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Intuitionistic fuzzy MOORA for supplier selection

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Abstract
The supplier selection is a critical activity within the administration of the supply chain. It is considered a complex problem given that it involves different aspects such as the alternatives to evaluate, the multiple criteria involved as well as the group of decision makers with different opinions. In this sense, the literature reports several methods to help in this difficult activity of selecting the best supplier. However, there are still some gaps in these methods; therefore, it is imperative to further develop research. Thus, the purpose of this paper is to report a hybrid method between MOORA and intuitionistic fuzzy sets for the selection of suppliers with a focus on multi-criteria and multi-group environment. The importance of decision makers, criteria and alternatives are evaluated in terms of intuitionistic fuzzy sets. Then, MOORA is used in order to determine the best supplier. An experimental case is developed in order to explain the proposed method in detail and to demonstrate its practicality and effectiveness.

Keywords: MCDM; MOORA; Intuitionistic fuzzy set; Supplier Selection.

MOORA versión difuso intuicionista para la selección de proveedores

Resumen
La selección de proveedores es una actividad crítica dentro de la administración de una cadena de suministro. Es considerado un problema complejo dado que involucra diferentes aspectos como son las mismas alternativas a evaluar, los múltiples criterios en consideración, así como el grupo de decisores con opiniones diferentes. En este sentido, la literatura reporta diversos métodos para ayudar en esta difícil actividad de seleccionar el mejor proveedor. Sin embargo, aún existen algunas brechas en dichos métodos por lo que resulta necesario seguir desarrollando investigación. Por lo tanto, el propósito del presente artículo es reportar un nuevo método basado en la hibridación de la técnica MOORA con conjuntos difusos intuicionistas para la selección de proveedores, con un enfoque de decisión multi-criterio y multi-grupal. La importancia de los decisores y criterios así como las alternativas se evalúan en términos de conjuntos difusos intuicionistas, posteriormente MOORA es usado para determinar la mejor alternativa. Un caso experimental es desarrollado con el fin de explicar el método propuesto de manera detallada y para demostrar su viabilidad y eficacia.

Palabras clave: MCDM; MOORA; Conjuntos difusos intuicionistas; Selección de Proveedores.

1. Introduction

Nowadays, market demands have motivated the industries to provide a fast and reliable service in order to meet customer requests that are sensitive in their requirements [1,2]. In this sense, supply chain management has fostered great interest in terms of company strategies to stay in global business. The works presented by [3- 5] claim that an important key issue for the administration of the supply chain is the correct selection of suppliers. [6,7] mention that the selection of suppliers is considered a multi-criteria problem in the field of decision-making. Additionally, the work of [8] argues that effective supplier selection is significant because it helps reduce operational costs. According to [9], the selection of the best supplier is a competitive advantage that can help to increase productivity

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and efficiency for any organization.

Hence, given the importance of selecting the best supplier, there are several multi-criteria methodologies that seek to provide support in the difficult task of making this decision. Such methodologies are being used by purchasing managers of companies, and even by top managers. Some of the most frequently reported methodologies in the literature are: artificial neural networks (1943, ANN), fuzzy sets (1965, FS), quality function deployment (1966, QFD), elimination and choice expressing reality (1968, ELECTRE), design of decision support systems (1971, DSS), simple multi-attribute rating technique (1971, SMART), genetic algorithm (1975, GA), data envelopment analysis (1978, DEA), analytic hierarchy process (1980, AHP), technique for order of preference by similarity to ideal solution (1981, TOPSIS), viseKriterijumsa optimizacija i kompromisno resenje (1998, VIKOR), dimensional analysis (1993, DA), analytic network process (1996, ANP), multi-objective optimization by ratio analysis (2006, MOORA), preference selection index (PSI, 2010), among several others [10-24]. We can therefore infer that the issue of decision-making has been investigated for many years and, as a result, several methodologies have been developed as support tools [25].

