Journal of Industrial Intelligence
https://www.acadlore.com/journals/JII

Intuitionistic Fuzzy Multi-Index Multi-Criteria Decision-Making for Smart Phone Selection Using Similarity Measures in a Fuzzy Environment

Jogjiban Chakraborty[1], Sathi Mukherjee[2], Laxminarayan Sahoo[3*]

[1] Department of Mathematics, Bankura University, 722155 Bankura, India
[2] Department of Mathematics, Gobinda Prasad Mahavidyalaya, 722133 Bankura, India
[3] Department of Computer and Information Science, Raiganj University, 733134 Raiganj, India

[*] Correspondence: Laxminarayan Sahoo (lxsahoo@raiganjuniversity.ac.in)

Received: 02-12-2023 **Revised:** 03-02-2023 **Accepted:** 03-15-2023

Citation: J. Chakraborty, S. Mukherjee, and L. Sahoo, "Intuitionistic fuzzy multi-index multi-criteria decision-making for smart phone selection using similarity measures in a fuzzy environment," *J. Ind Intell.*, vol. 1, no. 1, pp. 1–7, 2023. https://doi.org/10.56578/jii010101.

Abstract: Smart phone selection involves several product attributes and brand values of the manufacturing company, and the sets of alternatives, criteria, and decision-makers may be updated multiple times during the purchasing process. In this study, a multi-index multi-criteria decision-making approach is proposed using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique with intuitionistic fuzzy sets (IFS) measures based on score-based measures. The purchasing of electronic gadgets is considered, and a similarity-based solution to the multi-index, multi-criteria decision-making problem is proposed. The effectiveness of the suggested approach is demonstrated through a numerical scenario. The results highlight the efficacy of the proposed method in resolving specific decision-making problems in the marketplace.

Keywords: Multi-index; Similarity measure; Intuitionistic fuzzy sets; Score-function; Marketplace; Multi-criteria decision-making

1 Introduction

The smart phone has become one of the most crucial electrical appliances in our modern daily lives, providing access to information and skills that have transformed our daily routines. With numerous models available from various manufacturers, customers often find it challenging to choose the best model due to the distinct specifications of each one. This study aims to select the best smart phone model by using the TOPSIS technique in accordance with the multi-criteria decision-making (MCDM) [1, 2] methodology.

The TOPSIS (Technique for Order of Preferences by Similarity to Ideal Solution) is a versatile MCDM method that can be applied in any decision-making situation. The key principle of the TOPSIS is to select the alternative based on its separation measure, as well as closeness to the ideal solutions, respectively [3]. However, in conventional MCDM, all parameters related to MCDM problems are considered to have fixed values, despite the fact that these criteria are not firmly fixed due to uncertainty and inadequate knowledge. Several factors, such as decision makers being unaware of certain parameters or the unstable nature of the market economy due to competing markets and variable costs, could contribute to this uncertainty.

To address these circumstances, the fuzzy set (FS) theory is helpful in identifying potential situations. Zadeh [4] proposed the idea of a fuzzy set, which dealt with imprecision and ambiguity in everyday circumstances. Bellman and Zadeh established the idea of decision-making difficulties including uncertainty in the year 1970 [5]. In 1986, Atanassov established the notion of intuitionistic fuzzy sets (IFSs) by representing the real world concerning a variety of perspectives associated with support, opposition, and neutrality [6–11]. Since then, many researchers [12, 13] have investigated and used IFSs. When evidence is insufficiently available to establish imprecision using conventional FS, the idea of IFS offers an alternate definition of FS. The level of acceptance and level of rejection of an IFS define it. Information on fuzzy decision making, multi-criteria decision making, intuitionistic fuzzy sets, etc. can be found in the reference list [14–24].

In this study, we have considered IFS ranking based on score function. To quantify the gap between each alternative and the positive and negative ideal solutions, we used the score function to calculate the relative closeness coefficient. We have used the TOPSIS technique, which is based on score functions, to handle the multi-criteria decision-making (MCDM) problem, in which all the decision-makers' preferences are described as intuitionistic fuzzy decision matrices. To demonstrate the proficiency of the suggested method, we have provided a numerical illustration of selecting a smart phone from the market.

The remaining work is outlined as follows. Section 2 covers the essential mathematical foundations and procedures, including the MCDM problem and the calculation of criteria weight using the Entropy Method. Section 3 provides the TOPSIS approach, which is based on intuitionistic fuzzy sets, to execute the result. Section 4 covers the numerical illustration and outcomes. Finally, Section 5 provides the final conclusions, and the research scope of the proposed approach has been addressed in consideration of the relevant literature.

