute group decision-making (MAGDM) method based on the best-worst method (BWM) and MULTIMOORA method with two-dimension linguistic intuitionistic fuzzy variables (2DLIFVs) is proposed in this paper for the selection of UAV suppliers. First, the 2DLIFV is utilized to represent the uncertain, fuzzy, and linguistic evaluations of the experts on the evaluation attributes. Second, the two-dimension linguistic intuitionistic fuzzy BWM (2DLIF-BWM) is introduced to compute the weights of the attributes. Then, a novel expert weight calculation method that combines the uncertainty degree and consensus degree of the experts is introduced. Next, the 2DLIF-MULTIMOORA method is proposed, where the aggregation operators and distance measures of the 2DLIFVs are used to determine the ranking results of different alternatives. Finally, a real case of selecting a sustainable UAV supplier for power line inspection is presented to illustrate the process of the proposed method. The experimental results are further analyzed through sensitivity and comparative analyses to show the feasibility and effectiveness of the proposed method. From the results, it can be found that the proposed method can more flexibly represent the uncertain assessments while providing reasonable and reliable results.

Keywords: sustainable supplier selection; two-dimension linguistic intuitionistic fuzzy set; multiattribute group decision-making; best-worst method; MULTIMOORA



Citation: Li, C.; Huang, H.; Luo, Y. An Integrated Two-Dimension Linguistic Intuitionistic Fuzzy Decision-Making Approach for Unmanned Aerial Vehicle Supplier Selection. *Sustainability* **2022**, *14*, 11666. <https://doi.org/10.3390/su141811666>

Academic Editor: Tin-Chih Toly Chen

Received: 12 August 2022

Accepted: 12 September 2022

Published: 16 September 2022

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1. Introduction

Over the past decade, unmanned aerial vehicles (UAVs) have experienced rapid growth for their socioeconomic, military, and environmental benefits [1]. With the application of UAVs, the requirements for human in-person operations can be reduced, thus reducing the possibility of personal injury. Moreover, as the UAV only requires the presence of remote operators, it can be applied to various environments without the limitations of reachability [2,3]. Due to these advantages, UAVs have been widely used in various fields, not just limited to military applications [4], but also including resource monitoring [5], precision agriculture [6], and others [7]. One of the most significant applications of UAVs is power line inspection [8,9]. Traditionally, power line inspection is an in-person operation that requires constant and careful operation by inspectors. However, as the power lines are often constructed in complex terrain, power line inspection is a dirty and difficult task. By using UAVs to replace human inspectors, the power line company can reduce the cost of human inspectors and increase the efficiency of power line inspection as the UAVs can complete the inspection task with significantly less time and a higher accuracy [10–12]. However, the UAV-based power line inspection relies heavily on appropriate suppliers, not only because the sustainable supplier can provide reliable and appropriate UAVs, but also because the power line company relies on the supplier to provide services such as the remote control of the UAVs to ensure the success of power line inspections. Therefore, as

the foundation of UAV-based power line inspection, a sustainable UAV supplier selection has become an important issue as it can directly determine the quality and cost of the power line inspection.

In most cases, a sustainable supplier selection is conducted based on evaluations by several experts from economic, social, and environmental aspects [13]. Therefore, the sustainable supplier selection problem is a complex multiattribute group decision-making (MAGDM) problem. However, the sustainable supplier selection problem also faces many challenges [14–16]. Firstly, the evaluation by the experts is often uncertain, fuzzy, and linguistic due to the complex and uncertain nature of the problem, which makes it hard to model the evaluation information. Secondly, different evaluation attributes naturally have different importance on the selection problem, and a reliable attribute weight calculation method is often required. Thirdly, the selection process is a complex and uncertain decision-making process with several experts, which makes it hard to model the weights of different experts and aggregate the evaluation information. Several MAGDM methods have been applied to sustainable supplier selection problems [17–20]. However, due to the uncertainty of the real world, it is inevitable for the experts to feel hesitant about their evaluations, or even for them to want to provide additional information on the reliability of their evaluations, which has not been fully studied by the researchers.

The two-dimension linguistic intuitionistic fuzzy variable (2DLIFV) is a novel and effective knowledge representation scheme proposed by Verma and Merigó [21]. By combining linguistic intuitionistic fuzzy variable (LIFV) and two-dimension linguistic fuzzy variable (2DLFV), the 2DLIFV adopts the advantages of these methods in representing uncertain, fuzzy, and linguistic evaluation, where one LIFV is used to describe the evaluation, and the other LIFV is used to represent the reliability of the evaluation. Compared with other methods, 2DLIFV has more flexibility in representing uncertainty, fuzziness, and vagueness. However, there have been few studies on 2DLIFVs, and the extension of weight calculation methods and decision-making approaches into two-dimension linguistic intuitionistic fuzzy environment still requires further research.

The aim of this study is to propose a novel MAGDM method with two-dimension linguistic intuitionistic fuzzy variables for sustainable UAV supplier selection. Firstly, the 2DLIFVs are adopted to represent the uncertain, fuzzy, and linguistic evaluation of the experts. Then, the best-worst method (BWM) is extended with 2DLIFVs, and the two-dimension linguistic intuitionistic fuzzy best-worst method (2DLIF-BWM) is introduced to determine the weights of different attributes. Finally, the two-dimension linguistic intuitionistic fuzzy MULTIMOORA (2DLIF-MULTIMOORA) method is proposed to evaluate and rank different suppliers, where a novel expert weight calculation method is introduced to determine the weights of experts. The proposed method could more effectively and flexibly deal with the uncertain evaluation of the sustainable supplier selection problem. The main contributions of this study are summarized as follows.

(1) The two-dimension linguistic intuitionistic fuzzy BWM is proposed by extending BWM with 2DLIFV, where the linguistic preference information of the attributes is expressed by 2DLIFVs and quantified by the score function, and the optimization model for calculating the attribute weights is constructed.

(2) The two-dimension linguistic intuitionistic fuzzy MULTIMOORA method is proposed, where a 2DLIF ratio system, a 2DLIF reference point approach and a 2DLIF full multiplicative form are extended with 2DLIFV using the aggregation operators and Euclidean distance. Further, an expert weight calculation method that combines the uncertainty degree and consensus degree of the experts is introduced, which could effectively reflect the importance of the experts.

(3) An integrated MAGDM method based on the 2DLIF-BWM and 2DLIF-MULTIMOORA method is proposed for sustainable supplier selection, where 2DLIFVs are utilized to represent the uncertain and linguistic evaluation information of experts.

The remainder of this paper is organized as follows. In Section 2, recent studies on sustainable supplier selection and MAGDM methods are reviewed and analyzed. In

Section 3, some basic concepts of 2DLIFV are briefly reviewed. In Section 4, the integrated MAGDM method based on 2DLIF-BWM and 2DLIF-MULTIMOORA method is presented. In Section 5, a numerical example of UAV supplier selection is studied to show the process of the proposed method. The experimental results are analyzed in Section 6. Finally, Section 7 concludes the paper.

2. Related works

2.1. Sustainable Supplier Selection

Selecting a sustainable supplier that meets the needs of the customer with acceptable quality and price is important to the supply chain. Table 1 summarizes the relevant literature on sustainable supplier selection, and it shows that the research on sustainable supplier selection mainly focuses on two aspects: how to model the uncertain evaluation information and how to adopt appropriate decision-making methods.

Table 1. Summary of relevant research on sustainable supplier selection.

Ref	Year	Evaluation Representation	Method	Application
[22]	2017	Fuzzy set	BWM-TOPSIS	Sustainable supplier selection
[23]	2017	Fuzzy set	ANP-VIKOR	Wood and paper industry
[24]	2017	Interval type-2 fuzzy set	TODIM	Green supplier selection
[25]	2017	Intuitionistic fuzzy set	PROMETHEE	Automobile factory
[26]	2017	Fuzzy set	MULTIMOORA	Green supplier selection
[27]	2017	Interval 2-tuple linguistic variable	ANP-ELECTRE II	Sustainable supplier selection
[28]	2017	Interval type-2 fuzzy set	ELECTRE I	Sustainable supplier selection
[29]	2018	Fuzzy set	AHP-VIKOR	Electronic goods manufacturing company
[30]	2018	Fuzzy set	MOORA	Home appliance industry
[31]	2018	Fuzzy set	QFD	Beverage industry
[32]	2018	Interval-valued intuitionistic uncertain linguistic set	GRA-TOPSIS	Agri-food industry
[33]	2018	Interval type-2 fuzzy set	ANP-VIKOR	Sustainable supplier selection
[34]	2019	Interval-valued Pythagorean fuzzy set	TOPSIS	Home appliances manufacturer
[35]	2019	Interval type-2 fuzzy set	AHPSort II	Sustainable supplier selection
[36]	2019	Interval-valued intuitionistic uncertain linguistic set	BWM-AQM	Watch manufacturer
[37]	2019	Interval type-2 fuzzy set	BWM-VIKOR	Green supplier selection
[38]	2019	Probabilistic linguistic set	MABAC	Medical consumption products
[39]	2019	Interval-valued linguistic variable	TODIM	Green supplier selection
[40]	2019	Intuitionistic fuzzy set	TOPSIS	Automotive spare parts manufacturer
[41]	2020	Crisp number	MARCOS	Healthcare industry
[42]	2020	Fuzzy set	DEMATEL-TOPSIS	Smart supply chain
[43]	2020	Intuitionistic fuzzy set	TOPSIS	Green supplier selection
[44]	2020	Fuzzy set	BWM-CoCoSo'B	Home appliance manufacturer
[45]	2020	Fuzzy set	BWM-TOPSIS	Steel industry
[46]	2020	Fuzzy set	Fuzzy inference system	Iron and steel industry
[47]	2020	Fuzzy set	BWM	Refinery equipment supplier selection
[48]	2020	Fuzzy neutrosophic set	MABAC	Sustainable supplier selection
[49]	2020	Interval type-2 fuzzy set	AHP	Home appliance manufacturer
[50]	2020	Hesitant fuzzy set	PROMETHEE	Green supplier selection
[51]	2020	Probabilistic uncertain linguistic set	QUALIFLEX	Green supplier selection
[52]	2021	Probabilistic uncertain linguistic set	CODAS	Green supplier selection
[53]	2021	Pythagorean fuzzy set	AHP-TOPSIS	Agricultural tools and machinery company
[54]	2021	Interval-valued fuzzy neutrosophic set	CRITIC	Large dairy company
[55]	2021	Intuitionistic linguistic rough set	MULTIMOORA	Shared power bank supplier selection

For representation methods, fuzzy sets and linguistic variables have been the most widely used methods. For instance, Chen et al. [42] used a fuzzy set to model the uncertain evaluation of the experts and proposed a rough-fuzzy DEMATEL-TOPSIS approach. Memari et al. [40] used intuitionistic fuzzy sets to represent the vague and imprecise evaluations of the experts. Wu et al. [37] utilized interval type-2 fuzzy sets in modeling uncertain and complex evaluations of the experts, and proposed the IT2F-BWM-VIKOR method for supplier selection. Wei et al. [38] used a probabilistic linguistic set to represent the evaluation information.

