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METHODOLOGIES AND APPLICATION

A new hybrid intuitionistic approach for new product selection

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Abstract This paper proposes a new hybrid approach for multi-criteria decision-making problems combining intuitionistic fuzzy analytic hierarchy process and intuitionistic fuzzy multi-objective optimization by ratio analysis. Analytic hierarchy process has an inherent ability for handling intangible problems and implements a simple scale to represent evaluations in the structure of pairwise comparisons. Multi-objective optimization by ratio analysis optimizes the solution of a problem having two or more conflicting objectives, taking into account certain constraints. In real-life decision problems, evaluations of decision makers related to performance of alternatives and criteria weights can be expressed by linguistic terms comprising vagueness and uncertainty. These uncertain, vague and hesitant judgments of decision makers can be described more comprehensively by using intuitionistic fuzzy set theory. The proposed approach is a powerful tool for dealing with information which consists of hesitancy and vagueness. An illustrative example related to new product selection for a company is also presented to demonstrate the implementation of the approach.

Keywords Intuitionistic fuzzy sets · IFAHP · IFMOORA · New product selection

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1 Introduction

The multi-criteria decision-making (MCDM) approach consists of more than one decision makers (DMs), who evaluate alternatives according to several criteria. DMs determine the relative importance of the criteria and select the best alternative. One of the most commonly used MCDM approach is the analytic hierarchy process (AHP) introduced by Saaty (1977). The main principle of AHP is that it constructs simple and comprehensive hierarchical structure of objectives, criteria, subcriteria and alternatives. This method has an inherent ability for handling intangible problems and implements a simple scale to represent evaluations in the structure of pairwise comparisons (Xu and Liao 2014; Abdullah and Najib 2014). MOORA is also an MCDM approach that optimizes the solution of a problem having two or more conflicting objectives, taking into account certain constraints (Mandal and Sarkar 2012). The core concept of the MOORA is to compute the overall performance of each alternative by taking the difference between the sums of its normalized performances which belongs to cost and benefit criteria (Pérez-Domínguez et al. 2015).

Classical MCDM approaches include crisp measurements with the goal of determining the performance of alternatives with respect to each criterion and importance weights of the criteria. So, the ratings and rankings of the alternatives can be made without any problem. But in real-life decision cases, expressions of DMs related to performance of alternatives and criteria weights can be expressed by linguistic terms comprising vagueness and uncertainty. Fuzzy multi-criteria decision-making (FMCDM) approaches are devised to overcome such incomplete and imprecise information. However, evaluation of DMs may also contain hesitancy about an alternative; DMs can only state the satisfaction and dissatisfaction degree related to the same alternative by using

FMCDM. Intuitionistic fuzzy multi-criteria decision-making (IFMCDM) approaches offer a sound solution to address this problem. Intuitionistic fuzzy sets (IFSs) introduced by Atanassov (1986, 1999) are an extension of fuzzy sets (FSs) developed by Zadeh (1965) and an effective tool that can reflect the hesitancy degree of information in decision systems. Therefore, IFSs can express uncertainty much better than FSs. The IFSs have been applied to various fields such as decision making, logic programming, robotic systems and market prediction.

There are various studies which have implemented IFS theory for MCDM problems in the literature. Peng et al. (2005) proposed the concepts of fundamental fuzzy dominance relationship and developed a new ranking method based on credibility measures. Xu (2007) developed an approach based on intuitionistic fuzzy relation for evaluation of agroecological regions. Xu and Chen (2008) developed the distance and similarity measures to be utilized in MCDM approaches. Sadiq and Tesfamariam (2009) developed IFAHP for environmental decision making by using defuzzification factor. Abdullah et al. (2009) introduced a new AHP using intuitionistic fuzzy numbers (IFNs) without hesitation degree in intuitionistic preference relation. Wang et al. (2011) proposed a new IFAHP approach which synthesizes the eigenvectors of the intuitionistic fuzzy comparison matrixes. Khaleie and Fasanghari (2012) used IFS for selection of software vendor. Liao and Xu (2014) proposed the intuitionistic fuzzy priority derivation method for intuitionistic fuzzy relation implementation in flexible manufacturing systems of a company. Akkaya et al. (2015) integrated fuzzy AHP and fuzzy MOORA for industrial engineering sector choosing problem. Dutta and Guha (2015) introduced preference programming approach for solving IFAHP. Liao and Xu (2015) proposed a new type of aggregation operator named as simple intuitionistic fuzzy weighted geometric operator. Tan et al. (2015) applied new intuitionistic aggregation operators for intuitionistic group decision making. Pei (2015) introduced a novel concept of intuitionistic fuzzy variables to attempt extending the uncertainty theory. Tavana et al. (2016) introduced an integrated method combining IFAHP and SWOT approaches. As seen from the literature, there is no study which combines IFAHP and IFMOORA for decision-making cases.