[26,27] report a classification of these methodologies within two groups: individual and hybrid. The first group is made up by AHP, TOPSIS, DEA, DSS, VIKOR, ELECTRE, MOORA, SMART, DA, MOORA, FS, ANN, GA, among many more. The second group is represented by AHP-TOPSIS, TOPSIS-VIKOR, DS-AHP, FDEMATEL, FVIKOR, FELECTRE, FAHP, AHP-GA, AHP-ANN, FTOPSIS, DEA-AHP, IFTOPSIS, IFAHP, among others. The literature reviewed shows that AHP and TOPSIS are two of the most frequently reported methodologies especially in the task of supplier selection [25,28,29]. Furthermore, it can be observed that the most frequently reported hybrids contain these methodologies along with fuzzy sets [3,6,30-33]. However, these methodologies by themselves as well as the hybrids with fuzzy sets present some deficiencies.

First, the AHP method requires decision makers (DMs) to utilize perception capabilities to undertake pair-wise comparisons, but AHP lacks the ability to reflect the way humans think. In other words, AHP uses crisp values to represent the subjective opinion from DMs, which is hard to estimate by exact numerical values [7,31-35]. Even though the fuzzy AHP method handles the fuzziness in the experts' subjective judgment with the aid of fuzzy set theory, the mathematical foundation is rather poor; for example, in terms of the conditions of reciprocity and transitivity, particularly where, $\tilde{a}_{ij} = 1/\tilde{a}_{ji}$ is not equal to $\tilde{a}_{ij} \cdot \tilde{a}_{ji} = 1$. Besides, defining the fuzzy Eigen-values tends to be complex [2, 36-38].

Second, TOPSIS deals with Euclidean distance [39, 40]. Euclidean distance assumes that criteria in evaluation are independent, which is sometimes not the case [41]. The same issue remains in the fuzzy version. As a result, there exists the opportunity to further develop research in the field of decision making in order to counteract weaknesses that can lead to making a wrong decision.

Recent papers show that multi-criteria methods are being used in combination with intuitionistic fuzzy sets (IFS). Particularly, IFS, proposed by Atanassov (1986), are a generalization of the classical fuzzy sets reported by Zadeh (1965). A literature review shows that over the past few years, the use of IFS in multi-criteria decision making (MCDM) has increased significantly [42-57]. IFS are more capable than traditional fuzzy sets at handling vague and uncertain information in practice [55-57].

Hence, the aim of this work is to present the hybrid of the MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) method with IFS as an alternative methodology for MCDM.

The rest of this paper is organized as follows. Section 2 briefly presents the concepts related to IFS. Section 3 presents the description of MOORA. Section 4 describes the method proposed in this paper. In Section 5 a numerical case is presented in order to explain the proposed methodology. Finally, the conclusions and further works are presented in section 6.

2. Intuitionistic Fuzzy Set

A fuzzy set A in $X = \{x\}$ is given by $A = \{\langle x, \mu_A(x)\rangle | x \in X\}$. Where $\mu_A: X \to [0,1]$ is the membership function of the fuzzy set A; $\mu_A(x) \in [0,1]$ is the membership of $x \in X$ in A.

According to [58] an IFS is proposed by means of two functions expressing the degree of membership and non-membership of an element x to the set A. An IFS A in $X = \{x\}$ is defined as $A = \{\langle x, \mu_A(x), \upsilon_A(x)\rangle | x \in X\}$. Where $\mu_A: X \to [0,1]$; $\upsilon_A: X \to [0,1]$. With the condition $0 \le \mu_A(x) + \upsilon_A(x) \le 1, \forall\, x \in X$

The numbers $x, \mu_A(x), \upsilon_A(x) \in [0,1]$ denote respectively the degree of membership and degree of non-membership of element x to the set A.

The number $\pi_A(x) = 1 - (\mu_A(x) + \upsilon_A(x))$ is called the intuitionistic index of x in A. It is a measure of the degree of hesitancy of element x in set A. It should be noted that $0 \le \pi_A(x) \le 1$ for each $x \in X$.

