Transactions on Fuzzy Sets and Systems (TFSS)
URL: https://sanad.iau.ir/journal/tfss/
Online ISSN: 2821-0131
Vol.x, No.x, (year), pp-pp
DOI: http://doi.org/ 10.xxxxx/tfss.2022.yyyyy.zzzz

Article Type: Original Research Article
(Journal Pre-proof)

A novel method of decision-making based on intuitionistic fuzzy set theory

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Abstract. The notions of hesitation margin and non-membership function were not taken into account in fuzzy set theory, but they were included in intuitionistic fuzzy sets together with the membership function. Additionally, it should be noted that the intuitionistic fuzzy set is represented as a fuzzy set extension that includes a hesitation margin and accommodates both membership and non-membership functions. The sum of the membership function and the non-membership function in intuitionistic fuzzy set theory has a value between 0 and 1. We present a novel similarity measure method on an intuitionistic fuzzy set in this study. The suggested action can provide a precise outcome. The application section examines a real-world issue of choosing the best course of action among n options based on m criteria. A fictitious case study is created along with the method's algorithm.

AMS Subject Classification 2020: 90C70; 03F55.
Keywords and Phrases: Intuitionistic fuzzy sets, Modal operators, Measure of similarity, Optimal Solution.

1 Introduction

In 1965, L.A. Zadeh [18] created and introduced the idea of a fuzzy set. Eighteen years later, in 1983, Atanassov [1] introduced the concept of intuitionistic fuzzy sets as an extension of fuzzy sets. The fundamental distinction between these two ideas is that, in intuitionistic fuzzy set theory, hesitation margin is taken into account in addition to both membership function and non-membership function. In fuzzy set theory, only the membership function is taken into account. Scholars and researchers [7, 8, 10, 13, 14, 17] are exerting great effort to advance and refine this field.
The notion of modal operators were first introduced by Atanassov [2] in 1986. Modal operators ($\Box, \Diamond$) defined over the set of all intuitionistic fuzzy sets that convert every intuitionistic fuzzy set into a fuzzy set. Atanassov [2] also introduced the operators ($\boxplus, \boxtimes$) in intuitionistic fuzzy set. More relations and properties on these operators are regorously studied in [3, 5, 6, 7, 8, 10]. The second extension of the operators $\boxplus$ and $\boxtimes$ are introduced by K. Dencheva [12].
There are circumstances in which fuzzy set theory is not the best fit and should be replaced with intuitionistic fuzzy set theory. intuitionistic fuzzy set theory has been researched as a helpful resource for decision-making issues, logic programming, etc. In this work, we establish a similarity measure between two intuitionistic fuzzy sets A and B of a set E and apply it to a problem involving decision-making. The issue under consideration is choosing the best course of action from n options based on m criteria in cases when the information at hand is intuitionistic fuzzy.

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Received: dd mmmm yyyy; **Revised**: dd mmmm yyyy; **Accepted**: dd mmmm yyyy; **Available Online**: dd mmmm yyyy; **Published Online**: dd mmmm yyyy.

How to cite: Jaydip Bhattacharya. A novel method of decision-making based on intuitionistic fuzzy set theory. *Transactions on Fuzzy Sets and Systems.* year; vol(no): pp-pp. DOI: http://doi.org/10.xxxxx/xxxx.yyyyy.zzzz

2 Preliminary Concepts

Throughout this study, intuitionistic fuzzy set and fuzzy set are denoted by IFS and FS respectively.

Definition 2.1. [2] *Let X be a nonempty set. An intuitionistic fuzzy set A in X is an object having the form A=$\{\langle x, \mu_A(x), \nu_A(x)\rangle : x \in X\}$,where the functions $\mu_A, \nu_A : x \to [0,1]$define respectively, the degree of membership and degree of non-membership of the element $x \in X$ to the set A, which is a subset of X, and for every element $x \in X$, $0 \leq \mu_A(x) + \nu_A(x) \leq 1$.*
Furthermore, we have $\pi_A(x)$= 1-$\mu_A(x)$-$\nu_A(x)$ called the intuitionistic fuzzy set index or hesitation margin of x in A. $\pi_A(x)$ is the degree of indeterminacy of $x \in X$ to the IFS A and $\pi_A(x) \in [0,1]$ that is $\pi_A : x \to [0,1]$ and $0 \leq \pi_A(x) \leq 1$ for every $x \in X$.
$\pi_A(x)$ expresses the lack of knowledge of whether x belongs to IFS A or not.