The beverage sector is one of the most important building blocks of the national economy. At the same time it is the most dynamic sector due to its investment, production and employment structure. The firms in beverage sector should diversify their product portfolio to reach different consumer segments, and they should place the right product in the market. These are key issues for the firms which pursue the goal of acquiring competitive advantage. Several criteria should be considered for deciding on a new product which will be marketed. Therefore, the new product selection problem has a MCDM structure. Some of the criteria considered may be cost type, whereas some of them may be benefit type. In addition, evaluations about selection of a new product are intangible and related to human judgment. These judgments comprise uncertainty because of linguistics terms. In this study, a new hybrid intuitionistic fuzzy decision-making approach is proposed for prioritizing new product alternatives for one of the biggest firms in the beverage industry. To model uncertainty in the judgments of DMs, intuitionistic fuzzy numbers are used in the proposed approach. According to this model, criteria weights are computed by using intuitionistic fuzzy AHP (IFAHP) and considering these weights, ranking related to new product alternatives is determined by using intuitionistic fuzzy MOORA (IFMOORA).

2 Intuitionistic fuzzy concept

Same basic concepts related to IFS are introduced below which will be addressed throughout this study.

Definition 1 (*Intuitionistic fuzzy set*) Let a crisp set X be fixed, and let $A \subset X$ be a fixed set. IFS $\tilde{A}$ in X is an object of the following form:

$$\tilde{A} = \{(x, \mu_A(x), v_A(x) \backslash x \in X)\}$$

where $\mu_A : X \to [0, 1]$ and $v_A : X \to [0, 1]$.$\mu_A(x), v_A(x)$ indicate membership degree and non-membership degree of $x \in X$ in A, respectively. For each $x \in X, 0 \leq \mu_A(x) + v_A(x) \leq 1$. The hesitancy degree of x to A is denoted as $\pi_A(x)$, and it is calculated as $\pi_A(x) = 1 - \mu_A(x) - v_A(x)$.

Definition 2 An intuitionistic preference relation R on the set $X = \{x_1, x_2, \ldots, x_n\}$ is represented by a matrix $= (r_{is})_{n \times n}$, where $r_{is} = \langle (x_i, x_s), \mu(x_i, x_s), v(x_i, x_s) \rangle$ for all $i, s = 1, 2, \ldots, n$. For convenience, we let $r_{is} = (\mu_{is}, v_{is})$, where $\mu_{is} = \mu(x_i, x_s)$ denotes the degree to which the object x_i is preferred to the object x_s. $v_{is} = v(x_i, x_s)$ indicates the degree to which the object x_i is not preferred to the object x_s, and $\pi(x_i, x_s) = 1 - \mu(x_i, x_s) - v(x_i, x_s)$ is interpreted as an indeterminacy degree or hesitancy degree, with the condition

$$\mu_{is}, v_{is} \in [0, 1], \quad \mu_{is} + v_{is} \leq 1, \quad \pi_{is} = 1 - \mu_{is} - v_{is}$$

for all $i, s = 1, 2, \ldots, n$.

Definition 3 Intuitionistic fuzzy arithmetic operations

1.

$$r_{is} \oplus r_{tl} = (\mu_{is} + \mu_{tl} - \mu_{is}\mu_{tl}, v_{is}v_{tl}) \tag{1}$$

2.

$$r_{is} : r_{tl} = \left(\frac{\mu_{is}}{\mu_{tl}}, \frac{v_{is} - v_{tl}}{1 - v_{tl}}\right) \tag{2}$$

3.

$$r_{is} \otimes r_{tl} = (\mu_{is}\mu_{tl}, v_{is} + v_{tl} - v_{is}v_{tl}) \tag{3}$$

Definition 4 (Xu and Liao 2014) An intuitionistic preference relation $R = (r_{is})_{n\times n}$ with $r_{is} = (\mu_{is}, v_{is})$, $(i, s = 1, 2, \ldots, n)$ is multiplicative consistent if

$$\mu_{is} = \begin{cases} 0, & \text{if } (\mu_{it}, \mu_{ts}) \in \{(0,1), (1,0)\} \\ \frac{\mu_{it}\mu_{ts}}{\mu_{it}\mu_{ts} + (1-\mu_{it})(1-\mu_{ts})}, & \text{otherwise for all } i \le t \le s \end{cases}$$

$$v_{is} = \begin{cases} 0, & \text{if } (v_{it}, v_{ts}) \in \{(0,1), (1,0)\} \\ \frac{v_{it}v_{ts}}{v_{it}v_{ts} + (1-v_{it})(1-v_{ts})}, & \text{otherwise for all } i \le t \le s \end{cases}$$