For decision-making methods, many methods including TOPSIS, VIKOR, TODIM and MULTIMOORA have been adopted for this problem. One of the most widely used methods

is TOPSIS, whose main principle is that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). For instance, Yu et al. [34] adopted the TOPSIS to evaluate and rank different suppliers according to their relative closeness. Gupta and Barua [22] integrated the BWM with TOPSIS for selecting sustainable suppliers, where the attribute weights were computed using BWM, and the optimal supplier was obtained by using TOPSIS while taking attribute weights into consideration. Liu et al. [33] proposed a novel decision-making method for sustainable supplier selection based on the AHP and VIKOR. Wan et al. [50] proposed the hesitant fuzzy PROMETHEE method, and applied the proposed method to green supplier selection. Sen et al. [26] utilized the MULTIMOORA method with fuzzy set for selecting sustainable suppliers.

From these analyses, it can be found that for representing the evaluations of experts, fuzzy set-based methods and linguistic variable-based methods have shown to be effective, however, there have been few studies combining fuzzy sets with linguistic variables to ensure a more reliable and effective modeling of the evaluation information. Motivated by the above, this paper adopted 2DLIFV to represent the uncertain, fuzzy, and linguistic evaluations of the experts, and proposes a novel decision-making approach for sustainable supplier selection by integrating the BWM with MULTIMOORA method.

2.2. MAGDM Methods

2.2.1. Best-Worst Method

The BWM was initially developed as a way to evaluate the performance of decision-making problems [56,57]. Owing to its advantages of less pairwise comparisons and a higher consistency, the BWM has been used as the weight calculation method in various studies and applied to many fields [58]. For instance, Kheybari et al. [59] applied the BWM for evaluating various criteria to identify the best location for a bioethanol facility. Rezaei et al. [60] used the BWM to weigh different indicators of the logistics performance index. However, one important limitation of the BWM is that the pairwise comparison is presented with crisp numbers, which may not be suitable for many complex and uncertain problems. To this end, there have been a series of studies extending the BWM to a fuzzy environment. Hafezalkotob and Hafezalkotob [61] presented the fuzzy BWM, where the triangular fuzzy numbers were used to represent the preferences. Mou et al. [62] introduced the intuitionistic fuzzy multiplicative BWM by using an intuitionistic fuzzy multiplicative preference relation as the preference. Liao et al. [63] proposed the hesitant fuzzy linguistic BWM for hospital performance evaluation.

2.2.2. MULTIMOORA Method

The MULTIMOORA method is a comprehensive decision-making method that has been applied in various fields. As it combines the benefits of both value-measurement decision-making methods and reference-level decision-making methods, the MULTIMOORA method has received extensive attention in the past decade [64]. Wang et al. [65] integrated the fuzzy entropy weight method with the MULTIMOORA method to select a sustainable battery supplier. Zavadskas et al. [66] combined MULTIMOORA method with SWARA approach for building material selection. Moreover, the MULTIMOORA method has been extended to various fuzzy environments. Zhang et al. [67] extended the MULTIMOORA method with an intuitionistic fuzzy set for energy storage technologies evaluation. Gou et al. [68] developed the double-hierarchy hesitant fuzzy linguistic MULTIMOORA method. Wu et al. [69] extended the MULTIMOORA method with a probabilistic linguistic term set.

In summary, both the BWM and MULTIMOORA methods have been applied to various MAGDM problems and have achieved promising results. The BWM is widely used as a novel and reliable tool for weight calculation, and the MULTIMOORA method is useful for evaluating and ranking different alternatives. Thus, it is possible to combine the BWM with the MULTIMOORA method and propose an integrated MAGDM method

for sustainable supplier selection. Moreover, neither the BWM nor the MULTIMOORA method has been extended to 2DLIFV, therefore, it is necessary to extend these methods with 2DLIFVs to expand their application. Motivated by this, this paper developed an integrated MAGDM method based on a two-dimension linguistic intuitionistic fuzzy BWM (2DLIF-BWM) and a two-dimension linguistic intuitionistic fuzzy MULTIMOORA (2DLIF-MULTIMOORA) method for sustainable supplier selection.

3. Preliminaries

Definition 1 ([70]). Let U be a finite universal set, an intuitionistic fuzzy set A on U is defined as:

$$A = \{ \langle u, \mu_A(u), \nu_A(u) \rangle | u \in U \} \quad (1)$$

where $\mu_A(u) : U \rightarrow [0, 1]$ is called the membership degree, $\nu_A(u) : U \rightarrow [0, 1]$ is called the nonmembership degree and $\mu_A(u) + \nu_A(u) \leq 1$ for all $u \in U$. $\pi_A(x) = 1 - \mu_A(u) - \nu_A(u)$ is called the hesitancy degree of u to A . For simplicity, A can be written as $\langle \mu_A(u), \nu_A(u) \rangle$, which is called an intuitionistic fuzzy number (IFN).

Definition 2 ([71]). Let $\dot{S} = \{ \dot{s}_\alpha | \alpha = 1, 2, \dots, t \}$ and $\ddot{S} = \{ \ddot{s}_\beta | \beta = 1, 2, \dots, t' \}$ be two linguistic term sets (LTSs) with odd cardinalities. $s = (\dot{s}_\alpha, \ddot{s}_\beta)$ is called a two-dimension linguistic variable, such that $\dot{s}_\alpha \in \dot{S}$ is the I class linguistic information describing the decision maker's evaluation of an object and $\ddot{s}_\beta \in \ddot{S}$ is the II class linguistic information describing the decision maker's evaluation on the reliability of the given result.

Definition 3 ([21]). Let $\dot{S} = \{ \dot{s}_\alpha | \alpha = 1, 2, \dots, t \}$ and $\ddot{S} = \{ \ddot{s}_\beta | \beta = 1, 2, \dots, t' \}$ be two LTSs with odd cardinalities, a two-dimension linguistic intuitionistic fuzzy variable (2DLIFV) is defined as:

$$\tilde{s} = (\langle \dot{s}_\theta, \dot{s}_\sigma \rangle, \langle \ddot{s}_\phi, \ddot{s}_\psi \rangle) \quad (2)$$

where $\langle \dot{s}_\theta, \dot{s}_\sigma \rangle$ is the I class linguistic intuitionistic fuzzy information representing the evaluation of the decision maker and $\langle \ddot{s}_\phi, \ddot{s}_\psi \rangle$ is the II class linguistic intuitionistic fuzzy information representing the evaluation on reliability of the given result. $\dot{s}_\theta, \dot{s}_\sigma \in \dot{S}$, $\ddot{s}_\phi, \ddot{s}_\psi \in \ddot{S}$, $\theta + \sigma \leq t$ and $\phi + \psi \leq t'$. In order to reduce the loss of information, the discrete LTSs of 2DLIFVs can be extended to continuous LTSs as $\dot{s}_\theta, \dot{s}_\sigma \in \dot{S} = \{ \dot{s}_\alpha | \alpha \in [0, t] \}$, $\ddot{s}_\phi, \ddot{s}_\psi \in \ddot{S} = \{ \ddot{s}_\alpha | \alpha \in [0, t'] \}$.

Definition 4 ([21]). Let $A = (\langle \dot{s}_{\theta_A}, \dot{s}_{\sigma_A} \rangle, \langle \ddot{s}_{\phi_A}, \ddot{s}_{\psi_A} \rangle)$ and $B = (\langle \dot{s}_{\theta_B}, \dot{s}_{\sigma_B} \rangle, \langle \ddot{s}_{\phi_B}, \ddot{s}_{\psi_B} \rangle)$ be two 2DLIFVs and $\lambda > 0$ be a real number; the operational rules for 2DLIFVs are defined as follows:

1. $A \oplus B = \left(\left\langle \dot{s}_{\theta_A + \theta_B - \frac{\theta_A \theta_B}{t}}, \dot{s}_{\sigma_A + \sigma_B - \frac{\sigma_A \sigma_B}{t}} \right\rangle, \left\langle \ddot{s}_{\phi_A + \phi_B - \frac{\phi_A \phi_B}{t'}}, \ddot{s}_{\psi_A + \psi_B - \frac{\psi_A \psi_B}{t'}} \right\rangle \right).$
2. $A \otimes B = \left(\left\langle \dot{s}_{\frac{\theta_A \theta_B}{t}}, \dot{s}_{\sigma_A + \sigma_B - \frac{\sigma_A \sigma_B}{t}} \right\rangle, \left\langle \ddot{s}_{\frac{\phi_A \phi_B}{t'}}, \ddot{s}_{\psi_A + \psi_B - \frac{\psi_A \psi_B}{t'}} \right\rangle \right).$
3. $\lambda A = \left(\left\langle \dot{s}_{t \left(1 - \left(1 - \frac{\theta_A}{t} \right)^\lambda \right)}, \dot{s}_{t \left(\frac{\sigma_A}{t} \right)^\lambda} \right\rangle, \left\langle \ddot{s}_{t' \left(1 - \left(1 - \frac{\phi_A}{t'} \right)^\lambda \right)}, \ddot{s}_{t' \left(\frac{\psi_A}{t'} \right)^\lambda} \right\rangle \right).$
4. $A^\lambda = \left(\left\langle \dot{s}_{t \left(\frac{\theta_A}{t} \right)^\lambda}, \dot{s}_{t \left(1 - \left(1 - \frac{\sigma_A}{t} \right)^\lambda \right)} \right\rangle, \left\langle \ddot{s}_{t \left(\frac{\phi_A}{t'} \right)^\lambda}, \ddot{s}_{t' \left(1 - \left(1 - \frac{\psi_A}{t'} \right)^\lambda \right)} \right\rangle \right).$

Definition 5 ([21]). Let $A = (\langle \dot{s}_{\theta_A}, \dot{s}_{\sigma_A} \rangle, \langle \ddot{s}_{\phi_A}, \ddot{s}_{\psi_A} \rangle)$ be a 2DLIFV, the score function of A is defined as:

$$S(A) = s \left(\frac{t + \theta_A - \sigma_A}{2t} \right) \times \left(\frac{t' + \phi_A - \psi_A}{2t'} \right) \quad (3)$$

and the accuracy function of A is defined as:

$$H(A) = h \left(\frac{\theta_A + \sigma_A}{t} \right) \times \left(\frac{\phi_A + \psi_A}{t'} \right) \quad (4)$$

Definition 6 ([21]). Let $A = (\langle \dot{s}_{\theta_A}, \dot{s}_{\sigma_A} \rangle, \langle \ddot{s}_{\phi_A}, \ddot{s}_{\psi_A} \rangle)$ and $B = (\langle \dot{s}_{\theta_B}, \dot{s}_{\sigma_B} \rangle, \langle \ddot{s}_{\phi_B}, \ddot{s}_{\psi_B} \rangle)$ be two 2DLIFVs, then

1. If $S(A) > S(B)$, then $A \succ B$;
2. If $S(A) = S(B)$:
 - (a) If $H(A) > H(B)$, then $A \succ B$;
 - (b) If $H(A) = H(B)$, then $A = B$.