2 Preliminaries

This section aims to provide the key definitions of intuitionistic fuzzy sets (IFSs)

Intuitionistic fuzzy sets

In reference to Atanassov [7] an Intuitionistic fuzzy set (IFS) F in universe X is given by $F = \{< x, \mu_F(x), \gamma_F(x) : x \in X\}$. Where the functions $\mu_F(x) : X \to [0, 1]$ and $\gamma_F(x) : X \to [0, 1]$ such that $0 \leq \mu_F(x) + \gamma_F(x) \leq 1$ for every $x \in X$. The member functions $\mu_F(x), \gamma_F(x) \in [0, 1]$ denotes membership function and non-membership function of x to F. For each IFS in X, we define hesitancy function of x to F as $\pi_F(x) = 1 - \mu_F(x) - \gamma_F(x)$. It is to be stated that $0 \leq \pi_F(x) \leq 1$.

Here, we have defined the score function and accuracy function of IFS in X.

Definition 2.1: Score function of IFS $F = \{< x, \mu_F(x), \gamma_F(x) >: x \in X\}$ is denoted by $S_F(x)$ and is defined by $S_F(x) = \frac{1+\mu_F(x)-\gamma_F(x)}{2}$.

Definition 2.2: The Accuracy function of IFS $F = \{< x, \mu_F(x), \gamma_F(x) >: x \in X\}$ is denoted by $H_F(x)$ and is defined by $H_F(x) = \mu_F(x) + \gamma_F(x)$.

Property 2.1: If $F = \{< x, \mu_F(x), \gamma_F(x) >: x \in X\}$ be any IFS, then $0 \leq S_F(x) \leq 1$.

Proof: For any IFS $F = \{< x, \mu_F(x), \gamma_F(x) >: x \in X\}$, $0 \leq \mu_F(x) + \gamma_F(x) \leq 1$. Therefore, $1 + \mu_F(x) \leq 2 - \gamma_F(x)$ and hence, $1 + \mu_F(x) - \gamma_F(x) \leq 2(1 - \gamma_F(x))$. Again $0 \leq \gamma_F(x) \leq 1$,so $1 - \gamma_F(x) \geq 0$ and consequently $0 \leq S_F(x) \leq 1$.

Definition 2.3: Let $F_1 = \{< x, \mu_{1F}(x), \gamma_{1F}(x) >\}$ and $F_2 = \{< x, \mu_{2F}(x), \gamma_{2F}(x) >\}$ be two IFSs. If $S(F_1)$and $S(F_2)$ be the score function of F_1 and F_2 respectively, $H(F_1)$and $H(F_2)$ be the accuracy function of F_1 and F_2 respectively, then the results suggested below hold true.

(i) $S(F_1) < S(F_2) \Rightarrow F_1 < F_2$

(ii) $S(F_1) > S(F_2) \Rightarrow F_1 > F_2$

(iii) $(S(F_1) = S(F_2)) \wedge (H(F_1) < H(F_2)) \Rightarrow F_1 < F_2$

(iv) $(S(F_1) = S(F_2)) \wedge (H(F_1) > H(F_2)) \Rightarrow F_1 > F_2$

(v) $(S(F_1) = S(F_2)) \wedge (H(F_1) = H(F_2)) \Rightarrow F_1 = F_2$

Example 2.1: Let $F_1 = \{< x, 0.5, 0, 4 >\}$ and $F_2 = \{< x, 0.4, 0, 4 >\}$ be two IFSs. The score function values we evaluated are 0.55 and 0.50, in keeping with Definition 2.1. Hence $F_1 > F_2$.

2.1 Multi-Criteria Decision Making (MCDM) Problem

Multi-criteria decision making (MCDM) refers to the process of making judgments based on preferences over options that are characterized by numerous, frequently competing, features. Table 1 illustrates the construction of the alternative performance matrix, where w_j,$0 \leq w_j \leq 1$, represents the weight of criterion j and v_{ij} denotes the assessment of alternative i in connection with criterion j.

Table 1. Layout of the decision matrix

Weights	w_1	w_2		w_n
	Criterion 1 (C_1)	Criterion 2(C_2)	$\cdots$	Criterion n (C_n)
Alternative 1 (A_1)	v_{11}	v_{12}	.	v_{1n}
Alternative 2 (A_2)	v_{21}	v_{22}	$\cdots$	v_{2n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Alternative m (A_m)	v_{m1}	v_{m2}	$\cdots$	v_{mn}

Determining the appropriate weight for each criterion is a crucial aspect of MCDM, as each criterion has a distinct meaning and cannot be assumed to have equal importance. The literature offers a variety of weighting techniques, which can be broadly categorized into subjective and objective methods. Subjective weights are determined by the preference of decision makers, while objective methods involve solving mathematical frameworks without taking the decision maker's preferences into account. Several works have been conducted in this area, such as those by Golden et al. [25], Chu et al. [26], Hwang and Lin and Lin [27], Choo and Wedley [28], and Fan [29].