Definition 2.2. [2] *Let X be a nonempty set. If A is an IFS drawn from X, then the modal operators which are also termed as necessity and possibility operators can be defined as*

1. $\Box A$= $\{\langle x, \mu_A(x), 1-\mu_A(x)\rangle : x \in X\}$

2. $\Diamond A$= $\{\langle x, 1-\nu_A(x), \nu_A(x)\rangle : x \in X\}$

For a proper IFS, $\Box A \subset A \subset \Diamond A$ and $\Box A \neq A \neq \Diamond A$.

Definition 2.3. [2] *Let X be a nonempty set. If A is an IFS drawn from X, then,*

1. $\boxplus A$= $\{\langle x, \frac{\mu_A(x)}{2}, \frac{\nu_A(x)+1}{2}\rangle : x \in X\}$

2. $\boxtimes A$= $\{\langle x, \frac{\mu_A(x)+1}{2}, \frac{\nu_A(x)}{2}\rangle : x \in X\}$

For a proper IFS, $\boxplus A \subset A \subset \boxtimes A$ and $\boxplus A \neq A \neq \boxtimes A$.

Definition 2.4. [4] *Let $\alpha \in [0,1]$ and let A be an IFS. Then the first extension of the operators $\boxplus$ and $\boxtimes$ can be defined as*

1. $\boxplus_\alpha A$= $\{\langle x, \alpha\mu_A(x), \alpha\nu_A(x) + 1 - \alpha\rangle : x \in X\}$

2. $\boxtimes_\alpha A$= $\{\langle x, \alpha\mu_A(x) + 1 - \alpha, \alpha\nu_A(x)\rangle : x \in X\}$.

Definition 2.5. [12] *Let $\alpha, \beta, \alpha+\beta \in [0,1]$ and let A be an IFS. Then the second extension of the operators $\boxplus$ and $\boxtimes$ can be defined as*

1. $\boxplus_{\alpha,\beta} A$= $\{\langle x, \alpha\mu_A(x), \alpha\nu_A(x) + \beta\rangle : x \in X\}$

2. $\boxtimes_{\alpha,\beta} A = \{\langle x, \alpha\mu_A(x) + \beta, \alpha\nu_A(x)\rangle : x \in X\}$.

Definition 2.6. [11] *Let us consider two IFSs A and B of a fixed set E. The similarity measure between A and B denoted by $s(A, B)$ is defind by an interval $[e_{AB}, e'_{AB}]$, where*

$$e_{AB} = \max \min_{x \in E} \{\mu_A(x), \mu_B(x)\}$$

$$e'_{AB} = \max \min_{x \in E} \{\mu_A(x) + \pi_A(x), \mu_B(x) + \pi_B(x)\}$$

Here e_{AB} indicates the minimum amount of similarity and e'_{AB} indicates the maximum amount of similarity between A and B.
It can be noted that

1. $s(A, B) \subseteq [0, 1]$.

2. $s(A, B) = s(B, A)$.

3. *If $\pi_A(x) = 0$ and $\pi_B(x) = 0, \forall x \in E$, then $e_{AB} = e'_{AB}$.*

Moreover it may be mentioned that $e_{AB} \neq e'_{AB}$ for $A = B$.
.

Proposition 2.7. [11] *Let A and B be two IFSs and $s(A, B) = [e_{AB}, e'_{AB}]$, then*

1. $s(\Box A, \Box B) = e_{AB}$,

2. $s(\Diamond A, \Diamond B) = e'_{AB}$.

3 Measure of Similarity between Intuitionistic Fuzzy Sets

This section provides an example-based explanation of Definition 2.6, leading to some intriguing findings.

Example 3.1. Consider two IFSs A and B of $E = \{x_1, x_2, x_3, x_4\}$ given by the following table:

x	μ_A	ν_A	μ_B	ν_B
x_1	0.65	0.26	0.72	0.18
x_2	0.32	0.46	0.56	0.38
x_3	0.80	0.12	0.48	0.42
x_4	0.70	0.25	0.83	0.12

Using Definition 2.6, we have $e_{AB} = 0.70$, $e'_{AB} = 0.75$ and hence similarity measure between A and B is [0.70, 0.75].