Definition 7 ([21]). Let $A_i = (\langle \dot{s}_{\theta_{A_i}}, \dot{s}_{\sigma_{A_i}} \rangle, \langle \ddot{s}_{\phi_{A_i}}, \ddot{s}_{\psi_{A_i}} \rangle)$ be a collection of 2DLIFVs, then the two-dimension linguistic intuitionistic fuzzy weighted averaging (2DLIFWA) operator is defined as:

$$\begin{aligned} & 2DLIFWA(A_1, A_2, \dots, A_n) \\ &= \left(\left\langle \dot{s}_{t \left(1 - \prod_{i=1}^n \left(1 - \frac{\theta_{A_i}}{t} \right)^{\omega_i} \right)}, \dot{s}_{t \left(\prod_{i=1}^n \left(\frac{\sigma_{A_i}}{t} \right)^{\omega_i} \right)} \right\rangle, \right. \\ & \quad \left. \left\langle \ddot{s}_{t' \left(1 - \prod_{i=1}^n \left(1 - \frac{\phi_{A_i}}{t'} \right)^{\omega_i} \right)}, \ddot{s}_{t' \left(\prod_{i=1}^n \left(\frac{\psi_{A_i}}{t'} \right)^{\omega_i} \right)} \right\rangle \right) \end{aligned} \quad (5)$$

Definition 8 ([21]). Let $A_i = (\langle \dot{s}_{\theta_{A_i}}, \dot{s}_{\sigma_{A_i}} \rangle, \langle \ddot{s}_{\phi_{A_i}}, \ddot{s}_{\psi_{A_i}} \rangle)$ be a collection of 2DLIFVs, then the 2-dimension linguistic intuitionistic fuzzy weighted geometric (2DLIFWG) operator is defined as:

$$\begin{aligned} & 2DLIFWG(A_1, A_2, \dots, A_n) \\ &= \left(\left\langle \dot{s}_{t \left(\prod_{i=1}^n \left(\frac{\theta_{A_i}}{t} \right)^{\omega_i} \right)}, \dot{s}_{t \left(1 - \prod_{i=1}^n \left(1 - \frac{\sigma_{A_i}}{t} \right)^{\omega_i} \right)} \right\rangle, \right. \\ & \quad \left. \left\langle \ddot{s}_{t' \left(\prod_{i=1}^n \left(\frac{\phi_{A_i}}{t'} \right)^{\omega_i} \right)}, \ddot{s}_{t' \left(1 - \prod_{i=1}^n \left(1 - \frac{\psi_{A_i}}{t'} \right)^{\omega_i} \right)} \right\rangle \right) \end{aligned} \quad (6)$$

Definition 9 ([72]). Let $A = (\langle \dot{s}_{\theta_A}, \dot{s}_{\sigma_A} \rangle, \langle \ddot{s}_{\phi_A}, \ddot{s}_{\psi_A} \rangle)$ and $B = (\langle \dot{s}_{\theta_B}, \dot{s}_{\sigma_B} \rangle, \langle \ddot{s}_{\phi_B}, \ddot{s}_{\psi_B} \rangle)$ be two 2DLIFVs, then the Euclidean distance between A and B is defined as:

$$\begin{aligned} d(A, B) &= \frac{1}{2t} \sqrt{\frac{1}{2} [(\theta_A - \theta_B)^2 + (\sigma_A - \sigma_B)^2]} \\ & \quad + \frac{1}{2t'} \sqrt{\frac{1}{2} [(\phi_A - \phi_B)^2 + (\psi_A - \psi_B)^2]} \end{aligned} \quad (7)$$

4. The Proposed Approach

4.1. Framework of the Proposed Approach

The proposed method consists of two stages: the 2DLIF-BWM-based attribute weight calculation and the 2DLIF-MULTIMOORA-based supplier ranking and selection.

Firstly, the weights of the attributes should be determined first. Thus, the 2DLIF-BWM is proposed to calculate the weights of different attributes, where the 2DLIFVs are utilized to facilitate the fact that the experts may choose to provide linguistic judgments for the preference of different attributes. The detailed process of 2DLIF-BWM is presented in Section 4.2.

Secondly, different suppliers are ranked, and the optimal supplier is selected based on the 2DLIF-MULTIMOORA method. In order to better capture uncertainty and subjectivity in the evaluations of experts, the 2DLIFVs are used for representing the experts' evaluations, and all three components of the MULTIMOORA method, i.e., ratio system, reference point approach and full multiplicative form, are all extended with 2DLIFV. The process of the 2DLIF-MULTIMOORA method is detailed in Section 4.3.

4.2. Stage I: Attribute Weight Calculation

The BWM is a novel weight calculation method proposed by Rezaei [56], and it has significantly less computation and a higher consistency compared to the AHP. However, it is proposed with the assumption of crisp values, that is, the pairwise comparisons are expressed in terms of crisp values, which is impractical for some real-life problems, as uncertainty and subjectivity could cause the experts to provide linguistic terms as the pairwise comparison. To this end, this paper extends the BWM with 2DLIFV, and proposes the 2DLIF-BWM to calculate the weights of different attributes. The detailed process of the proposed method is as follows.

Step 1: Best and worst attributes identification

Based on the analysis of evaluation criteria, the experts identify the best (most important) attribute C_B and the worst (least important) attribute C_W among all evaluation attributes.

Step 2: Obtain the best-to-others vector

The best-to-others vector is one of the pairwise comparisons used in the BWM, and it represents the preference of the best attribute over other attributes. By using 2DLIFVs to represent the preference of the best criterion C_B over other criteria, the two-dimension linguistic intuitionistic fuzzy best-to-others vector is obtained as:

$$\tilde{v}_{BO} = (\tilde{s}_{B1}, \tilde{s}_{B2}, \dots, \tilde{s}_{Bn}) \quad (8)$$

where $\tilde{s}_{Bj} = (\langle \dot{s}_{\theta_{Bj}}, \dot{s}_{\sigma_{Bj}} \rangle, \langle \ddot{s}_{\phi_{Bj}}, \ddot{s}_{\psi_{Bj}} \rangle)$ is the two-dimension linguistic intuitionistic fuzzy preference of the best attribute C_B over the j attribute C_j .

Step 3: Obtain the others-to-worst vector

The others-to-worst vector denotes the preference of other attributes over the worst attribute, together with the best-to-others vector, they constitute all the pairwise comparisons in the BWM. By using 2DLIFVs, the two-dimension linguistic intuitionistic fuzzy others-to-worst vector is obtained as:

$$\tilde{v}_{OW} = (\tilde{s}_{1W}, \tilde{s}_{2W}, \dots, \tilde{s}_{nW}) \quad (9)$$

where $\tilde{s}_{jW} = (\langle \dot{s}_{\theta_{jW}}, \dot{s}_{\sigma_{jW}} \rangle, \langle \ddot{s}_{\phi_{jW}}, \ddot{s}_{\psi_{jW}} \rangle)$ is the two-dimension linguistic intuitionistic fuzzy preference of the j attribute C_j over the worst attribute C_W .

Step 4: Calculate the attribute weights

The attribute weights are calculated by solving an optimization model that minimizes the absolute difference $|w_B/(w_B + w_j) - \tilde{s}_{Bj}|$ and $|w_j/(w_j + w_W) - \tilde{s}_{jW}|$ as:

$$\begin{aligned} \min \max_j & \left\{ \left| \frac{w_B}{w_j} - \tilde{s}_{Bj} \right|, \left| \frac{w_j}{w_W} - \tilde{s}_{jW} \right| \right\} \\ \text{s.t.} & \begin{cases} \sum_{j=1}^n w_j = 1 \\ 0 \leq w_j \leq 1, j = 1, 2, \dots, n \end{cases} \end{aligned} \quad (10)$$

where w_B is the weight of C_B , w_W is the weight of C_W , w_j is the weight of the j th attribute and $\tilde{s}_{Bj}$ and $\tilde{s}_{jW}$ are the 2DLIF preference of C_B to C_j and the 2DLIF preference of C_j to C_W , respectively.

As the 2DLIFVs are utilized as the preference, the score function for 2DLIFVs is used, and the optimization model Equation (10) can be written as:

$$\begin{aligned} & \min \zeta \\ \text{s.t.} & \begin{cases} |S(\tilde{s}_{Bj})\omega_B - \omega_j| \leq \zeta \\ |S(\tilde{s}_{jW})\omega_j - \omega_W| \leq \zeta \\ \sum_{j=1}^n \omega_j = 1 \\ 0 \leq \omega_j \leq 1, j = 1, 2, \dots, n \end{cases} \end{aligned} \quad (11)$$

Thus, the attribute weights $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ can be obtained by solving the above model.

4.3. Stage II: Supplier Ranking and Selection

In order to rank and select the optimal supplier, the MULTIMOORA method was adopted in this paper. Moreover, as the 2DLIFVs were used as the evaluations of the experts and the conventional MULTIMOORA method cannot properly deal with 2DLIFVs, an extended two-dimension linguistic intuitionistic fuzzy MULTIMOORA (2DLIF-MULTIMOORA) method was proposed. The 2DLIF-MULTIMOORA consisted of three subordinates: a two-dimension linguistic intuitionistic fuzzy ratio system, a two-dimension linguistic intuitionistic fuzzy reference point approach and a two-dimension linguistic intuitionistic fuzzy full multiplicative form. The detailed process of the 2DLIF-MULTIMOORA-based supplier ranking and selection is described as follows.

Step 1: Construct the decision matrix of the experts

The supplier selection can be viewed as an MAGDM problem with m different supplier alternatives $A = \{A_1, A_2, \dots, A_m\}$ to be selected from with regard to n attributes $C = \{C_1, C_2, \dots, C_n\}$, and $w = \{w_1, w_2, \dots, w_n\}$ are the weights of the evaluation attributes. As an MAGDM problem, several experts are invited to provide their evaluations, that is, for each expert, a decision matrix that represents their evaluations is constructed. As the evaluations provided by the experts are in the form of 2DLIFVs, for the k th expert ($k = 1, 2, \dots, l$), the 2DLIF decision matrix can be constructed as:

$$R_k = \begin{bmatrix} \tilde{r}_{11}^k & \tilde{r}_{12}^k & \dots & \tilde{r}_{1n}^k \\ \tilde{r}_{21}^k & \tilde{r}_{22}^k & \dots & \tilde{r}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{m1}^k & \tilde{r}_{m2}^k & \dots & \tilde{r}_{mn}^k \end{bmatrix} \quad (12)$$

where $\tilde{r}_{ij}^k = \left(\left\langle \tilde{s}_{\theta_{ij}}^k, \tilde{s}_{\sigma_{ij}}^k \right\rangle, \left\langle \tilde{s}_{\phi_{ij}}^k, \tilde{s}_{\psi_{ij}}^k \right\rangle \right)$ is the 2DLIF evaluation of the i th alternative with regard to the j th attribute by the k th expert.