Elements of a perfect multiplicative consistent intuitionistic preference relation $\bar{R} = (\bar{r}_{is})_{n\times n}$ matrix are denoted as $\bar{r}_{is} = (\bar{\mu}_{is}, \bar{v}_{is})$, for $s > i+1$ and calculated by using Eqs. (4) and (5)

$$\bar{\mu}_{is} = \frac{\sqrt[s-i-1]{\prod_{t=i+1}^{s-1} \mu_{it}\mu_{ts}}}{\sqrt[s-i-1]{\prod_{t=i+1}^{s-1} \mu_{it}\mu_{ts}} + \sqrt[s-i-1]{\prod_{t=i+1}^{s-1} (1-\mu_{it})(1-\mu_{ts})}} \quad s > i+1 \tag{4}$$

$$\bar{v}_{is} = \frac{\sqrt[s-i-1]{\prod_{t=i+1}^{s-1} v_{it}v_{ts}}}{\sqrt[s-i-1]{\prod_{t=i+1}^{s-1} v_{it}v_{ts}} + \sqrt[s-i-1]{\prod_{t=i+1}^{s-1} (1-v_{it})(1-v_{ts})}} \quad s > i+1 \tag{5}$$

Then, for $s = i+1$ let $\bar{r}_{is} = r_{is}$ and for $s < i$ let $\bar{r}_{is} = (\bar{v}_{si}, \bar{\mu}_{si})$.

Definition 5 Let R be an intuitionistic preference relation, then R is an acceptable multiplicative consistent intuitionistic preference relation, if

$$d(R, \bar{R}) < \varepsilon$$

where $d(R, \bar{R})$ is the distance measure between the given intuitionistic preference relation R and its corresponding perfect multiplicative consistent intuitionistic preference relation $\bar{R}$, which can be calculated by

$$d\left(R, \bar{R}\right) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n} \sum_{s=1}^{n} (|\bar{\mu}_{is} - \mu_{is}| + |\bar{v}_{is} - v_{is}| + |\bar{\pi}_{is} - \pi_{is}|) \tag{6}$$

and ε is the consistency threshold.

Definition 6 Let importance of kth decision maker $\mathrm{DM}_k = \{\mu_k, v_k, \pi_k\}$ be an IFN. Then, relative importance of h DM, λ_k is computed by Eq. (7).

$$\lambda_k = \frac{\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)}{\sum_{k=1}^{l} \left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)} \tag{7}$$

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

Definition 7 Intuitionistic fuzzy weighted averaging operator (IFWA) proposed by Xu (2007).

$$\mathrm{IFWA}_\lambda \left(r_{is}^k\right) = \left(1 - \prod_{k=1}^{l} \left(1 - \mu_{is}^k\right)^{\lambda_k}, \prod_{k=1}^{l} \left(v_{is}^k\right)^{\lambda_k}\right) \quad (i, s = 1, \ldots, n) \tag{8}$$

Definition 8 Intuitionistic fuzzy averaging operator (IFA) proposed by Xu (2007)

$$\mathrm{IFA}\left(r_{is}\right) = \left(1 - \prod_{i=1}^{n} (1 - \mu_{is})^{1/n}, \prod_{i=1}^{n} (v_{is})^{1/n}\right) \quad (i, s = 1, \ldots, n) \tag{9}$$

3 A new hybrid intuitionistic approach

The proposed hybrid intuitionistic approach is described in the following steps:

Step 1: Determine the set of alternatives $A = \{A_1, A_2, \ldots, A_i, \ldots, A_n\}, (i = 1, \ldots, s, \ldots, n)$ and criteria $C = \left\{C_1, C_2, \ldots, C_j, \ldots, C_m\right\}, (j = 1, \ldots, t, \ldots, m)$. The scale depicted in Table 1 formed by IFNs is used to establish pairwise comparison matrix of criteria and performance value matrix of alternatives.
Step 2: Form the DMs group, $\mathrm{DM} = \{\mathrm{DM}_1, \mathrm{DM}_2, \ldots, \mathrm{DM}_k, \ldots, \mathrm{DM}_l\}, (k = 1, \ldots, l)$ and determine the importance of each DM. Table 1 is used for assigning importance weight to DMs.
Step 3: Construct the intuitionistic preference relation matrixes R_{1j}^k and R_2^k. R_{1j}^k indicates that the performance value matrix of alternatives formed from the kth DM for jth criteria, R_2^k also presents the pairwise comparison matrix of criteria established from kth DM.
where

$$R_{1j}^k = (r_{is})_{n\times n}^k \quad k = 1, .., l \quad j = 1, 2, \ldots, m \text{ with}$$
$$r_{is} = (\mu_{is}, v_{is}) \quad (i, s = 1, 2, \ldots, n)$$
$$R_2^k = (r_{jp})_{m\times m}^k k = 1, \ldots, l \text{ with}$$
$$r_{jp} = \left(\mu_{jp}, v_{jp}\right) (j, p = 1, 2, \ldots, m)$$