Theorem 3.2. *Let A and B be two IFSs and $s(A,B) = [e_{AB}, e'_{AB}]$, then*

1. $s(\boxplus A, \boxplus B) = [\frac{1}{2}e_{AB},\ \frac{1}{2}e'_{AB}\ ]$,

2. $s(\boxtimes A, \boxtimes B) = [\frac{1}{2}e_{AB} + \frac{1}{2},\ \frac{1}{2}e'_{AB} + \frac{1}{2}]$.

Proof. 1. L.H.S $= \max\min_{x\in E}\{\frac{\mu_A(x)}{2}, \frac{\mu_B(x)}{2}\}, \max\min_{x\in E}\{\frac{\mu_A(x)}{2} + \frac{\pi_A(x)}{2}, \frac{\mu_B(x)}{2} + \frac{\pi_B(x)}{2}\}$
$= \max\min_{x\in E}\frac{1}{2}\{\mu_A(x), \mu_B(x)\}, \max\min_{x\in E}\frac{1}{2}\{\mu_A(x)+\pi_A(x), \mu_B(x)+\pi_B(x)\}$
$= \frac{1}{2}\max\min_{x\in E}\{\mu_A(x), \mu_B(x)\}, \frac{1}{2}\max\min_{x\in E}\{\mu_A(x)+\pi_A(x), \mu_B(x)+\pi_B(x)\}$
$= [e_{AB}, e'_{AB}]$
Similarly the other statement can be proved.

□

Theorem 3.3. *Let $\alpha \in [0,1]$ and let A & B be two IFSs. If $s(A,B) = [e_{AB}, e'_{AB}]$, then*

1. $s(\boxplus_\alpha A, \boxplus_\alpha B) = [\alpha e_{AB},\ \alpha e'_{AB}]$,

2. $s(\boxtimes_\alpha A, \boxtimes_\alpha B) = [\alpha e_{AB} + 1 - \alpha,\ \alpha e'_{AB} + 1 - \alpha\ ]$.

Proof. 1. L.H.S $= \max\min_{x\in E}\{\alpha\mu_A(x), \alpha\mu_B(x)\}, \max\min_{x\in E}\{\alpha\mu_A(x)+\alpha\pi_A(x), \alpha\mu_B(x)+\alpha\pi_B(x)\}$
$= \alpha\max\min_{x\in E}\{\mu_A(x), \mu_B(x)\}, \alpha\max\min_{x\in E}\{\mu_A(x)+\pi_A(x), \mu_B(x)+\pi_B(x)\}$
$= [\alpha e_{AB}, \alpha e'_{AB}]$
Similarly the other statement can be proved.
□

Theorem 3.4. *Let A & B be two IFSs with $\alpha, \beta \in [0,1]$ and $\alpha + \beta = 1$. If $s(A,B) = [e_{AB}, e'_{AB}]$, then*

1. $s(\boxplus_{\alpha,\beta} A, \boxplus_{\alpha,\beta} B) = [\alpha e_{AB},\ \alpha e'_{AB}]$,

2. $s(\boxtimes_{\alpha,\beta} A, \boxtimes_{\alpha,\beta} B) = [\alpha e_{AB} + \beta,\ \alpha e'_{AB} + \beta\ ]$.

Proof. Similar to the Theorem 3.3 □
The above theorem is not true for $\alpha, \beta \in [0,1]$ and $\alpha + \beta < 1$.
If we consider the example 3.1 with $\alpha = 0.7$ and $\beta = 0.1$ then it is found that $s(\boxplus_{\alpha,\beta} A, \boxplus_{\alpha,\beta} B) = [0.49,\ 0.725]$ $\neq [\alpha e_{AB},\ \alpha e'_{AB}]$ and $s(\boxtimes_{\alpha,\beta} A, \boxtimes_{\alpha,\beta} B) = [0.59,\ 0.825] \neq [\alpha e_{AB} + \beta,\ \alpha e'_{AB} + \beta\ ]$.

Example 3.5. Consider the IFSs A and B of E as in example 3.1. To find $s(\Box A, \Box B)$ and $s(\Diamond A, \Diamond B)$ we have to construct the new tables as

x	μ_A	$1-\mu_A$	μ_B	$1-\mu_B$
x_1	0.65	0.35	0.72	0.28
x_2	0.32	0.68	0.56	0.44
x_3	0.80	0.20	0.48	0.52
x_4	0.70	0.30	0.83	0.17

Hence $s(\Box A, \Box B) = 0.70 = e_{AB}$.
And

x	$1-\nu_A$	ν_A	$1-\nu_B$	ν_B
x_1	0.74	0.26	0.82	0.18
x_2	0.54	0.46	0.62	0.38
x_3	0.88	0.12	0.58	0.42
x_4	0.75	0.25	0.88	0.12

Hence $s(\Diamond A, \Diamond B) = 0.75 = e'_{AB}$.