Step 2: Construct the combined 2DLIF decision matrix

In order to solve the supplier selection problem, the evaluations of different experts should be aggregated to obtain the combined evaluation of each alternative with regard to each attribute. However, as different experts could have different experiences and understandings, the weights of their evaluations may not necessarily be the same, instead, the uncertainty and consensus of experts should be taken into consideration when combining their evaluations. Thus, in this step, the weights of the experts are determined at first, and the evaluations of different experts are then combined on the basis of that.

Step 2-1: Calculate the weights of different experts

Step 2-1-1: Calculate the uncertainty degree of the experts

Due to the complexity and uncertainty of the real world, it is inevitable for the experts to provide their evaluations under uncertainty and fuzziness. For the evaluation of the i th alternative regarding the j th attribute by the k th expert $\tilde{r}_{ij}^k$, its uncertainty is computed by:

$$\pi_{\tilde{r}_{ij}}^k = \frac{1}{2} \left[t - \left(\theta_{\tilde{r}_{ij}}^k + \sigma_{\tilde{r}_{ij}}^k \right) + t' - \left(\phi_{\tilde{r}_{ij}}^k + \psi_{\tilde{r}_{ij}}^k \right) \right] \quad (13)$$

For the k th expert, the uncertainty degree of its evaluations is calculated as:

$$\rho_k = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n \pi_{\tilde{r}_{ij}}^k \quad (14)$$

Step 2-1-2: Calculate the consensus degree of the experts

The consensus degree denotes the degree of agreement between one expert and other experts; clearly, the expert with a higher consensus degree could provide more reliable evaluations, and thus would have higher weight. For the k th expert E_k , the degree of agreement between it and the t th expert E_t can be calculated based on the Euclidean distance as:

$$\alpha(k, t) = \frac{1}{2 \times m \times n} \sum_{i=1}^m \sum_{j=1}^n \left(\frac{1}{t} \sqrt{\frac{1}{2} \left[\left(\theta_{\tilde{r}_{ij}}^k - \theta_{\tilde{r}_{ij}}^t \right)^2 + \left(\sigma_{\tilde{r}_{ij}}^k - \sigma_{\tilde{r}_{ij}}^t \right)^2 \right]} + \frac{1}{t'} \sqrt{\frac{1}{2} \left[\left(\phi_{\tilde{r}_{ij}}^k - \phi_{\tilde{r}_{ij}}^t \right)^2 + \left(\psi_{\tilde{r}_{ij}}^k - \psi_{\tilde{r}_{ij}}^t \right)^2 \right]} \right) \quad (15)$$

Thus, the consensus degree of the k th expert can be calculated by:

$$\chi_k = \frac{1}{l-1} \sum_{\substack{t=1 \\ t \neq k}}^l \alpha(k, t) \quad (16)$$

Step 2-1-3: Calculate the weights of the experts

By combining the uncertainty degree and the consensus degree, the importance degree of the k th expert could be obtained as:

$$\tau_k = \frac{\varepsilon_1}{\varepsilon_1 + \varepsilon_2} \times (1 - \rho_k) + \frac{\varepsilon_2}{\varepsilon_1 + \varepsilon_2} \times \chi_k \quad (17)$$

where ε_1 denotes the uncertainty weight of the k th expert, ε_2 denotes the consensus weight of the k th expert.

Therefore, the weights of the experts could be computed by normalizing the importance degree of the experts as:

$$\omega_k = \frac{\tau_k}{\sum_{k=1}^l \tau_k} \quad (18)$$

Step 2-2: Combine the evaluations of different experts

Based on the 2DLIFWA operator, the combined evaluation of the i th alternative regarding the j th attribute $\tilde{r}_{ij}$ can be obtained by combining the evaluations of all l experts as:

$$\begin{aligned} \tilde{r}_{ij} &= \left(\left\langle \dot{s}_{\theta_{\tilde{r}_{ij}}}, \dot{s}_{\sigma_{\tilde{r}_{ij}}} \right\rangle, \left\langle \ddot{s}_{\phi_{\tilde{r}_{ij}}}, \ddot{s}_{\psi_{\tilde{r}_{ij}}} \right\rangle \right) \\ &= 2DLIFWA(\tilde{r}_{ij}^1, \tilde{r}_{ij}^2, \dots, \tilde{r}_{ij}^l) \\ &= \left(\left\langle \dot{s}_t \left(1 - \prod_{k=1}^l \left(1 - \frac{\theta_{\tilde{r}_{ij}}^k}{t} \right)^{\omega_k} \right), \dot{s}_t \left(\prod_{k=1}^l \left(\frac{\sigma_{\tilde{r}_{ij}}^k}{t} \right)^{\omega_k} \right) \right\rangle, \right. \\ &\quad \left. \left\langle \ddot{s}_{t'} \left(1 - \prod_{k=1}^l \left(1 - \frac{\phi_{\tilde{r}_{ij}}^k}{t'} \right)^{\omega_k} \right), \ddot{s}_{t'} \left(\prod_{k=1}^l \left(\frac{\psi_{\tilde{r}_{ij}}^k}{t'} \right)^{\omega_k} \right) \right\rangle \right) \end{aligned} \quad (19)$$

Thus, the combined 2DLIF decision matrix is obtained as:

$$R = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{m1} & \tilde{r}_{m2} & \cdots & \tilde{r}_{mn} \end{bmatrix} \quad (20)$$

where $\tilde{r}_{ij}$ is the combined 2DLIF evaluation of the i th alternative with regard to the j th attribute.

Step 3: Two-dimension linguistic intuitionistic fuzzy ratio system calculation

To compute the utility value of the 2DLIF ratio system, the additive utility function is utilized, that is, the evaluations of all attributes are combined considering their weights to obtain the utility value. Thus, the 2DLIFWA operator is used to compute the utility of the 2DLIF ratio system by:

$$y_i^s = 2DLIFWA(\tilde{r}_{i1}, \tilde{r}_{i2}, \dots, \tilde{r}_{in})$$

$$= \left(\left\langle \dot{s}_t \left(1 - \prod_{j=1}^n \left(1 - \frac{\theta_{\tilde{r}_{ij}}}{t} \right)^{\omega_j} \right), \dot{s}_t \left(\prod_{j=1}^n \left(\frac{\sigma_{\tilde{r}_{ij}}}{t} \right)^{w_j} \right) \right\rangle, \right.$$

$$\left. \left\langle \ddot{s}_{t'} \left(1 - \prod_{j=1}^n \left(1 - \frac{\phi_{\tilde{r}_{ij}}}{t'} \right)^{\omega_j} \right), \ddot{s}_{t'} \left(\prod_{j=1}^n \left(\frac{\psi_{\tilde{r}_{ij}}}{t'} \right)^{w_j} \right) \right\rangle \right)$$
(21)

where $y_i^s = \left(\left\langle \dot{s}_{\theta_{y_i^s}}, \dot{s}_{\sigma_{y_i^s}} \right\rangle, \left\langle \ddot{s}_{\phi_{y_i^s}}, \ddot{s}_{\psi_{y_i^s}} \right\rangle \right)$ ($i = 1, 2, \dots, m$) is a 2DLIFV. Clearly, y_i^s cannot be directly used for comparison, thus, the score function is utilized, and the crisp utility value of 2DLIF ratio system is calculated using a subscript as:

$$\bar{y}_i^s = \left(\frac{t + \theta_{y_i^s} - \sigma_{y_i^s}}{2t} \right) \times \left(\frac{t' + \phi_{y_i^s} - \psi_{y_i^s}}{2t'} \right)$$
(22)

Step 4: Two-dimension linguistic intuitionistic fuzzy reference point approach calculation

The 2DLIF reference point approach consists of (1) identifying the reference point and (2) calculating the Chebyshev distance from the reference point to each alternative. The reference point $r = (\tilde{r}_1^*, \tilde{r}_2^*, \dots, \tilde{r}_n^*)$ denotes the optimal situation among all alternatives, where $\tilde{r}_j^*$ is a 2DLIFV representing the optimal situation of the j th attribute as:

$$\tilde{r}_j^* = \left(\left\langle \dot{s}_{\theta_{\tilde{r}_j^*}}, \dot{s}_{\sigma_{\tilde{r}_j^*}} \right\rangle, \left\langle \ddot{s}_{\phi_{\tilde{r}_j^*}}, \ddot{s}_{\psi_{\tilde{r}_j^*}} \right\rangle \right)$$

$$\begin{cases} s_{\theta_{\tilde{r}_j^*}} = \max_i s_{\theta_{\tilde{r}_{ij}}} \\ s_{\sigma_{\tilde{r}_j^*}} = \min_i s_{\sigma_{\tilde{r}_{ij}}} \\ s_{\phi_{\tilde{r}_j^*}} = \max_i s_{\phi_{\tilde{r}_{ij}}} \\ s_{\psi_{\tilde{r}_j^*}} = \min_i s_{\psi_{\tilde{r}_{ij}}} \end{cases}$$
(23)

Then, the distance between the evaluation of the i th alternative and the reference point with regard to the j th attribute can be computed by using the Euclidean distance as:

$$d_{ij} = \frac{1}{2t} \sqrt{\frac{1}{2} \left[(\theta_{\tilde{r}_{ij}} - \theta_{\tilde{r}_j^*})^2 + (\sigma_{\tilde{r}_{ij}} - \sigma_{\tilde{r}_j^*})^2 \right]} + \frac{1}{2t'} \sqrt{\frac{1}{2} \left[(\phi_{\tilde{r}_{ij}} - \phi_{\tilde{r}_j^*})^2 + (\psi_{\tilde{r}_{ij}} - \psi_{\tilde{r}_j^*})^2 \right]}$$
(24)

Following the principle of the Chebyshev distance, the maximum distance from the reference point to each alternative can be used as the utility as:

$$y_i^r = \max_j d_{ij}$$
(25)

where a lower value indicates a better option. Thus, for better comparison and aggregation purposes, the crisp utility value of 2DLIF reference point approach is calculated by:

$$\bar{y}_i^r = \frac{\min_i y_i^r}{y_i^r}$$
(26)

Step 5: Two-dimension linguistic intuitionistic fuzzy full multiplicative form calculation

The multiplicative utility function is used to compute the utility of the 2DLIF full multiplicative form. Therefore, the 2DLIFWG operator is utilized, and the utility of the i th alternative is calculated by:

$$y_i^f = 2DLIFWG(\tilde{r}_{i1}, \tilde{r}_{i2}, \dots, \tilde{r}_{in}) \\ = \left(\left\langle \dot{s}_t \left(\prod_{j=1}^n \left(\frac{\theta_{fij}}{t} \right)^{\omega_j} \right), \dot{s}_t \left(1 - \prod_{j=1}^n \left(1 - \frac{\sigma_{fij}}{t} \right)^{w_j} \right) \right\rangle, \right. \\ \left. \left\langle \dot{s}_{t'} \left(\prod_{j=1}^n \left(\frac{\phi_{fij}}{t'} \right)^{\omega_j} \right), \dot{s}_{t'} \left(1 - \prod_{j=1}^n \left(1 - \frac{\psi_{fij}}{t'} \right)^{w_j} \right) \right\rangle \right) \quad (27)$$

where $y_i^f = \left(\left\langle \dot{s}_{\theta_{y_i^f}}, \dot{s}_{\sigma_{y_i^f}} \right\rangle, \left\langle \dot{s}_{\phi_{y_i^f}}, \dot{s}_{\psi_{y_i^f}} \right\rangle \right)$ ($i = 1, 2, \dots, m$) is a 2DLIFV. Therefore, the score function is adopted to calculate the crisp utility value of the i th alternative as:

$$\bar{y}_i^f = \left(\frac{t + \theta_{y_i^f} - \sigma_{y_i^f}}{2t} \right) \times \left(\frac{t' + \phi_{y_i^f} - \psi_{y_i^f}}{2t'} \right) \quad (28)$$

Step 6: Sort and rank the alternatives

The 2DLIF-MULTIMOORA method consists of three subordinates, and the overall utility can be obtained by aggregating the crisp utility values of all three subordinates as:

$$u_i = \delta_1 \bar{y}_i^s + \delta_2 \bar{y}_i^r + \delta_3 \bar{y}_i^f \quad (29)$$

where δ_1 , δ_2 and δ_3 are the importance coefficient of the 2DLIF ratio system, 2DLIF reference point approach and 2DLIF full multiplicative form, respectively, such that $\sum_{i=1}^3 \delta_i = 1$.