Hence, an IFS A in $X = \{x\}$ is fully defined with the form $A = \{\langle x, \mu_A(x), \upsilon_A(x), \pi_A(x)\rangle | x \in X\}$. Where $\mu_A: X \to [0,1]$; $\upsilon_A: X \to [0,1]$ and $\pi_A: X \to [0,1]$. Different relations and operations are introduced over the IFSs [59] some of them are shown in eq. (1) and (2).

$$A \cdot B = \{\langle x, \mu_A(x) \cdot \mu_B(x), \nu_A(x) + \nu_B(x) - \nu_A(x) \cdot \nu_B(x)\rangle | x \in X\} \quad (1)$$

$$A + B = \{\langle x, \mu_A(x) + \mu_B(x) - \mu_A(x).\mu_B(x), \upsilon_A(x).\upsilon_B(x)\rangle | x \in X\} \quad (2)$$

3. MOORA

Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) was introduced by Brauers and Zavadskas for first time in 2006 [60]. The basic idea of the MOORA method is to calculate the overall performance of each alternative as the difference between the sums of its normalized performances which belongs to cost and benefit criteria. Thus, the MOORA method can be expressed concisely using the five following steps:

Step 1. Determine the decision-making matrix. The method begins with the identification of available alternatives and criteria. Then, the decision-making matrix (DMM) is constructed, which contains n rows that represent the alternatives $A^1 \dots A^n$ in evaluation, and $J+L$ columns that represent criteria under evaluation (J quantitative criteria and L qualitative criteria). In this way, according to [61], the MDF is computed using eq. (3).

$$MDF = [VO, VST] = \begin{matrix} A^1 \\ A^2 \\ \cdot \\ \cdot \\ A^n \end{matrix} \begin{bmatrix} x_1^1 & \dots & x_J^1 & x_{J+1}^1 & \dots & x_{J+L}^1 \\ x_1^2 & \dots & x_J^2 & x_{J+1}^2 & \dots & x_{J+1}^2 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ x_1^n & \dots & x_J^n & x_{J+1}^n & \dots & x_{J+L}^n \end{bmatrix} \quad (3)$$

where, A_i represent the alternatives, for $i = 1 \dots . n$ and x_j^i represents the entries of the alternative i with respect to criterion j.

Step 2. Calculate the normalized decision-making matrix. It is possible that the evaluation attributes are expressed in different units or scales of measurement; thereby, normalization is carried out [60]. Where the Euclidean norm is obtained according to eq. (4) to the criterion x_j.

$$|X_j| = \sqrt{\sum_1^n x_i^2} \quad (4)$$

Thus, the normalization of each entry in the MDF is undertaken according to eq. (5).

$$Nx_{ij} = \frac{x_{ij}}{|X_j|} \quad (5)$$

The results obtained using eq. (5) are dimensionless values that lack scale, which allows the operations between criteria to be additive [61,62].

Step 3. Calculate the weighted normalized decision-making matrix. Considering [63] the different importance of criteria, the weighted normalized ratings WNx_{ij} are calculated with eq.(6).

$$WNx_{ij} = w_i . Nx_{ij} \quad (6)$$

Step 4. Calculate the overall ratings of cost and benefit criteria for each alternative. The overall ratings of benefit criteria Nx_i are calculated as the sum of weighted normalized ratings of benefit criteria using eq. (7).

$$Nx_i = wNx_i | \in J^{max} \quad (7)$$

where J^{max} is associated with benefit criteria.

Similarly, the overall ratings of cost criteria Nx_j are calculated with eq. (8).

$$Nx_j = wNx_j | \in J^{min} \quad (8)$$

where J^{min} is associated with cost criteria.

Step 5 Compute the contribution of each alternative Ny_i. The contribution of each alternative is obtained using eq. (9) proposed by [60].

$$Ny_i = \sum_{i=1}^{g} N\, x_i - \sum_{j=g+1}^{m} Nx_j \quad (9)$$

where Ny_i represents the contribution of each alternative $i = 1 \dots . . n$, $i = 1 \dots . . g$ are the maximum criteria and $j = g+1, g+2, \dots . m$ are the minimum criteria

Finally, the Ny_i value can be positive or negative depending on the totals of its maxima (benefit criteria) and minima (cost criteria) in the decision matrix. An ordinal ranking of Ny_i shows the final preferenc Ny_i value.

4. Intuitionistic Fuzzy MOORA

Let $A = \{A_1, A_2, \dots, A_i, \dots, A_n\}$ be a set of alternatives and $X = \{x_1, x_2, \dots, x_j, \dots, x_m\}$ be a set of criteria to be evaluated. The Intuitionistic Fuzzy MOORA (IF-MOORA) procedure is described in the following steps:

Step 1. Constitute a group of Decision Makers and determine the importance of each one. Where $DM = \{DM_1, DM_2, \dots, DM_k, \dots, DM_l\}$ is the set of decision makers (DMs). The importance of each DM is rated through a linguistic term expressed by intuitionistic fuzzy numbers. The linguistic terms and their corresponding intuitionistic fuzzy number (IFN) used for rating the weight of each one of the DMs are shown in Table 1.