Table 1 Conversion of 1–9 scale to 0.1–0.9 scale

1–9 scale	0.1–0.9 scale	Linguistic terms
1/9	0.1	Extremely not important (EXNI)/beginner (B)
1/7	0.2	Very strongly not important (VSNI)
1/5	0.3	Strongly not important (SNI)/practitioner (Pr)
1/3	0.4	Moderately not important (MNI)
1	0.5	Equally important (EI)/proficient (Pt)
3	0.6	Moderately important (MI)
5	0.7	Strongly important (SI)/expert (E)
7	0.8	Very strongly important (VSI)
9	0.9	Extremely important (EXI)/master(M)
Other values between 1/9 and 9	Other values between 0 and 1	Intermediate values used to present compromise

Construct a perfect multiplicative consistent intuitionistic preference relation $\bar{R}_{1j}^k = (\bar{r}_{is})_{n\times n}$ and $\bar{R}_2^k = \left(\bar{r}_{jp}\right)_{m\times m}$. If $R_{1j}^k = (r_{ik})_{n\times n}$ and $R_2^k = \left(r_{jl}\right)_{m\times m}$ are acceptable multiplicative consistent intuitionistic preference relations then

$$d\left(R_{1j}^k, \bar{R}_{1j}^k\right) < \varepsilon \text{ and } d\left(R_2^k, \bar{R}_2^k\right) < \varepsilon$$

where $d\left(R_{1j}^k, \bar{R}_{1j}^k\right)$ is the distance measure between the given intuitionistic preference relation R_{1j}^k and its corresponding perfect multiplicative consistent intuitionistic preference relation $\bar{R}_{1j}^k$ for kth DM. $d\left(R_2^k, \bar{R}_2^k\right)$ is the distance measure between the given intuitionistic preference relation R_2^k and its corresponding perfect multiplicative consistent intuitionistic preference relation $\bar{R}_2^k$ for kth DM, which can be calculated by Eq. (6), and ε is the consistency threshold. Referring to Saaty (1977), the consistency ratio must be less than 0.10 for the acceptable multiplicative preference relation consistency.

Step 4: Compute the relative importance of each DM by using Eq. (7). Then, construct the aggregated intuitionistic fuzzy decision matrixes $\ddot{R}_{1j} = (\ddot{r}_{is})_{n\times n}$ and $\ddot{R}_2 = (\ddot{r}_{jp})_{m\times m}$ by applying IFWA operator given in Eq. (8).

Step 5: Construct the normalized decision-making matrix $\ddot{\ddot{R}}_{1j} = \left(\ddot{\ddot{r}}_{is}\right)_{n\times n}$ and $\ddot{\ddot{R}}_2 = \left(\ddot{\ddot{r}}_{jp}\right)_{m\times m}$. Intuitionistic arithmetic operations in Eqs. (1) and (2) are used to form $\ddot{\ddot{R}}_{1j}$ and $\ddot{\ddot{R}}_2$.

Step 6: Construct the performance value of alternatives matrix $\tilde{R} = [W_{11}, W_{12}, \ldots, W_{1m}]$. $\tilde{R}$ matrix is formed by W_{1j} $j = 1, 2, \ldots, m$. W_{1j} vectors constructed for each criterion are computed with the average of normalized matrix rows as in Eq. (9). Criteria weight vector $\boldsymbol{W}_2 = [W_{21}, W_{22}, \ldots, W_{2m}]^t$ is established, and aggregated weighted intuitionistic fuzzy decision matrix R' is constructed by

$$R' = (r'_{is})_{n\times m} = [W_{21}\times W_{11}, W_{22}\times W_{12}, \ldots, W_{2m}\times W_{1m}] \tag{10}$$

where $r'_{is} = \left(\mu'_{is}, \upsilon'_{is}\right)$. Arithmetic operators Eqs. (1) and (3) are used for constructing the aggregated weighted intuitionistic fuzzy decision matrix R'.

Step 7: Compute the sum of costs and benefits by using Eq. (1) for each alternative. The criteria under consideration are examined by dividing them into two groups as benefit (BN_i) and cost (C_i), $(i = 1, \ldots, n)$ as in Eqs. (11) and (12).

$$\mathrm{BN}_i = \sum\nolimits_{j=1}^{g} \left(\mu'_{is}, \upsilon'_{is}\right)_j = \left(\mu'_{\mathrm{BN}_i}, \upsilon'_{\mathrm{BN}_i}\right), \quad i = 1, \ldots, n \tag{11}$$

$$C_i = \sum\nolimits_{j=g+1}^{m} \left(\mu'_{is}, \upsilon'_{is}\right)_j = \left(\mu'_{C_i}, \upsilon'_{C_i}\right), \quad i = 1, \ldots, n \tag{12}$$

where in m criteria, g indicates the number of benefit criteria $(i = 1, 2, \ldots, g)$ and remaining $m - g$ denotes the number of cost criteria $(i = g + 1, g + 2, \ldots, m)$.