Example 3.6. Consider the IFSs A and B of E as in example 3.1. To find $s(\boxplus A, \boxplus B)$ and $s(\boxtimes A, \boxtimes B)$ we have to construct the new tables as

x	$\frac{\mu_A(x)}{2}$	$\frac{\nu_A(x)+1}{2}$	$\frac{\mu_B(x)}{2}$	$\frac{\nu_B(x)+1}{2}$
x_1	0.325	0.63	0.36	0.59
x_2	0.16	0.73	0.28	0.69
x_3	0.40	0.56	0.24	0.71
x_4	0.35	0.625	0.415	0.56

Hence $s(\boxplus A, \boxplus B) = [0.35,\, 0.375] = [\frac{e_{AB}}{2}, \frac{e'_{AB}}{2}]$.
And

x	$\frac{\mu_A(x)+1}{2}$	$\frac{\nu_A(x)}{2}$	$\frac{\mu_B(x)+1}{2}$	$\frac{\nu_B(x)}{2}$
x_1	0.825	0.13	0.86	0.09
x_2	0.66	0.23	0.78	0.19
x_3	0.90	0.06	0.74	0.21
x_4	0.85	0.125	0.915	0.06

Hence $s(\boxtimes A, \boxtimes B) = [0.85,\, 0.875] = [\frac{e_{AB}}{2} + \frac{1}{2}, \frac{e'_{AB}}{2} + \frac{1}{2}]$.

Example 3.7. Consider the IFSs A and B of E as in example 3.1. To find $s(\boxplus_\alpha A, \boxplus_\alpha B)$ we construct the table with $\alpha = 0.7$.

x	$\alpha\mu_A(x)$	$\alpha\nu_A(x)+1-\alpha$	$\alpha\mu_B(x)$	$\alpha\nu_B(x)+1-\alpha$
x_1	0.455	0.482	0.504	0.426
x_2	0.224	0.622	0.392	0.566
x_3	0.56	0.384	0.336	0.594
x_4	0.49	0.475	0.581	0.384

Hence $s(\boxplus_\alpha A, \boxplus_\alpha B) = [0.49,\, 0.525] = [\alpha e_{AB}, \alpha e'_{AB}]$.
In a similar manner, we create the table that follows to locate $s(\boxtimes_\alpha A, \boxtimes_\alpha B)$.

x	$\alpha\mu_A(x)+1-\alpha$	$\alpha\nu_A(x)$	$\alpha\mu_B(x)+1-\alpha$	$\alpha\nu_B(x)$
x_1	0.755	0.182	0.804	0.126
x_2	0.524	0.322	0.692	0.266
x_3	0.86	0.084	0.636	0.294
x_4	0.79	0.175	0.881	0.084

Hence $s(\boxtimes_\alpha A, \boxtimes_\alpha B) = [0.79,\, 0.825] = [\alpha e_{AB} + 1 - \alpha, \alpha e'_{AB} + 1 - \alpha]$.

Example 3.8. Consider the IFSs A and B of E as in example 3.1. To find $s(\boxplus_{\alpha,\beta}A, \boxplus_{\alpha,\beta}B)$ we construct the table taking $\alpha = 0.7$ and $\beta = 0.3$ with $\alpha, \beta \in [0, 1]$ and $\alpha + \beta = 1$.

x	$\alpha\mu_A(x)$	$\alpha\nu_A(x) + \beta$	$\alpha\mu_B(x)$	$\alpha\nu_B(x) + \beta$
x_1	0.455	0.482	0.504	0.426
x_2	0.224	0.622	0.392	0.566
x_3	0.56	0.384	0.336	0.594
x_4	0.49	0.475	0.581	0.384

Hence $s(\boxplus_{\alpha,\beta}A, \boxplus_{\alpha,\beta}B) = [0.49, 0.525] = [\alpha e_{AB}, \alpha e'_{AB}]$.
In a similar manner, we create the table that follows to locate $s(\boxtimes_{\alpha,\beta}A, \boxtimes_{\alpha,\beta}B)$.