Therefore, the alternatives are sorted according to their overall utility: the bigger the overall utility value u_i is, the better the alternative A_i is, and the alternative with the highest overall utility value is selected as the optimal solution.

5. Case Study

In order to demonstrate the process of the proposed method, a numerical example of sustainable unmanned aerial vehicle supplier selection problem is presented.

5.1. Problem Description

In recent years, with the rapid development of control and automation technologies, unmanned aerial vehicles have received extension attention, and many UAV companies have emerged. The application of UAVs in power line inspection has shown to be effective and cheap, as it reduces the requirements for in-person inspection, which is sometimes dangerous and impractical due to the complex terrain situation of the power line. Thus, power line companies could greatly benefit from the application of UAVs in power line inspection. After a careful analysis, it is obvious that the UAVs used for power line inspection are the most changeable and the most replaceable part of the UAV-based power line inspection. Therefore, by analyzing and selecting the most suitable UAV supplier for UAV-based power line inspection, the power line company could achieve the greatest sustainable development benefits given the global trend of automation. However, the selection of UAV supplier has shown to be a difficult task, as it is not only affected by factors such as the cost and quality of the UAV, but also determined by factors regarding their usage and maintenance, as human operators are always required for the operation of the UAV. Moreover, many of the factors that affect the selection process are not quantitative or even certain, which makes the UAV supplier selection a complex MAGDM under uncertainty and fuzziness. Therefore, though it is an important company strategy for power line companies to select suitable UAV suppliers, it is a difficult problem that should consider various quantitative and qualitative factors.

In this case, a power line company (hereinafter referred to as “the company”) was the direct customer and the UAV supplier was the supplier. The problem for the company was to select the most suitable UAV supplier for power line inspection, and the decision problem was described as follows:

(1) An expert committee $E = \{E_1, E_2, E_3\}$ was established, which included a supply chain manager, an inspection engineer and a professor who all had more than ten years of experience in this field.

(2) After initial selection, four UAV companies were determined as candidate UAV suppliers for evaluation, denoted by $A = \{A_1, A_2, A_3, A_4\}$.

(3) Based on discussion and experiences, the experts committee identified eight evaluation attributes for this problem considering the unique characteristics of this problem, shown in Table 2.

(4) Each expert used 2DLIFVs to evaluate four alternatives with regard to the evaluation attributes, where the I class linguistic term set was defined as $\dot{S} = \{\dot{s}_0, \dot{s}_1, \dot{s}_2, \dot{s}_3, \dot{s}_4, \dot{s}_5, \dot{s}_6\}$, and the II class linguistic set was defined as $\ddot{S} = \{\ddot{s}_0, \ddot{s}_1, \ddot{s}_2, \ddot{s}_3, \ddot{s}_4\}$.

An illustration of the sustainable UAV supplier selection problem is shown in Figure 1.

Table 2. Evaluation attributes for sustainable UAV supplier selection.

Aspect	Attribute	Specification	Source
Economic	C ₁ : price	The lowest price of the product and the service the supplier could offer.	[41,73,74]
	C ₂ : quality	The supplier should provide UAV and service that could meet the requirements. This attribute denotes how the UAV and service of the supplier satisfy the requirements.	[40,41,74–76]
	C ₃ : delivery	The supplier should be able to provide the UAV and service on time. This attribute represents the ability of the supplier to deliver the UAV and service within the time limits.	[77–80]
	C ₄ : technology	The product provided by the supplier should be innovative and with new technology. This attribute represents the integrated technology behind the UAV and service provided by the supplier.	[76–78]
Social	C ₅ : reliability	The UAV should be able to complete the task even under extreme circumstances. This attribute represents the ability of the UAV to complete the tasks.	[41,81]
	C ₆ : training	The completion of the task not only requires a quality product, but also depends on the employees of the supplier to provide reliable services. This attribute represents the training and education of the employees.	[41]
Environmental	C ₇ : pollution	Pollution is an important aspect for sustainability and environmental protection. This attribute represents the ability of the supplier to control and reduce pollution of the UAV.	[41,77–80]
	C ₈ : eco-friendly	The UAV and service of the supplier should be sustainable for natural ecosystems. This attribute represents the ability of the supplier to provide the UAV and service in a green and eco-friendly way.	[41,73,77]

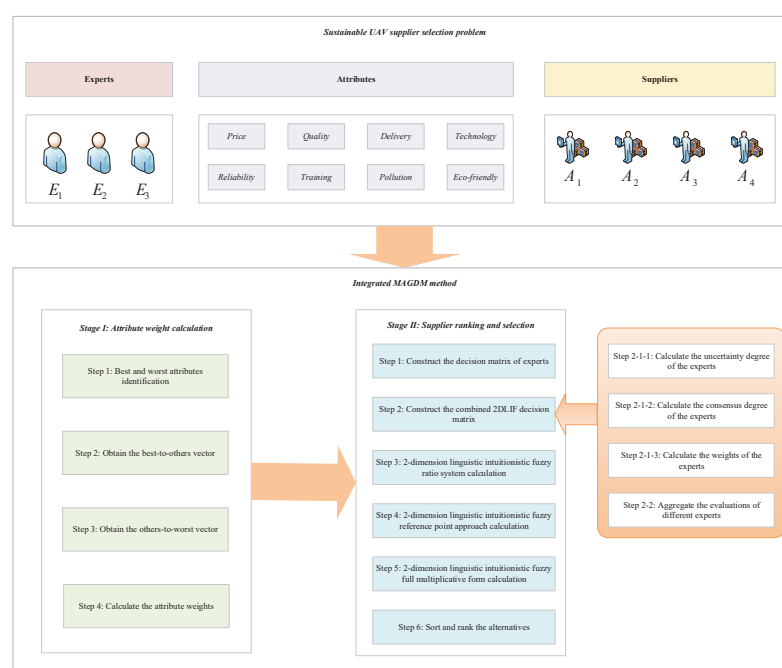


Figure 1. Framework for sustainable UAV supplier selection.

5.2. Decision-Making Process

Stage I: Attribute weight calculation

Step 1: Best and the worst attributes identification

The best and the worst attributes were determined based on the knowledge of the experts. Based on the analysis, C_2 was identified to be the best attribute, and C_3 was identified to be the worst attribute.

Step 2: Obtain the best-to-others vector

After determining the best attribute, the best-to-others vector was obtained based on the knowledge of experts, where the elements were expressed in the form of 2DLIFVs, as shown in Table 3.

Step 3: Obtain the others-to-worst vector

Similarly, the others-to-worst vector was obtained based on the knowledge of the experts using 2DLIFVs, as listed in Table 3.

Table 3. Evaluation attributes for sustainable UAV supplier selection.

Attribute	$\tilde{v}_{BO}$	$\tilde{v}_{OW}$
C_1	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_4, \dot{s}_0 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
C_2	$\{\langle \dot{s}_6, \dot{s}_0 \rangle, \langle \dot{s}_4, \dot{s}_0 \rangle\}$	$\{\langle \dot{s}_1, \dot{s}_5 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$
C_3	$\{\langle \dot{s}_1, \dot{s}_5 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_6, \dot{s}_0 \rangle, \langle \dot{s}_4, \dot{s}_0 \rangle\}$
C_4	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$
C_5	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$
C_6	$\{\langle \dot{s}_5, \dot{s}_0 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_1, \dot{s}_5 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$
C_7	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$
C_8	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$

Step 4: Calculate the attribute weights

Based on the best-to-others and others-to-worst vectors, the optimization model for calculating the attribute weights was constructed as:

$$\begin{aligned}
 & \min \zeta \\
 & s.t. \begin{cases} |S(\tilde{s}_{2j})w_B - w_j| \leq \zeta \\ |S(\tilde{s}_{j3})w_j - w_W| \leq \zeta \\ \sum_{j=1}^n w_j = 1 \\ 0 \leq w_j \leq 1, j = 1, 2, \dots, 8 \end{cases}
 \end{aligned}$$

By solving the above model, the optimal attribute weights were obtained as:

$$\begin{aligned}
 w &= (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8) \\
 &= (0.1472, 0.2493, 0.0270, 0.0969, \\
 &\quad 0.1571, 0.1904, 0.0502, 0.0818)
 \end{aligned}$$

Stage II: Supplier ranking and selection

Step 1: Construct the decision matrix of the experts

For each expert, a 2DLIF decision matrix could be constructed based on the evaluations of different alternatives regarding each attribute, as shown in Tables 4–6.

Table 4. The two-dimension linguistic intuitionistic fuzzy decision matrix of E_1 .

Alternative	C_1	C_2	C_3	C_4
A_1	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$
A_2	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_3	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$
A_4	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
Alternative	C_5	C_6	C_7	C_8
A_1	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$
A_2	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$
A_3	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$
A_4	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$

Table 5. The two-dimension linguistic intuitionistic fuzzy decision matrix of E_2 .

Alternative	C_1	C_2	C_3	C_4
A_1	$\{\langle \dot{s}_1, \dot{s}_5 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_2	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_3	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$
A_4	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
Alternative	C_5	C_6	C_7	C_8
A_1	$\{\langle \dot{s}_1, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$
A_2	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_3	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_4	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_0 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$

Table 6. The two-dimension linguistic intuitionistic fuzzy decision matrix of E_3 .