Let $DM_{k=}\{\mu_k, \nu_k, \pi_k\}$ be an intuitionistic fuzzy number for rating of kth DM. Then, the corresponding weight of kth DM is obtained using the concept proposed by [52]:

$$\lambda_k = \frac{\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \nu_k}\right)\right)} \quad (10)$$

where $\sum_{k=1}^{l} \lambda_k = 1$

Step 2. Determine the importance of criteria. Normally, all criteria may not be assumed to be of equal importance, and DMs might give different opinions about the same criteria. Hence, all opinions need to be considered and combined into one. Linguistic terms shown in Table 1 are used to rate the importance of criteria by every DM.

Table 1.
Linguistic terms for rating the importance of decision maker and criteria.

Linguistic Term	IFN (μ, ν, π)
Beginner (B) / Very Unimportant (VU)	{0.1, 0.9, 0}
Practitioner (Pr) / Unimportant (U)	{0.35, 0.6, 0.05}
Proficient (Pt) / Medium (M)	{0.5, 0.45, 0.05}
Expert (E) / Important (I)	{0.75, 0.2, 0.05}
Master (M) / Very Important (VI)	{0.9, 0.1, 0}

Source: The authors.

Let $w_j^{(k)} = \{\mu_j^{(k)}, \nu_j^{(k)}, \pi_j^{(k)}\}$ be an intuitionistic fuzzy number assigned to criterion x_j by the kth DM. Then, the weights of the criteria are computed using the IFWA operator proposed by [53]:

$$w_j = IFWA\left(w_j^{(1)}, w_j^{(2)}, \dots, w_j^{(k)}, \dots, w_j^{(l)}\right)$$

$$= \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \oplus \dots \oplus \lambda_k w_j^{(k)} \oplus \dots \oplus \lambda_l w_j^{(l)}$$

$$= \left[1 - \prod_{k=1}^{l}\left(1 - \mu_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1 - \mu_j^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(\nu_j^{(k)}\right)^{\lambda_k}\right] \quad (11)$$

where $w_j = \{\mu_j, \nu_j, \pi_j\}$ and $W = \{w_1, w_2, \dots, w_j, \dots, w_m\}$.

Step 3. Construct the aggregated intuitionistic fuzzy decision matrix representing the rating of alternatives A_i based on the opinions of decision makers.

Let $R^{(k)} = (x_{ij}^{(k)})_{nxm}$ be an intuitionistic fuzzy decision matrix (IFDM) of each DM. The linguistic terms used to evaluate each one of the alternatives according to the criteria are shown in Table 2.

Table 2.
Linguist terms for rating alternatives.

Linguistic Term	IFN (μ, ν, π)
Extremely Bad (EB) / Extremely Low (EL)	{0.1, 0.9, 0}
Very Bad (VB) / Very Low (VL)	{0.1, 0.75, 0.15}
Bad (B) / Low (L)	{0.25, 0.6, 0.15}
Medium Bad (MB) / Medium Low (ML)	{0.4, 0.5, 0.1}
Fair (F) / Medium (M)	{0.5, 0.4, 0.1}
Medium Good (MG) / Medium High (MH)	{0.6, 0.3, 0.1}
Good (G) / High (H)	{0.7, 0.2, 0.1}
Very Good (VG) / Very High (VH)	{0.8, 0.1, 0.1}
Excellent (E) / Extremely High (EH)	{1, 0, 0}

Source: The authors.