Step 8: Defuzzify the sum of benefits and costs by using Eqs. (13) and (14), respectively, for each alternative.

$$\mathrm{Def}_i(\mathrm{BN}) = \frac{1 - \upsilon'_{\mathrm{BN}_i}}{1 - \pi'_{\mathrm{BN}_i}}, \quad i = 1, \ldots, n \tag{13}$$

$$\mathrm{Def}_i(C) = \frac{1 - \upsilon'_{C_i}}{1 - \pi'_{C_i}}, \quad i = 1, \ldots, n \tag{14}$$

Step 9: Compute the contribution of each alternative by using Eq. (15) and rank the alternatives according to descending order of Cont_i.

Table 2 Pairwise comparison matrix of criteria R_2^1 for DM_1

	IC $\{\mu_1, v_1, \pi_1\}$	CC $\{\mu_2, v_2, \pi_2\}$	ERMS $\{\mu_3, v_3, \pi_3\}$	CP $\{\mu_4, v_4, \pi_4\}$	SP $\{\mu_5, v_5, \pi_5\}$
IC	{0.5, 0.5, 0.0}	{0.6, 0.2, 0.2}	{0.6, 0.2, 0.2}	{0.7, 0.1, 0.2}	{0.7, 0.1, 0.2}
CC	{0.2, 0.6, 0.2}	{0.5, 0.5, 0.0}	{0.6, 0.2, 0.2}	{0.7, 0.3, 0.0}	{0.6, 0.2, 0.2}
ERMS	{0.2, 0.6, 0.2}	{0.2, 0.6, 0.2}	{0.5, 0.5, 0.0}	{0.6, 0.2, 0.2}	{0.6, 0.2, 0.2}
CP	{0.1, 0.7, 0.2}	{0.3, 0.7, 0.0}	{0.2, 0.6, 0.2}	{0.5, 0.5, 0.0}	{0.6, 0.2, 0.2}
SP	{0.1, 0.7, 0.2}	{0.2, 0.6, 0.2}	{0.2, 0.6, 0.2}	{0.2, 0.6, 0.2}	{0.5, 0.5, 0.0}

Table 3 Pairwise comparison matrix of criteria R_2^2 for DM_2

	IC $\{\mu_1, v_1, \pi_1\}$	CC $\{\mu_2, v_2, \pi_2\}$	ERMS $\{\mu_3, v_3, \pi_3\}$	CP $\{\mu_4, v_4, \pi_4\}$	SP $\{\mu_5, v_5, \pi_5\}$
IC	{0.5, 0.5, 0.0}	{0.4, 0.2, 0.4}	{0.5, 0.2, 0.3}	{0.7, 0.1, 0.2}	{0.7, 0.2, 0.1}
CC	{0.2, 0.4, 0.4}	{0.5, 0.5, 0.0}	{0.8, 0.2, 0.0}	{0.8, 0.1, 0.1}	{0.9, 0.1, 0.0}
ERMS	{0.2, 0.5, 0.3}	{0.2, 0.8, 0.0}	{0.5, 0.5, 0.0}	{0.7, 0.1, 0.2}	{0.8, 0.1, 0.1}
CP	{0.1, 0.7, 0.2}	{0.1, 0.8, 0.1}	{0.1, 0.7, 0.2}	{0.5, 0.5, 0.0}	{0.8, 0.1, 0.1}
SP	{0.2, 0.7, 0.1}	{0.1, 0.9, 0.0}	{0.1, 0.8, 0.1}	{0.1, 0.8, 0.1}	{0.5, 0.5, 0.0}

$$\mathrm{Cont}_i = \mathrm{Def}_i(\mathrm{BN}) - \mathrm{Def}_i(C) \tag{15}$$

The Cont_i values may be positive or negative. As a result, an ordinal ranking of Cont_i represents the final contribution of each alternative. The highest Cont_i demonstrates the best alternative.

4 Implementation of the proposed approach for new product selection

This study was carried out in one of the biggest companies in the beverage sector in Turkey, which wanted to produce a new product for increasing its market share. For this purpose, the company determined four new product alternatives as carbonated beverage, pure natural fruit juice, mineral water and herbal tea. These alternatives were determined according to the product portfolio and market shares of the opponents. For evaluation and making a selection among these alternatives, 5 criteria were identified among the opinions of senior executives of the firm. These criteria were investment cost, competitive conditions, ease of raw material supply, consumer preferences and sale price. The executives set the objective of decreasing some of the criteria values and increasing the rest. In this context, the considered 5 criteria were examined in two different structures as benefit-type criteria and cost-type criteria. Among the 5 criteria, consumer preferences, sale price and ease of raw material supply were the benefit criteria. Investment cost and competitive conditions were the cost criteria. Following the interviews with the company executives, two DMs were selected for constructing the decision matrixes through their own opinions. As DMs had different levels of experience and knowledge, their opinions were weighted in decision-making process.