Alternative	C_1	C_2	C_3	C_4
A_1	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_1, \dot{s}_4 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$
A_2	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$
A_3	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_4	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$
Alternative	C_5	C_6	C_7	C_8
A_1	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_3 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$
A_2	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$
A_3	$\{\langle \dot{s}_2, \dot{s}_3 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_2 \rangle, \langle \dot{s}_2, \dot{s}_2 \rangle\}$	$\{\langle \dot{s}_2, \dot{s}_4 \rangle, \langle \dot{s}_3, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_3 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$
A_4	$\{\langle \dot{s}_4, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_4, \dot{s}_2 \rangle, \langle \dot{s}_3, \dot{s}_0 \rangle\}$	$\{\langle \dot{s}_5, \dot{s}_1 \rangle, \langle \dot{s}_1, \dot{s}_1 \rangle\}$	$\{\langle \dot{s}_3, \dot{s}_1 \rangle, \langle \dot{s}_2, \dot{s}_1 \rangle\}$

Step 2: Construct the combined 2DLIF decision matrix

By using the 2DLIFWA operator, the evaluations of each expert regarding the same attribute could be aggregated considering the weights of the experts, and the combined 2DLIF decision matrix $R = [\tilde{r}_{ij}]_{4 \times 8}$ could be constructed.

Step 2-1: Calculate the weights of different experts

Firstly, the uncertainty degrees of the experts $\rho_k (k = 1, 2, 3)$ were calculated as:

$$\rho_1 = 0.5781, \rho_2 = 0.8281, \rho_3 = 0.6406$$

Next, the consensus degrees of the experts $\chi_k (k = 1, 2, 3)$ were calculated based on the Euclidean distance as:

$$\chi_1 = 0.2137, \chi_2 = 0.1907, \chi_3 = 0.2067$$

In this case, the uncertainty weight ε_1 and the consensus weight ε_1 were set as $\varepsilon_1 = \varepsilon_2 = 0.5$. Thus, the weight of the experts $\omega_k (k = 1, 2, 3)$ could be computed by combining the uncertainty degree and consensus degree as:

$$\omega_1 = 0.4063, \omega_2 = 0.2318, \omega_3 = 0.3619$$

Step 2-2: Combine the evaluations of different experts

After determining the weights of different experts, the evaluations of different experts on the same evaluation attribute could be combined using the 2DLIFWA operator, and the combined 2DLIF decision matrix was constructed, as shown in Table 7.

Table 7. The combined two-dimension linguistic intuitionistic fuzzy decision matrix.

Alternative	C ₁	C ₂
A ₁	{⟨ $\dot{s}_{2.7222}, \dot{s}_{2.5507}$ ⟩, ⟨ $\ddot{s}_{1.0000}, \ddot{s}_{1.8351}$ ⟩}	{⟨ $\dot{s}_{2.9819}, \dot{s}_{2.2773}$ ⟩, ⟨ $\dot{s}_{2.0277}, \ddot{s}_{1.4882}$ ⟩}
A ₂	{⟨ $\dot{s}_{3.6839}, \dot{s}_{1.0000}$ ⟩, ⟨ $\ddot{s}_{1.8029}, \ddot{s}_{1.2851}$ ⟩}	{⟨ $\dot{s}_{3.4557}, \dot{s}_{2.3161}$ ⟩, ⟨ $\dot{s}_{2.6747}, \ddot{s}_{1.0000}$ ⟩}
A ₃	{⟨ $\dot{s}_{2.2580}, \dot{s}_{3.3291}$ ⟩, ⟨ $\ddot{s}_{1.4094}, \ddot{s}_{1.1743}$ ⟩}	{⟨ $\dot{s}_{3.4557}, \dot{s}_{2.0000}$ ⟩, ⟨ $\dot{s}_{2.6747}, \ddot{s}_{1.0000}$ ⟩}
A ₄	{⟨ $\dot{s}_{4.4909}, \dot{s}_{1.5091}$ ⟩, ⟨ $\ddot{s}_{2.4909}, \ddot{s}_{1.2851}$ ⟩}	{⟨ $\dot{s}_{3.0882}, \dot{s}_{2.0626}$ ⟩, ⟨ $\dot{s}_{2.0277}, \ddot{s}_{1.4882}$ ⟩}
Alternatives	C ₃	C ₄
A ₁	{⟨ $\dot{s}_{1.9433}, \dot{s}_{3.3291}$ ⟩, ⟨ $\ddot{s}_{2.0803}, \ddot{s}_{1.2851}$ ⟩}	{⟨ $\dot{s}_{2.0000}, \dot{s}_{2.2659}$ ⟩, ⟨ $\dot{s}_{2.4437}, \ddot{s}_{1.3253}$ ⟩}
A ₂	{⟨ $\dot{s}_{3.6418}, \dot{s}_{1.5627}$ ⟩, ⟨ $\ddot{s}_{1.6418}, \ddot{s}_{1.5563}$ ⟩}	{⟨ $\dot{s}_{4.1649}, \dot{s}_{1.5563}$ ⟩, ⟨ $\dot{s}_{1.6839}, \ddot{s}_{1.4882}$ ⟩}
A ₃	{⟨ $\dot{s}_{2.9819}, \dot{s}_{2.0521}$ ⟩, ⟨ $\ddot{s}_{1.4557}, \ddot{s}_{1.7032}$ ⟩}	{⟨ $\dot{s}_{3.2308}, \dot{s}_{1.7097}$ ⟩, ⟨ $\dot{s}_{1.4094}, \ddot{s}_{1.3253}$ ⟩}
A ₄	{⟨ $\dot{s}_{4.1649}, \dot{s}_{1.5627}$ ⟩, ⟨ $\ddot{s}_{2.2903}, \ddot{s}_{1.5563}$ ⟩}	{⟨ $\dot{s}_{3.6839}, \dot{s}_{2.3161}$ ⟩, ⟨ $\dot{s}_{2.4437}, \ddot{s}_{1.0000}$ ⟩}
Alternative	C ₅	C ₆
A ₁	{⟨ $\dot{s}_{2.2524}, \dot{s}_{1.9197}$ ⟩, ⟨ $\ddot{s}_{1.2691}, \ddot{s}_{2.3161}$ ⟩}	{⟨ $\dot{s}_{2.6280}, \dot{s}_{3.0696}$ ⟩, ⟨ $\dot{s}_{1.4557}, \ddot{s}_{1.2900}$ ⟩}
A ₂	{⟨ $\dot{s}_{3.4557}, \dot{s}_{1.5563}$ ⟩, ⟨ $\ddot{s}_{2.2968}, \ddot{s}_{1.2851}$ ⟩}	{⟨ $\dot{s}_{3.6418}, \dot{s}_{1.7032}$ ⟩, ⟨ $\dot{s}_{2.3422}, \ddot{s}_{1.0000}$ ⟩}
A ₃	{⟨ $\dot{s}_{2.6709}, \dot{s}_{2.5443}$ ⟩, ⟨ $\ddot{s}_{1.0000}, \ddot{s}_{1.3253}$ ⟩}	{⟨ $\dot{s}_{3.4557}, \dot{s}_{1.5091}$ ⟩, ⟨ $\dot{s}_{1.9918}, \ddot{s}_{1.7032}$ ⟩}
A ₄	{⟨ $\dot{s}_{4.2968}, \dot{s}_{1.3253}$ ⟩, ⟨ $\ddot{s}_{2.4909}, \ddot{s}_{1.0000}$ ⟩}	{⟨ $\dot{s}_{4.4909}, \dot{s}_{1.2851}$ ⟩, ⟨ $\dot{s}_{2.2903}, \ddot{s}_0$ ⟩}
Alternatives	C ₇	C ₈
A ₁	{⟨ $\dot{s}_{2.4413}, \dot{s}_{2.5702}$ ⟩, ⟨ $\ddot{s}_{1.4094}, \ddot{s}_{2.0082}$ ⟩}	{⟨ $\dot{s}_{2.6280}, \dot{s}_{2.0082}$ ⟩, ⟨ $\dot{s}_{2.1649}, \ddot{s}_{1.5563}$ ⟩}
A ₂	{⟨ $\dot{s}_{4.4437}, \dot{s}_{1.1743}$ ⟩, ⟨ $\ddot{s}_{1.4557}, \ddot{s}_{2.0000}$ ⟩}	{⟨ $\dot{s}_{4.3422}, \dot{s}_{1.0000}$ ⟩, ⟨ $\dot{s}_{2.1649}, \ddot{s}_{1.5627}$ ⟩}
A ₃	{⟨ $\dot{s}_{2.9695}, \dot{s}_{2.5807}$ ⟩, ⟨ $\ddot{s}_{2.4437}, \ddot{s}_{1.1743}$ ⟩}	{⟨ $\dot{s}_{3.6839}, \dot{s}_{1.7475}$ ⟩, ⟨ $\dot{s}_{1.6418}, \ddot{s}_{1.5627}$ ⟩}
A ₄	{⟨ $\dot{s}_{4.4437}, \dot{s}_0$ ⟩, ⟨ $\ddot{s}_{1.6839}, \ddot{s}_{1.1743}$ ⟩}	{⟨ $\dot{s}_{4.0277}, \dot{s}_{1.3253}$ ⟩, ⟨ $\dot{s}_{2.3422}, \ddot{s}_{1.0000}$ ⟩}

Step 3: Calculation of the 2DLIF ratio system

By adopting the 2DLIFWA operator, the utility of the 2DLIF ratio system of each alternative $y_i^s (i = 1, 2, 3, 4)$ could be obtained as:

$$\begin{aligned} y_1^s &= \{ \langle \dot{s}_{2.5974}, \dot{s}_{2.3994} \rangle, \langle \ddot{s}_{1.7189}, \ddot{s}_{1.6067} \rangle \} \\ y_2^s &= \{ \langle \dot{s}_{3.7473}, \dot{s}_{1.5578} \rangle, \langle \ddot{s}_{2.2368}, \ddot{s}_{1.2191} \rangle \} \\ y_3^s &= \{ \langle \dot{s}_{3.1515}, \dot{s}_{2.0951} \rangle, \langle \ddot{s}_{1.9341}, \ddot{s}_{1.2912} \rangle \} \\ y_4^s &= \{ \langle \dot{s}_{4.0562}, \dot{s}_{0.0000} \rangle, \langle \ddot{s}_{2.2882}, \ddot{s}_{0.0000} \rangle \} \end{aligned}$$

Hence, by using the score function, the crisp utility value $\bar{y}_i^s (i = 1, 2, 3, 4)$ of different alternatives was calculated as:

$$\bar{y}_1^s = 0.2655, \bar{y}_2^s = 0.4280, \bar{y}_3^s = 0.3413, \bar{y}_4^s = 0.6587$$