x	$\alpha\mu_A(x) + \beta$	$\alpha\nu_A(x)$	$\alpha\mu_B(x) + \beta$	$\alpha\nu_B(x)$
x_1	0.755	0.182	0.804	0.126
x_2	0.524	0.322	0.692	0.266
x_3	0.86	0.084	0.636	0.294
x_4	0.79	0.175	0.881	0.084

Hence $s(\boxtimes_{\alpha,\beta}A, \boxtimes_{\alpha,\beta}B) = [0.79, 0.825] = [\alpha e_{AB} + \beta, \alpha e'_{AB} + \beta]$.
The measure of similarity has been thoroughly explored and defined in intuitionistic fuzzy set theory by numerous authors [11, 15, 16].
Chen [9] defined a similarity measure between two fuzzy sets A and B of X using the vector approach as follows:

$$s(A, B) = \frac{\overline{A}.\overline{B}}{\overline{A}^2 \vee \overline{B}^2} \tag{1}$$

Where, $\overline{A}$ is the vector $\langle \mu_A(x_1), \mu_A(x_2), ...\rangle$, $\overline{B}$ is the vector $\langle \mu_B(x_1), \mu_B(x_2), ...\rangle$ and $X = \{x_1, x_2, x_3, ...\}$, the symbol "." stands for scalar product of two vectors.
De. S. K. et al.[11] also provide an analogous definition for the similarity measurement between two IFSs A and B of E.

$$s(A, B) = \frac{\sum_{x\in E} \overline{A}_x.\overline{B}_x}{\sum_{x\in E}(\overline{A}_x^2) \vee \sum_{x\in E}(\overline{B}_x^2)} \tag{2}$$

Where $\overline{A}_x$ is the vector $[\mu_A(x), \pi_A(x)]$ and $\overline{B}_x$ is the vector $[\mu_B(x), \pi_B(x)] \forall x \in E$.
Clearly,

1. $s(A, B) \in [0, 1]$.

2. $s(A, B) = s(B, A)$.

3. $e_{AB} = e'_{AB}$ if $A = B$.

4. If $\pi_A(x) = 0$ and $\pi_B(x) = 0, \forall x \in E$, then $s(A, B)$ becomes equal to the measure of similarity defined by Chen [9].

In this section, a new kind of similarity measure between two intuitionistic fuzzy sets are defined.

Definition 3.9. *Let us consider two IFSs A and B of a fixed set E. Similarity measure $s(A,B)$ between A and B is defined by*

$$s(A,B) = \frac{e_{AB}}{e'_{AB}} = \frac{\max\min_{x\in E}\{\mu_A(x), \mu_B(x)\}}{\max\min_{x\in E}\{\mu_A(x)+\pi_A(x), \mu_B(x)+\pi_B(x)\}} \quad (3)$$

The larger the value of $s(A,B)$, the more the similarity between the intuitionistic fuzzy sets.
Now let's look at example 3.1. It may be demonstrated that, for equation (2), the value of similarity measure $s(A,B) = 0.9254$, while, by Definition 3.9, similarity measure $s(A,B) = 0.9333$. Therefore, Definition 3.9 is more suited to offer the optimal solution.

Theorem 3.10. *For any two IFSs A and B of a fixed set E, the following statements are true:*

1. $0 \leq s(A,B) \leq 1$.
2. $s(A,B) = s(B,A)$.
3. *If $\pi_A(x) = 0$ and $\pi_B(x) = 0, \forall x \in E$, then $s(A,B)$ becomes equal to 1.*

Proof. Obvious. □
In the above theorem, $e_{AB} \neq e'_{AB}$ if $A = B$.

4 Application for Decision making

This section describes a procedure for determining, given n possibilities, the most efficient course of action based on m criteria. Suppose that there are n actions A, B, C,...where each action depends upon all of the m criteria x_1, x_2, x_3,... .
A criterion-value $\langle\mu_A, \nu_A\rangle$ consists of the membership value and the non-membership value of the alternative A. The indeterministic or hesitation part is the remaining amount $\pi_A = 1 - \mu_A - \nu_A$. Here $\langle\mu_A, \nu_A\rangle$ are the IFSs of the set A under all criteria.
For two IFSs A and B of E, A is said to dominate B if $s(S,A) \geq s(S,B)$. It is clear that the super IFS S dominates all.

4.1 Algorithm

The steps of algorithm of this method are as follows:
First step: Construct the criteria-matrix using the standard and available alternatives.
Second step: Calculate $s(S,X) = \frac{e_{SX}}{e'_{SX}}$.
Third step: Find all the similarity measures like $s(S,X)$, where $X = A, B, C, D$ and E.
Fourth step: If $s(S,X)$ has more than one value, choose that one corresponding to which the indeterministic part is greatest.
Fifth step: Choose the optimal action.