Step 1: The set of alternatives is,

$$A = \{\mathrm{CB}, \mathrm{PNFJ}, \mathrm{MW}, \mathrm{HT}\}$$

where A_1 is carbonated beverage (CB), A_2 pure natural fruit juice (PNFJ), A_3 mineral water (MW) and A_4 herbal tea (HT).

The set of criteria is,

$$C = \{\mathrm{IC}, \mathrm{CC}, \mathrm{ERMS}, \mathrm{CP}, \mathrm{SP}\}$$

where C_1 is investment cost (IC), C_2 competitive conditions (CC), C_3 ease of raw material supply (ERMS), C_4 consumer preferences (CP) and C_5 sales price (SP).

Step 2: Two DMs, DM_1 and DM_2, formed the expert group.

$$\mathrm{DM} = \{\mathrm{DM}_1, \mathrm{DM}_2\}$$

Step 3: The intuitionistic preference relation matrices R_2^1 and R_2^2 were formed by DM_1 and DM_2 separately. These matrices are depicted in Tables 2 and 3.

The perfect multiplicative consistent intuitionistic preference relation matrixes $\bar{R}_2^1$ and $\bar{R}_2^2$ were formed by DM_1 and DM_2 separately. These matrixes are given in Tables 4 and 5.

Distance measures $d(R_{1j}^k, \bar{R}_{1j}^k)$, $j = 1, \ldots, 5, k = 1, 2$ and $d(R_2^k, \bar{R}_2^k)$, $k = 1, 2$ are shown in Table 6.

As seen from Table 6 all distance measures $d(R_{1j}^k, \bar{R}_{1j}^k) < \varepsilon j = 1, \ldots, 5, k = 1, 2$ and $d(R_2^k, \bar{R}_2^k) < \varepsilon k = 1, 2$ are less than $\varepsilon = 0, 1$.

Step 4: The importance of each DM is determined using Table 1. Therefore, DM_1 is evaluated as an "Expert" and DM_2 is assessed as a "Proficient." These evaluations are expressed as IFNs given below.

Table 4 Perfect multiplicative consistent intuitionistic preference relation matrix $\bar{R}_2^1$ for DM_1

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
IC	{0.50, 0.50, 0.00}	{0.60, 0.20, 0.20}	{0.60, 0.20, 0.20}	{0.74, 0.08, 0.19}	{0.81, 0.01, 0.18}
CC	{0.20, 0.60, 0.20}	{0.50, 0.50, 0.00}	{0.60, 0.20, 0.20}	{0.60, 0.20, 0.20}	{0.74, 0.08, 0.19}
ERMS	{0.20, 0.60, 0.20}	{0.20, 0.60, 0.20}	{0.50, 0.50, 0.00}	{0.60, 0.20, 0.20}	{0.60, 0.20, 0.20}
CP	{0.08, 0.74, 0.19}	{0.20, 0.60, 0.20}	{0.20, 0.60, 0.20}	{0.50, 0.50, 0.0}	{0.60, 0.20, 0.20}
SP	{0.01, 0.81, 0.18}	{0.08, 0.74, 0.19}	{0.20, 0.60, 0.20}	{0.20, 0.60, 0.20}	{0.50, 0.50, 0.00}

Table 5 Perfect multiplicative consistent intuitionistic preference relation matrix $\bar{R}_2^2$ for DM_2

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
IC	{0.50, 0.50, 0.00}	{0.40, 0.20, 0.40}	{0.62, 0.20, 0.18}	{0.71, 0.03, 0.26}	{0.94, 0.00, 0.06}
CC	{0.20, 0.40, 0.40}	{0.50, 0.50, 0.00}	{0.80, 0.20, 0.00}	{0.75, 0.14, 0.10}	{0.94, 0.02, 0.04}
ERMS	{0.20, 0.62, 0.18}	{0.20, 0.80, 0.00}	{0.50, 0.50, 0.00}	{0.70, 0.10, 0.20}	{0.75, 0.10, 0.15}
CP	{0.03, 0.71, 0.26}	{0.14, 0.75, 0.10}	{0.10, 0.70, 0.20}	{0.50, 0.50, 0.00}	{0.80, 0.10, 0.10}
SP	{0.00, 0.94, 0.06}	{0.02, 0.94, 0.04}	{0.10, 0.75, 0.15}	{0.10, 0.80, 0.10}	{0.50, 0.50, 0.00}