Step 4: Calculation of the 2DLIF reference point approach

Based on the combined 2DLIF decision matrix, the reference point $r = (\bar{r}_1^*, \bar{r}_2^*, \dots, \bar{r}_8^*)$ could be obtained following Equation (23) as:

$$\begin{aligned}
\tilde{r}_1^* &= \{ \langle \dot{s}_{4.4909}, \dot{s}_{1.0000} \rangle, \langle \dot{s}_{2.4909}, \dot{s}_{1.1743} \rangle \} \\
\tilde{r}_2^* &= \{ \langle \dot{s}_{3.4557}, \dot{s}_{2.0000} \rangle, \langle \dot{s}_{2.6747}, \dot{s}_{1.0000} \rangle \} \\
\tilde{r}_3^* &= \{ \langle \dot{s}_{4.1649}, \dot{s}_{1.5627} \rangle, \langle \dot{s}_{2.2903}, \dot{s}_{1.2851} \rangle \} \\
\tilde{r}_4^* &= \{ \langle \dot{s}_{4.1649}, \dot{s}_{1.5563} \rangle, \langle \dot{s}_{2.4437}, \dot{s}_{1.0000} \rangle \} \\
\tilde{r}_5^* &= \{ \langle \dot{s}_{4.2968}, \dot{s}_{1.3253} \rangle, \langle \dot{s}_{2.4909}, \dot{s}_{1.0000} \rangle \} \\
\tilde{r}_6^* &= \{ \langle \dot{s}_{4.4909}, \dot{s}_{1.2851} \rangle, \langle \dot{s}_{2.3422}, \dot{s}_{0.0000} \rangle \} \\
\tilde{r}_7^* &= \{ \langle \dot{s}_{4.4437}, \dot{s}_{0.0000} \rangle, \langle \dot{s}_{2.4437}, \dot{s}_{1.1743} \rangle \} \\
\tilde{r}_8^* &= \{ \langle \dot{s}_{4.3422}, \dot{s}_{1.0000} \rangle, \langle \dot{s}_{2.3422}, \dot{s}_{1.0000} \rangle \}
\end{aligned}$$

By using the Euclidean distance, the utility $y_s^r (i = 1, 2, 3, 4)$ of different alternatives could be obtained as:

$$y_1^r = 0.3094, y_2^r = 0.1830, y_3^r = 0.2857, y_4^r = 0.0936$$

Thus, by using Equation (26), the crisp utility $\bar{y}_i^s (i = 1, 2, 3, 4)$ of different alternatives were calculated as:

$$\bar{y}_1^r = 0.3087, \bar{y}_2^r = 0.5296, \bar{y}_3^r = 0.3312, \bar{y}_4^r = 1.0000$$

Step 5: Calculation of the 2DLIF full multiplicative form

By using the 2DLIFWG operator, the utility $y_i^f (i = 1, 2, 3, 4)$ of the 2DLIF full multiplicative form could be calculated as:

$$\begin{aligned}
y_1^f &= \{ \langle \dot{s}_{2.5710}, \dot{s}_{2.4511} \rangle, \langle \dot{s}_{1.6001}, \dot{s}_{1.6729} \rangle \} \\
y_2^f &= \{ \langle \dot{s}_{3.7128}, \dot{s}_{1.6569} \rangle, \langle \dot{s}_{2.1626}, \dot{s}_{1.2602} \rangle \} \\
y_3^f &= \{ \langle \dot{s}_{3.0849}, \dot{s}_{2.2108} \rangle, \langle \dot{s}_{1.7306}, \dot{s}_{1.3390} \rangle \} \\
y_4^f &= \{ \langle \dot{s}_{3.9340}, \dot{s}_{1.6048} \rangle, \langle \dot{s}_{2.2675}, \dot{s}_{1.0336} \rangle \}
\end{aligned}$$

The crisp utility value $\bar{y}_i^f (i = 1, 2, 3, 4)$ of different alternatives was computed as:

$$\bar{y}_1^f = 0.2504, \bar{y}_2^f = 0.4114, \bar{y}_3^f = 0.3145, \bar{y}_4^f = 0.4541$$

Step 6: Sort and rank the alternatives

By combining the crisp utility values of the 2DLIF ratio system, 2DLIF reference point approach and 2DLIF full multiplicative form, the overall utility value of different alternatives could be obtained. In this case, all three subordinates were set to have the same importance on determining the final results, that is, $\delta_1 = \delta_2 = \delta_3 = 1/3$, and the overall utility $u_i (i = 1, 2, 3, 4)$ of different alternatives were calculated as:

$$u_1 = 0.2751, u_2 = 0.4563, u_3 = 0.3288, u_4 = 0.7045$$

Thus, based on the overall utility of different alternatives, the UAV supplier could be ranked as $A_4 \succ A_2 \succ A_3 \succ A_1$, and A_4 could be selected as the optimal sustainable supplier.

6. Results and Discussion

In this section, the experimental results were further verified through a validity test, sensitivity analysis and comparative analysis to show the effectiveness and feasibility of the proposed method.

6.1. Sensitivity Analysis

To analyze the impact of the weight fluctuations of the evaluation attributes on the ranking results, a sensitivity analysis of the attribute weights was conducted. In this

analysis, the attribute weight fluctuated by 10%, 20% and 30% lower than the original weight and 10%, 20% and 30% higher than the original weight. For each attribute, there were six tests, which meant there were 48 (6×8) tests in total. When the weight of a certain attribute changed by decreasing or increasing by 10%, 20% or 30%, the weights of all other attributes changed accordingly. The weight of the analyzed attribute C_k was changed into $\omega'_k = \mu\omega_k$, where the value of μ was 70%, 80%, 90%, 110%, 120% and 130%, respectively, and the weights of other attributes were changed to:

$$\omega_j = \frac{1 - \omega'_k}{1 - \omega_k} \omega_j, j = 1, 2, \dots, 8, j \neq k \quad (30)$$

The results of the sensitivity analysis are shown in Figures 2–9, where the blue, red, yellow and purple lines represent the overall utilities of alternative A_1 , A_2 , A_3 and A_4 , respectively. From Figures 2–9, it can be found that no matter how the weights of the attributes fluctuate, the ranking orders of all four alternatives remain stable and consistent. Alternative A_4 remains the optimal supplier, whereas alternative A_1 is always the least optimal supplier. It can be seen that with the changes in the attribute weight, the curves of the overall utility are rather quite smooth, which indicates the stable and robust performance of the proposed method, where all alternatives are shown to be stable when the weights of attributes fluctuate. Moreover, it can be seen from Figure 5 that alternative A_4 has a certain sensitivity to attribute C_2 , as its overall utility decreases slightly with the increase of the attribute weight, indicating that the performance of the attribute C_2 for alternative A_4 is not as stable as other alternatives. However, it is worth noting that the overall fluctuation range of this attribute is quite insignificant. Therefore, in general, it can be concluded that the proposed sustainable supplier selection method has a good robustness and applicability.

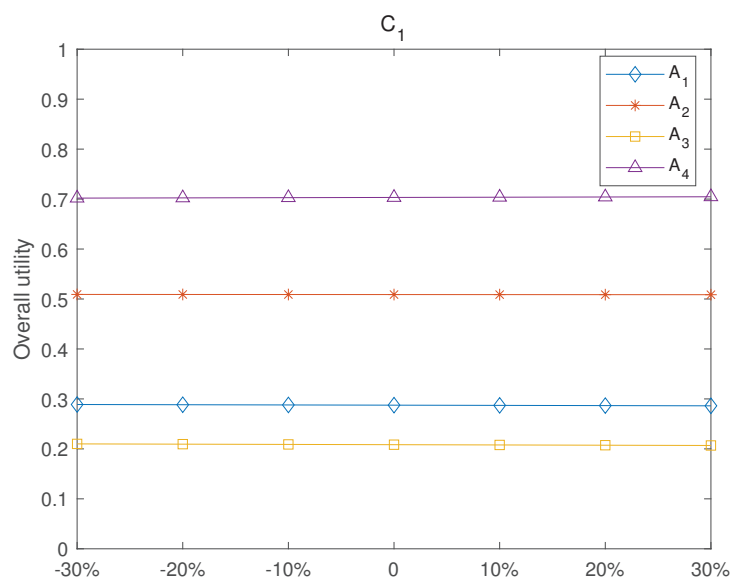


Figure 2. Evaluation results with changes in attribute weight of C_1 .

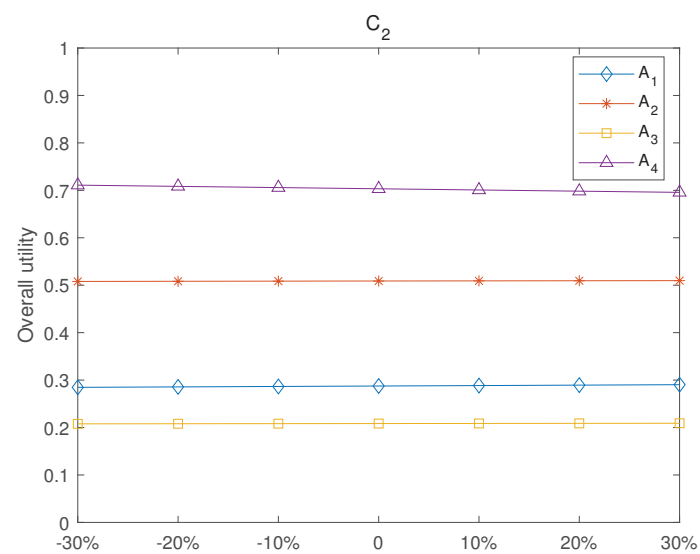


Figure 3. Evaluation results with changes in attribute weight of C_2 .

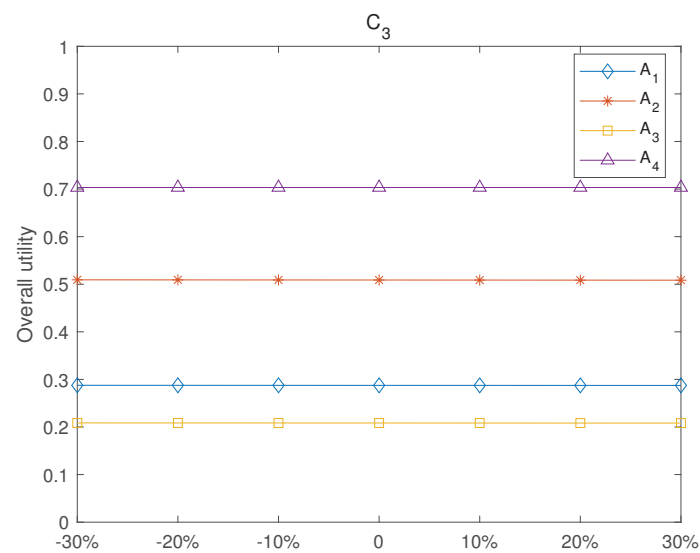


Figure 4. Evaluation results with changes in attribute weight of C_3 .