All opinions of DMs need to be included into an aggregated intuitionistic fuzzy decision matrix (AIFDM). IFWA operator might be used. $R = (x_{ij})_{nxm}$

$$x_{ij} = IFWA\left(x_{ij}^{(1)}, x_{ij}^{(2)}, \dots, x_{ij}^{(k)}, \dots, x_{ij}^{(l)}\right)$$

$$= \lambda_1 x_{ij}^{(1)} \oplus \lambda_2 x_{ij}^{(2)} \oplus \dots \oplus \lambda_k x_{ij}^{(k)} \oplus \dots \oplus \lambda_l x_{ij}^{(l)}$$

$$= \left[1 - \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(\nu_{ij}^{(k)}\right)^{\lambda_k}\right] \quad (12)$$

where $x_{ij} = \left\{\mu_{A_i(x_j)}, \nu_{A_i(x_j)}, \pi_{A_i(x_j)}\right\} (i = 1, 2, \dots, n; j = 1, 2, \dots, m)$.

Then, the AIFDM is defined as:

$$AIFDM = R = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}$$

Specifically,

$$R = \begin{bmatrix} \{\mu_{A_1(X_1)}, \nu_{A_1(X_1)}, \pi_{A_1(X_1)}\} & \cdots & \{\mu_{A_1(X_m)}, \nu_{A_1(X_m)}, \pi_{A_1(X_m)}\} \\ \vdots & \ddots & \vdots \\ \{\mu_{A_n(X_1)}, \nu_{A_n(X_1)}, \pi_{A_n(X_1)}\} & \cdots & \{\mu_{A_n(X_m)}, \nu_{A_n(X_m)}, \pi_{A_n(X_m)}\} \end{bmatrix}$$

Step 4. Compute the aggregated weighted intuitionistic fuzzy decision matrix (AWIFDM). In this step, the AWIFDM is computed by considering the AIFDM, obtained in Step 3, and the vector of criteria weights, obtained in Step 2. The elements of AWIFDM are calculated using Eq. (1).

$$AWIFDM = R' = R \cdot W = \{\langle x, \mu_{A_i}(x) \cdot \mu_W(x), \nu_{A_i}(x) + \nu_W(x) - \nu_{A_i}(x) \cdot \nu_W(x)\rangle | x \in X\} \quad (13)$$

$$AWIFDM = R' = \begin{bmatrix} \{\mu_{A'_1(X_1)}, \nu_{A'_1(X_1)}, \pi_{A'_1(X_1)}\} & \cdots & \{\mu_{A'_1(X_m)}, \nu_{A'_1(X_m)}, \pi_{A'_1(X_m)}\} \\ \vdots & \ddots & \vdots \\ \{\mu_{A'_n(X_1)}, \nu_{A'_n(X_1)}, \pi_{A'_n(X_1)}\} & \cdots & \{\mu_{A'_n(X_m)}, \nu_{A'_n(X_m)}, \pi_{A'_n(X_m)}\} \end{bmatrix}$$

Step 5. Compute the sum of costs and benefits. In this step, the benefit (BN) and cost criteria (C) are identified. In this sense, the benefit criteria are the ones where maximum values are desired. On the other hand, cost criteria are where minimum values are preferred.

Thus, eq. (14) represents the sum of benefit criteria

$$BNx_i = \sum_{i=1}^{g} (\mu_{A'_i}(x_i), \nu_{A'_i}(x_i), \pi_{A'_i}(x_i)) \quad (14)$$

where, BNx_i are the benefit criteria for the alternative $i = 1 \dots .. n. X_i = 1 \dots .. g$ represent maximum criteria. Then, eq. (15) define the sum of the cost criteria.

$$Cx_j = \sum_{j=g+1}^{m} (\mu_{A'_i}(x_j), \nu_{A'_i}(x_j), \pi_{A'_i}(x_j)) \quad (15)$$

where, Cx_j represents the sum of the cost criteria for alternative $i = 1 \dots .. n$, and $X_j = g + 1, g + 2, \dots . m$ are minimum criteria.

Step 6. Defuzzification of the sum of benefits and costs. In this step, the maximum x_i and minimum x_j criteria are defuzzified using the eq. (16) proposed by [54].

$$Nx_i = 1 - \frac{1 - \mu_{A'_i}(x_i)}{1 - \pi_{A'_i}(x_i)} \quad (16)$$

$$Nx_j = 1 - \frac{1 - \mu_{A_i'}(x_j)}{1 - \pi_{A_i'}(x_j)}$$

Step 7. Compute the contribution of each alternative Ny_i. Calculate the contribution of each alternative Ny_i with eq. (17).

$$Ny_i = Nx_i - Nx_j \quad (17)$$

The Ny_i value can be positive or negative depending on the totals of beneficial criteria and cost criteria in the decision matrix. An ordinal ranking of Ny_i shows the final contribution of each alternative. Thus, the best alternative has the highest Ny_i value, while the worst alternative has the lowest Ny_i value.