Table 6 Distance measures $d(R_{1j}^k, \bar{R}_{1j}^k)$, $j = 1, \ldots, 5, k = 1, 2$ *and* $d(R_2^k, \bar{R}_2^k)$, $k = 1, 2$

k	j	$d(R_{1j}^k, \bar{R}_{1j}^k)$	$d(R_2^k, \bar{R}_2^k)$
1	1	0.074	0.080
	2	0.088	
	3	0.088	
	4	0.098	
	5	0.083	
2	1	0.061	0.098
	2	0.071	
	3	0.074	
	4	0.071	
	5	0.076	

$$DM_1 = \{\mu_1, \upsilon_1, \pi_1\} = \{0, 7, 0, 2, 0, 1\}$$
$$DM_2 = \{\mu_2, \upsilon_2, \pi_2\} = \{0, 5, 0, 4, 0, 1\}$$

Then, the corresponding weights of DM_1 and DM_2 are computed as $\lambda_1 = 0.583$ and $\lambda_2 = 0.417$, respectively.

Table 8 Column summation of aggregated intuitionistic fuzzy decision matrix $\ddot{R}_2$

	$\{\mu_1, \upsilon_1, \pi_1\}$
IC	{0.7532, 0.0690, 0.1777}
CC	{0.8763, 0.0356, 0.0882}
ERMS	{0.9536, 0.0087, 0.0378}
CP	{0.9887, 0.0010, 0.0104}
SP	{0.9977, 0.0002, 0.0028}

Aggregated intuitionistic fuzzy decision matrix $\ddot{R}_2$ is given in Table 7.

Step 5: Summation of each column in aggregated intuitionistic fuzzy decision matrix $\ddot{R}_2$ given as Table 7 is computed by using summation operator in Eq. (1), and results of column summations are depicted in Table 8.

In addition, each value in Table 7 is divided by summation of each criterion in Table 8 by utilizing dividing operator in Eq. (2). Thus, normalized decision matrix $\dddot{R}_2$ given in Table 9 is constructed.

Table 7 Aggregated intuitionistic fuzzy decision matrix $\ddot{R}_2$

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
IC	{0.50, 0.50, 0.00}	{0.53, 0.20, 0.27}	{0.56, 0.20, 0.24}	{0.75, 0.10, 0.06}	{0.70, 0.13, 0.17}
CC	{0.20, 0.51, 0.29}	{0.50, 0.50, 0.00}	{0.70, 0.20, 0.10}	{0.75, 0.19, 0.06}	{0.78, 0.15, 0.07}
ERMS	{0.20, 0.56, 0.24}	{0.20, 0.68, 0.12}	{0.50, 0.50, 0.00}	{0.65, 0.15, 0.20}	{0.70, 0.15, 0.15}
CP	{0.10, 0.70, 0.20}	{0.22, 0.74, 0.04}	{0.16, 0.64, 0.20}	{0.50, 0.50, 0.0}	{0.70, 0.15, 0.15}
SP	{0.14, 0.70, 0.16}	{0.16, 0.71, 0.13}	{0.16, 0.68, 0.16}	{0.16, 0.68, 0.16}	{0.50, 0.50, 0.00}

Table 9 Normalized decision matrix $\ddot{\tilde{R}}_2$

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
IC	{0.00, 1.00, 0.00}	{0.60, 0.17, 0.23}	{0.59, 0.19, 0.22}	{0.71, 0.10, 0.19}	{0.70, 0.13, 0.16}
CC	{0.27, 0.52, 0.26}	{0.00,1.00, 0.00}	{0.73, 0.19, 0.07}	{0.76, 0.19, 0.06}	{0.78, 0.15, 0.07}
ERMS	{0.27, 0.52, 0.21}	{0.23, 0.66, 0.11}	{0.00, 1.00, 0.00}	{0.65, 0.15, 0.20}	{0.70, 0.15, 0.15}
CP	{0.13, 0.68, 0.19}	{0.25, 0.73, 0.02}	{0.17, 0.64, 0.20}	{0.00,1.00, 0.00}	{0.70, 0.15, 0.15}
SP	{0.19, 0.13, 0.13}	{0.18, 0.70, 0.12}	{0.17, 0.67, 0.16}	{0.16, 0.68, 0.16}	{0.00,1.00, 0.00}

Table 10 Performance value of alternatives matrix $\tilde{R}$

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
CB	{0.62, 0.22, 0.16}	{0.60, 0.26, 0.14}	{0.60, 0.25, 0.14}	{0.48, 0.38, 0.14}	{0.50, 0.30, 0.20}
PNFJ	{0.42, 0.43, 0.14}	{0.45, 0.28, 0.27}	{0.47, 0.44, 0.08}	{0.53, 0.33, 0.15}	{0.61, 0.23, 0.16}
MW	{0.20, 0.69, 0.11}	{0.32, 0.52, 0.16}	{0.39, 0.45, 0.16}	{0.50, 0.38, 0.11}	{0.38, 0.50, 0.11}
PT	{0.36, 0.50, 0.14}	{0.19, 0.69, 0.12}	{0.18, 0.73, 0.09}	{0.18, 0.74, 0.07}	{0.16, 0.76, 0.08}

Table 11 Criteria weight vector W_2

	$\{\mu_1, \upsilon_1, \pi_1\}$
IC	{0.57, 0.21, 0.21}
CC	{0.60, 0.30, 0.10}
ERMS	{0.43, 0.38, 0.19}
CP	{0.31, 0.54, 0.15}
SP	{0.14, 0.74, 0.12}

Step 6: Performance value of alternatives matrix $\tilde{R} = [W_{11}, W_{12}, \ldots, W_{15}]$ is given in Table 10 and criteria weight vector $W_2; [W_{21}, W_{22}, \ldots, W_{25},]^t$ is presented in Table 11.