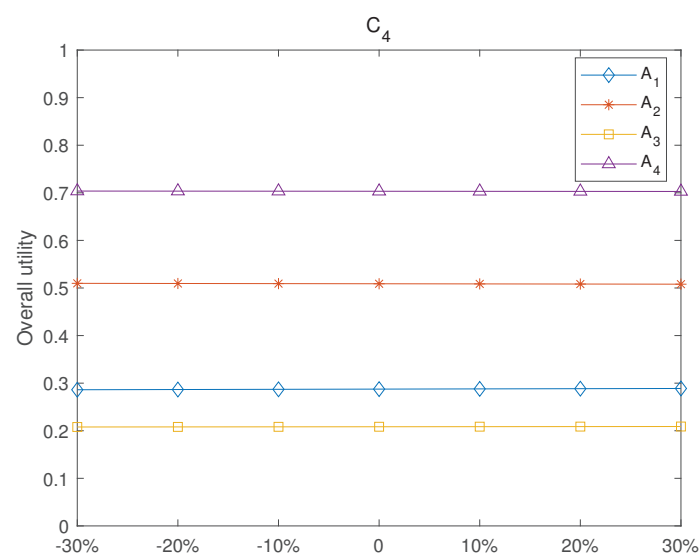


Figure 5. Evaluation results with changes in attribute weight of C_4 .

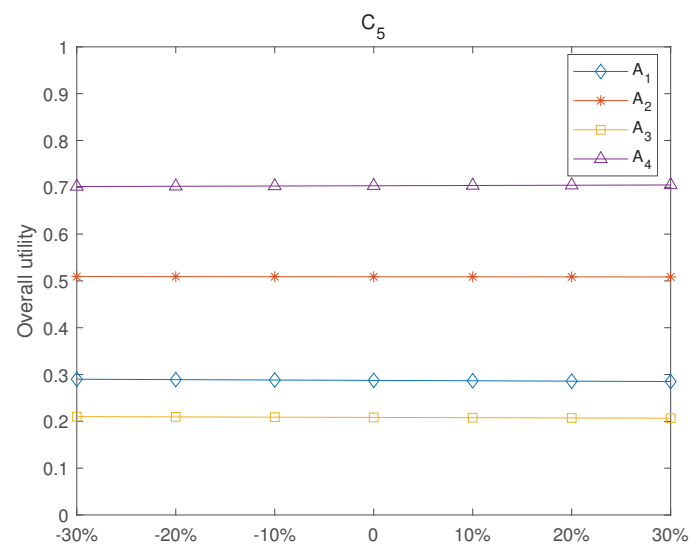


Figure 6. Evaluation results with changes in attribute weight of C_5 .

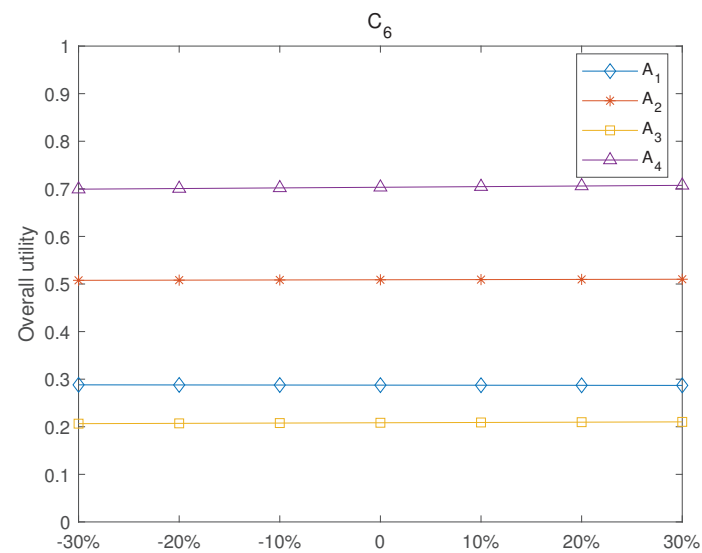


Figure 7. Evaluation results with changes in attribute weight of C_6 .

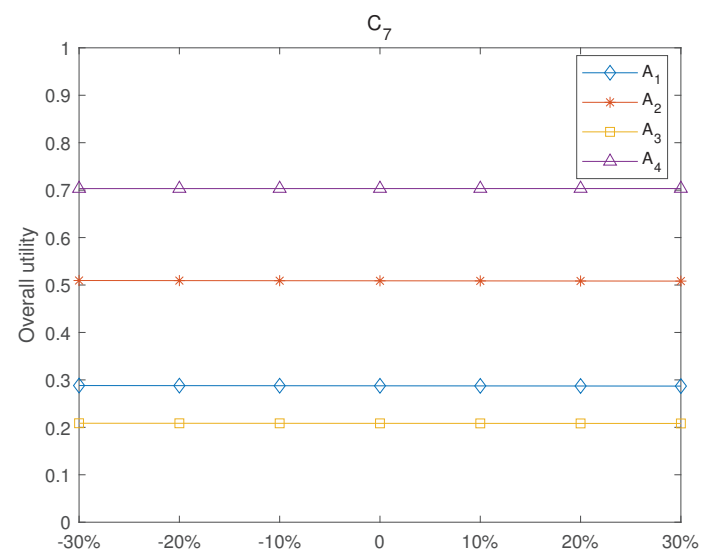


Figure 8. Evaluation results with changes in attribute weight of C_7 .

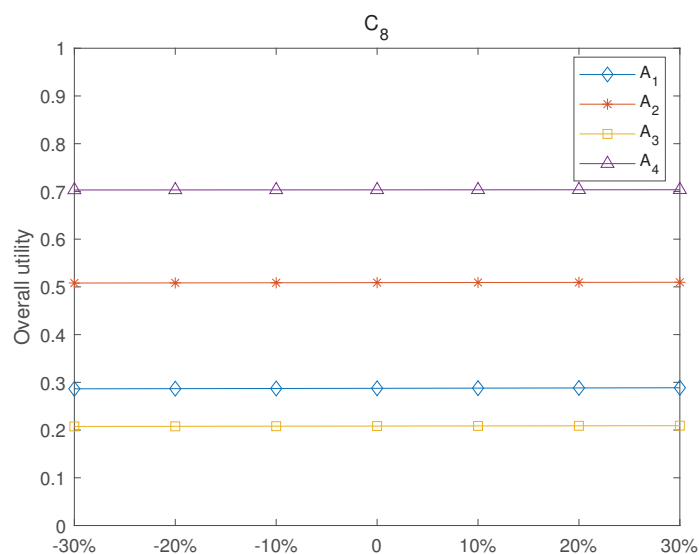


Figure 9. Evaluation results with changes in attribute weight of C_8 .

6.2. Comparative Analysis

In order to further illustrate the effectiveness and feasibility of the proposed method, the results of the proposed method were compared with the results using TOPSIS, VIKOR, PROMETHEE and the method introduced by Verma and Merigo [21]. It should be noted that for TOPSIS, VIKOR and PROMETHEE, as these methods were under the linguistic intuitionistic fuzzy environment, the two-dimension linguistic intuitionistic fuzzy information used in this paper was reduced to linguistic intuitionistic fuzzy information, where the II class linguistic intuitionistic fuzzy information was removed. As for Verma's method, the two-dimension linguistic intuitionistic fuzzy information was directly used. Furthermore, for these methods, the weights of the attributes calculated in this study were directly used, whereas the weights of the experts were calculated using the corresponding methods. The ranking orders of these different methods are listed in Table 8.

Table 8. Ranking orders of different methods.

Method	Ranking Order
TOPSIS	$A_4 \succ A_3 \succ A_2 \succ A_1$
VIKOR	$A_4 \succ A_2 \succ A_3 \succ A_1$
PROMETHEE	$A_4 \succ A_3 \succ A_2 \succ A_1$
Verma's method	$A_4 \succ A_2 \succ A_3 \succ A_1$
Proposed method	$A_4 \succ A_2 \succ A_3 \succ A_1$

From Table 8, it can be seen that the ranking orders of different methods are similar, as alternative A_4 is evaluated as the optimal supplier by all these methods and alternative A_1 is evaluated to be the least optimal one. However, it is worth noting that the ranking order of alternatives A_2 and A_3 of the proposed method is slightly different from that of TOPSIS and PROMETHEE, as the proposed method evaluates alternative A_2 to be superior to alternative A_3 , whereas TOPSIS and PROMETHEE methods evaluate alternative A_2 to be inferior to alternative A_3 . That is mainly caused by the fact that the proposed method uses two-dimension linguistic intuitionistic fuzzy information as the evaluations of different attributes, while TOPSIS and PROMETHEE use linguistic intuitionistic fuzzy information, which could lead to the loss of certain evaluation information. Based on the comparison, the proposed method has the following advantages:

(1) The proposed method is developed based on the 2DLIFVs, which could provide the experts more freedom in expressing their uncertain, fuzzy and linguistic evaluations. Compared to the proposed method, other methods use LIFs and 2DLFs, which are particular cases of 2DLIFVs.

(2) The 2DLIF-BWM is adopted as the attribute weight calculation method in the proposed method, which enables a consistent and reliable attribute weight calculation approach with significantly fewer pairwise comparisons.

(3) The weights of the experts are calculated based on both the uncertainty degree and the consensus degree of the experts, which could more effectively and reliably reflect the relative importance of different experts.

(4) The 2DLIF-MULTIMOORA method is developed for ranking different alternatives, where the results of 2DLIF ratio system, 2DLIF reference point approach and 2DLIF full multiplicative form are aggregated to obtain the final results, which increases the reliability of the proposed method.

7. Conclusions

This paper proposed an integrated MAGDM method based on the BWM and the MULTIMOORA method under a two-dimension linguistic intuitionistic fuzzy environment for selecting sustainable UAV suppliers. The main results of this study can be summarized as follows.

(1) With respect to the evaluation of the experts, the proposed method provided a more convenient and flexible way for experts to provide their uncertain, fuzzy and linguistic evaluations of the attributes by using 2DLIFVs.

(2) With respect to the attribute weights, the proposed method presented an effective yet simple way to calculate the weights of different attributes by expanding the BWM with 2DLIFV, where the preferences among different attributes were expressed by 2DLIFVs.

(3) With respect to the expert weights, the proposed method enabled a more balanced and reliable calculation of the expert weights by combining the uncertainty degree and consensus degree of the experts, which could embed both the uncertainty and the consensus of the experts into the experts' weights.

(4) With respect to the ranking alternatives, the proposed method introduced an effective and reliable method by proposing the 2DLIF-MULTIMOORA method, where the evaluation results were obtained by aggregating the results of all three subordinates.

In addition, the case study further proved the effectiveness and feasibility of the proposed method. From the experimental results, it can be concluded that the proposed method provides a novel and effective way for sustainable supplier selection under uncertain, fuzzy and linguistic environment.

One limitation of the proposed method is that the proposed method was presented under the static assumption, and the dynamic characteristics of the sustainable supplier selection were not considered. Moreover, the subjectivity of the experts' evaluations is another inevitable limitation. In the future, more attention should be paid to expanding the proposed method to dynamic environments.

For future work, we will further extend the proposed method using a group consensus method to enhance the reliability of the evaluation information provided by the experts. Moreover, we will also investigate the possibility of extending the proposed method to large-scale group decision-making problems to increase the practicability of the proposed method.

Author Contributions: Conceptualization, C.L. and H.H.; methodology, C.L. and Y.L.; validation, C.L., H.H. and Y.L.; writing—original draft preparation, C.L.; writing—review and editing, H.H. and Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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