Step 8. Rank the alternatives. Alternatives are sorted according to descending order of Ny_i.

5. Numerical Case

An assembly company dedicated to the production of submersible pumps has to assemble several components in its production line. In the process, there is a packing that unites two shells that maintain an electrical system running under water. A common failure of this packing is detected by a short circuit generated that disables the pump. In order to repair the pump, the packaging has to be removed to change it and replace the faulty electrical system.

Following pre-evaluation to identify potential suppliers of the packaging, five suppliers were found that could easily supply the material in the region where the assembly company is established. A group decision (GD) with two decision makers has been integrated. The GD has been determined to evaluate five suppliers for the new packing component. The procedure followed to choose the best supplier is shown below:

Four criteria are considered for representing the most significant features of the suppliers. Thus, the criteria considered are:

- Cost (x_1): Low values are desired.
- Service (x_2): Good evaluations are desired.
- Management (x_3): Good evaluations are desired.
- Technology (x_4): Good evaluations are desired.

Five suppliers are considered for evaluation. Thus, the set of suppliers are denoted by $A = \{A_1, A_2, A_3, A_4, A_5\}$.

Step 1. Constitute a group of DMs and determine the importance of each one. Two DMs constitute the group and their importance is shown in Table 3. Linguistic terms used for rating are shown in Table 1. In order to obtain the weight of each DM, eq. (10) was used, and for this case in particular all DMs have the same importance.

$$\lambda_{1,2} = \frac{\left(0.75 + 0.05\left(\frac{0.75}{0.75+0.2}\right)\right)}{\left(0.75 + 0.05\left(\frac{0.75}{0.75+0.2}\right)\right) + \left(0.75 + 0.05\left(\frac{0.75}{0.75+0.2}\right)\right)} = 0.5$$

Table 3.
The importance of decision makers

Decision Maker	1	2
Linguistic Term	E	E
IF number	{0.75,0.2,0.05}	{0.75,0.2,0.05}
Weight	0.5	0.5

Source: The authors

Table 4.
The importance of criteria.

Decision Maker	x_1	x_2	x_3	x_4
DM_1	I	M	U	VU
DM_2	M	I	U	U

Source: The authors.

Table 5.
The ratings of qualitative criteria.

Decision Maker	Supplier	Criteria			
		X_1	X_2	X_3	X_4
DM1	A_1	VL	B	E	VG
	A_2	ML	G	F	G
	A_3	VH	VG	VG	VB
	A_4	MH	VB	VB	B
	A_5	M	MB	MG	F
DM2	A_1	L	MB	E	E
	A_2	M	VG	B	VG
	A_3	H	E	G	B
	A_4	MH	B	EB	MB
	A_5	L	F	MB	MB

Source: The authors.

Step 2. Determine the importance of criteria. The evaluation of each DM about the importance of the criteria represented as linguistic terms is shown in Table 4.

Opinions of DMs are integrated by eq. (11) as follows:

$$W_{\{x_1,x_2,x_3,x_4\}} = \begin{bmatrix} \{0.646,0.300,0.054\} \\ \{0.646,0.300,0.054\} \\ \{0.350,0.600,0.050\} \\ \{0.235,0.735,0.030\} \end{bmatrix}^T$$

Step 3. Construct the AIFDM representing the rating of alternatives A_i based on the opinions of decision makers. The ratings given by every DM are given in Table 5. The AIFDM is obtained by eq. (12) and it is shown as follows,

$$R = \begin{bmatrix} \{0.2,0.7,0.2\} & \{0.3,0.6,0.1\} & \{1.0,0.0,0.0\} & \{1.0,0.0,0.0\} \\ \{0.5,0.5,0.1\} & \{0.8,0.1,0.1\} & \{0.4,0.5,0.1\} & \{0.8,0.1,0.1\} \\ \{0.8,0.1,0.1\} & \{1.0,0.0,0.0\} & \{0.8,0.1,0.1\} & \{0.2,0.7,0.2\} \\ \{0.6,0.3,0.1\} & \{0.2,0.7,0.2\} & \{0.1,0.8,0.1\} & \{0.3,0.6,0.1\} \\ \{0.4,0.5,0.1\} & \{0.5,0.5,0.1\} & \{0.5,0.4,0.1\} & \{0.5,0.5,0.1\} \end{bmatrix}$$