Aggregated weighted intuitionistic fuzzy decision matrix R' is presented in Table 12.

Step 7. Sum of benefits (BN_i) and cost (C_i) criteria is given in Table 13.

Step 8: Defuzzified values of BN_i and C_i are presented in Table 14.

As seen from Table 14, mineral water (MW) is the best alternative since it has the highest Cont_i value.

Table 13 BN_i and C_i for each alternative

	BN_i $\{\mu_1, \upsilon_1, \pi_1\}$	C_i $\{\mu_1, \upsilon_1, \pi_1\}$
CB	{0.37, 0,38, 0.25}	{0.62, 0,15, 0.23}
PNFJ	{0.33, 0.45, 0.21}	{0.50, 0.22, 0.28}
MW	{0.30, 0.47, 0.23}	{0.32, 0.44, 0.24}
PT	{0.13, 0.74, 0.14}	{0.31, 0.45, 0.24}

Table 14 Defuzzified values of BN_i, C_i and rankings

	Def_i (BN)	Def_i (C)	Cont_i	Rank
CB	0.49	0.69	−0.19	**3**
PNFJ	0.45	0.61	−0.16	**2**
MW	0.43	0.45	−0.02	**1**
PT	0.23	0.45	−0.21	**4**

5 Conclusion

The new hybrid intuitionistic approach combining AHP and MOORA is proposed in this study. The relative importance

Table 12 Aggregated weighted intuitionistic fuzzy decision matrix R'

	IC $\{\mu_1, \upsilon_1, \pi_1\}$	CC $\{\mu_2, \upsilon_2, \pi_2\}$	ERMS $\{\mu_3, \upsilon_3, \pi_3\}$	CP $\{\mu_4, \upsilon_4, \pi_4\}$	SP $\{\mu_5, \upsilon_5, \pi_5\}$
CB	{0.36, 0,39, 0.26}	{0.36, 0.48, 0.16}	{0.26, 0.53, 0.20}	{0.15, 0.72, 0.14}	{0.07, 0.81, 0.11}
PNFJ	{0.24, 0.55, 0.20}	{0.27, 0.50, 0.23}	{0.20, 0.65, 0.14}	{0.16, 0.69, 0.15}	{0.09, 0.80, 0.12}
MW	{0.11, 0.76, 0.13}	{0.19, 0.67, 0.14}	{0.17, 0.66, 0.17}	{0.15, 0.72, 0.13}	{0.05, 0.87, 0.08}
PT	{0.20, 0.61, 0.19}	{0.11, 0.78, 0.10}	{0.08, 0.83, 0.09}	{0.06, 0.88, 0.06}	{0.02, 0.94, 0.04}

of DMs, the weightings of the criteria and the performance values of alternatives for the criteria are presented in terms of IFNs in the proposed approach. Uncertainty, vagueness and hesitation of the subjective judgments of DMs can be described more comprehensively by using IFNs. The criteria weights are determined by implementing IFAHP, and rankings of the new product alternatives are obtained by IFMOORA. A numerical example related to new product selection is also illustrated to demonstrate that the proposed intuitionistic approach is capable of determining rankings of new product alternatives in a flexible manner.

The main advantages of the proposed approach are given as follows:

- Since the proposed approach is quite comprehensive in nature, it can be successfully applied to any decision-making problem.
- The proposed approach provides a solution of group decision making by aggregating different DM judgments by considering their relative importance.
- MOORA is a powerful MCDM approach because of its easy implementation using both benefit- and cost-type criteria.
- AHP is a commonly used MCDM approach, and it provides a more efficient tool to model interaction among decision criteria.
- The proposed approach is a valid MCDM approach taking into account the consistency degrees for all matrices related to criteria weights and performance values of alternatives matrices.
- Ranking orders obtained in this study were derived through this new approach which assures that different alternatives are ranked in different positions. It is shown that the proposed approach has a great distinguishing capability.

For the future studies, different MCDM approaches can be combined in an intuitionistic environment to work out new hybrid approaches to deal with real-life decision-making problems. Additionally, the proposed algorithm can be performed in different decision-making cases such as equipment selection and personnel selection.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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