4.2 A case-study

Here, we look at how a student might be selected for a desirable engineering branch based on a few different factors. Let S be the standard alternative and A, B, C, D, and E, are the available alternatives or the desirable engineering branches as Computer Science, Electronics, Biotechnology, Chemical and Mechanical Engineering. Moreover, the criteria are

1. Cut-off marks in entrance test (x_1),
2. Students' choice (x_2),
3. Availability of subjects or branches (x_3),
4. Availability of seats (x_4).

Here, we create a case study using hypothetical information. The criteria-matrix is displayed as follows.

x	S $\langle \mu_S, \nu_S \rangle$	A $\langle \mu_A, \nu_A \rangle$	B $\langle \mu_B, \nu_B \rangle$	C $\langle \mu_C, \nu_C \rangle$	D $\langle \mu_D, \nu_D \rangle$	E $\langle \mu_E, \nu_E \rangle$
x_1	$\langle 0.9, 0.05 \rangle$	$\langle 0.7, 0.2 \rangle$	$\langle 0.76, 0.2 \rangle$	$\langle 0.86, 0.1 \rangle$	$\langle 0.9, 0.02 \rangle$	$\langle 0.75, 0.2 \rangle$
x_2	$\langle 0.8, 0.1 \rangle$	$\langle 0.75, 0.22 \rangle$	$\langle 0.83, 0.14 \rangle$	$\langle 0.78, 0.18 \rangle$	$\langle 0.79, 0.15 \rangle$	$\langle 0.79, 0.15 \rangle$
x_3	$\langle 0.85, 0.05 \rangle$	$\langle 0.81, 0.12 \rangle$	$\langle 0.8, 0.1 \rangle$	$\langle 0.7, 0.2 \rangle$	$\langle 0.81, 0.14 \rangle$	$\langle 0.83, 0.13 \rangle$
x_4	$\langle 0.88, 0.05 \rangle$	$\langle 0.65, 0.25 \rangle$	$\langle 0.61, 0.24 \rangle$	$\langle 0.68, 0.3 \rangle$	$\langle 0.57, 0.28 \rangle$	$\langle 0.67, 0.28 \rangle$

Hence we get,
$s(S, A) = \frac{e_{SA}}{e'_{SA}} = \frac{\max\{0.70,0.75,0.81,0.65\}}{\max\{0.80,0.78,0.88,0.75\}} = \frac{0.81}{0.88} = 0.92045.$
$s(S, B) = \frac{e_{SB}}{e'_{SB}} = \frac{\max\{0.76,0.80,0.80,0.61\}}{\max\{0.80,0.86,0.90,0.76\}} = \frac{0.80}{0.90} = 0.88889.$
$s(S, C) = \frac{e_{SC}}{e'_{SC}} = \frac{\max\{0.86,0.78,0.70,0.68\}}{\max\{0.90,0.82,0.80,0.70\}} = \frac{0.86}{0.90} = 0.95556.$
$s(S, D) = \frac{e_{SD}}{e'_{SD}} = \frac{\max\{0.90,0.79,0.81,0.57\}}{\max\{0.95,0.85,0.86,0.72\}} = \frac{0.90}{0.95} = 0.94737.$
$s(S, E) = \frac{e_{SE}}{e'_{SE}} = \frac{\max\{0.75,0.79,0.83,0.67\}}{\max\{0.80,0.85,0.87,0.72\}} = \frac{0.83}{0.87} = 0.95402.$
This indicates that the best alternative is C i.e., Biotechnology is the optimal solution.

5 Conclusion

In order to determine the similarity measure between intuitionistic fuzzy sets, we describe a model or method for intuitionistic fuzzy sets in this study. The primary characteristic of this model is that the hesitation margin has also been taken into account and computed.We looked at a multi-criteria decision-making problem where the data were intuitionistic fuzzy rather than crisp. We accomplish this by comparing each of the criterion value sets with the super intuitionistic fuzzy set S. The best effective course of action is determined to be the criteria value set that most closely resembles S. The similarity measuring method is the name of the procedure. In addition to determining the best course of action, the method assists in creating a panel that reveals the second, third, and so on ideal actions.

Conflict of Interest: The authors declare that there is no conflict of interest concerning the reported research findings.

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