Step 4. Compute the aggregated weighted intuitionistic fuzzy decision matrix. The AWIFDM is obtained using eq. (13).

$$R' = \begin{bmatrix} \{0.1,0.8,0.1\} & \{0.2,0.8,0.1\} & \{0.4,0.6,0.1\} & \{0.2,0.7,0.0\} \\ \{0.3,0.6,0.1\} & \{0.5,0.4,0.1\} & \{0.1,0.8,0.1\} & \{0.2,0.8,0.1\} \\ \{0.5,0.4,0.1\} & \{0.6,0.3,0.1\} & \{0.3,0.7,0.1\} & \{0.0,0.9,0.0\} \\ \{0.4,0.5,0.1\} & \{0.1,0.8,0.1\} & \{0.0,0.9,0.0\} & \{0.1,0.9,0.0\} \\ \{0.3,0.6,0.1\} & \{0.3,0.6,0.1\} & \{0.2,0.8,0.1\} & \{0.1,0.9,0.0\} \end{bmatrix}$$

Step 5. Compute the sum of benefits and costs. Service, Management and Technology are benefit criteria $BN = \{x_2, x_3, x_4\}$; while Cost is a cost criteria $C = \{x_1\}$. Table 6 shows the sum of benefit criteria for each alternative in evaluation is obtained using eq. (14).

Table 7 shows the sum of cost criteria for each alternative in evaluation calculated using eq. (15).

Step 6. Defuzzification of the sum of benefits and costs. The maximum x_i (benefit criteria) and minimum criteria x_j (cost criteria) are defuzzified by using eq. (16). The results are shown in the Table 8 and Table 9.

Step 7. Compute the contribution of each alternative Ny_i. The contribution of each alternative Ny_i is computed by using eq. (17). Table 10 shows the ratio for each alternative and its ranking.

Table 6.
Sum of Benefit criteria.

Supplier	μ	ν	π
A_1	0.609	0.301	0.09
A_2	0.636	0.245	0.119
A_3	0.751	0.18	0.069
A_4	0.212	0.629	0.159
A_5	0.481	0.395	0.125

Source: The authors.

Table 7.
Sum of Cost criteria.

Supplier	μ	ν	π
A1	0.115	0.77	0.115
A2	0.292	0.613	0.095
A3	0.488	0.399	0.113
A4	0.388	0.51	0.102
A5	0.251	0.643	0.106

Source: The authors.

Table 8.
Defuzzification of Benefits Nx_i.

Supplier	Crisp
A_1	0.641
A_2	0.675
A_3	0.767
A_4	0.32
A_5	0.538

Source: The authors

Table 9.
Defuzzification of Costs Nx_j

Supplier	Crisp
A1	0.207
A2	0.354
A3	0.54
A4	0.445
A5	0.323

Source: The authors.

Table 10.
Contribution and rank for each alternative.

Supplier	MOORA	Rank
A_1	0.434	1
A_2	0.321	2
A_3	0.227	3
A_4	-0.124	5
A_5	0.215	4

Source: The authors.

Step 8. Rank the alternatives. The alternatives are ranked as $A_1 \succ A_2 \succ A_3 \succ A_5 \succ A_4$. Then, alternative 1 is selected as the best supplier among the rest.

6. Conclusions

This paper presents a hybrid of MOORA and intuitionistic fuzzy sets for supplier selection. The method consists of eight steps and a numerical example was shown in order to illustrate it. The proposed methodology provides a robust hybrid technique that can assist decision makers in selecting the best alternative since IFS has the capability of handling subjective information that provides greater flexibility to solve problems in the field of decision-making.

As future work, it would be interesting to apply IF-MOORA in different areas where there are factors of decision-making regarding the selection of alternatives; for example, robot selection, personnel selection, projects selection, etc. Finally, it is suggested that comparisons are made with other methods and that the results be evaluated.

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