The Shannon entropy concept has been proposed as one of the objective weighting measures [30]. The entropy notion has been employed in numerous branches of science. Shannon's entropy, which is used to describe a broad measure of uncertainty, plays a significant role in information theory. The entropy weight technique measures the ability of each assessment criterion to incorporate decision information in order to estimate the relative importance of characteristics. It uses the amount of entropy value to show how random a message appears. The decision matrix can be used to estimate the entropy weight.

2.2 Calculation of Criteria Weight Using Entropy Method

In this study, we have utilized the entropy method to determine the criteria weights. If, $S(F) = S(F_{ij})_{m\times n}$ be the decision matrix then following are the different steps to calculate the criteria weight w_j, $j = 1, 2, ..., n$, where $0 \leq w_j \leq 1$ and $\sum w_j = 1$.

Step 1: For $j = 1, 2, ..., n$ calculate $p_{ij} = \frac{S(F_{ij})}{\sum\limits_{i=1}^{m} S(F_{ij})}$, $i = 1, 2, ..., m$

Step 2: For $j = 1, 2, ..., n$ calculate $E_j = -\frac{1}{\log(m)} \sum\limits_{i=1}^{m} p_{ij} \log(p_{ij})$. For the purpose of calculation, it is important to note that $\lim\limits_{p_{ij}\to 0\,.} p_{ij} \log p_{ij} \to 0$.

Step 3: Evaluate $w_j = \frac{1-E_j}{\sum\limits_{j=1}^{n} 1-E_j}$, for $j = 1, 2, ..., n$

3 TOPSIS Method Based on Intuitionistic Fuzzy Sets

This section outlines the methodology for applying the TOPSIS technique to MCDM problems where the criterion weights are unknown, and the decision makers' (DMs') desired knowledge is expressed in the form of IFSs, which can be determined using the Shannon Entropy method [30, 31]. To calculate the coefficient of relative closeness, we used the Score function values of IFSs, which can be obtained using the formula given in definition 2.1.

Assuming that there are m alternatives $A_i (i = 1, 2, ..., m)$ and n criteria $C_j (j = 1, 2, ..., n)$, along with the criteria weight vector $w = (w_1, w_2, ..., w_n)$, where $0 \leq w_j \leq 1$ and $\sum w_j = 1$, the desirable features of alternatives A_i with respect to the criteria C_j can be represented by an IFS $F_{ij} = \{< x, \mu_{ijF}(x), \gamma_{ijF}(x)\}$, $(i = 1, 2, ..., m; j = 1, 2, ..., n)$. The decision matrix $F = (F_{ij})_{m\times n}$ can be used to express the features of an alternative in relation to the requirements provided by F_{ij}, where $i = 1, 2, ..., m$ and $j = 1, 2, ..., n$. Therefore, the decision matrix $F = (F_{ij})_{m\times n}$ can be used to define the MCDM problem, which can be expressed as follows:

$$F = (F_{ij})_{m\times n} = \begin{pmatrix} F_{11} & F_{12} & \cdots & F_{1n} \\ F_{21} & F_{22} & \dots & F_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ F_{m1} & F_{m2} & \dots & F_{mn} \end{pmatrix} \tag{1}$$

The decision matrix $F = (F_{ij})_{m\times n}$ has been transformed into the following matrix $S(F)_{m\times n}$ using the score function, as shown below:

$$S(F)_{m\times n} = \begin{pmatrix} S(F_{11}) & S(F_{12}) & \cdots & S(F_{1n}) \\ S(F_{21}) & S(F_{22}) & \dots & S(F_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ S(F_{m1}) & S(F_{m2}) & \dots & S(F_{mn}) \end{pmatrix} \tag{2}$$

$S(F_{ij})$, the scored value of the intuitionistic fuzzy set F_{ij},can be calculated using the formula $S(F_{ij}) = \frac{1+\mu_{ijF}(x)-\gamma_{ijF}(x)}{2}$, $i = 1, 2, ..., m$and $j = 1, 2, ..., n$. The decision matrix for the suggested MCDM problem is expressed by Eq. (2). Let $\text{IDL}^+ = (1, 1, ..., 1)$ and $\text{IDL}^- = (0, 0, ..., 0)$ denote the positive and negative ideal solutions, respectively, for the m alternatives A_i, $i = 1, 2, ..., m$. The separation measures ${d_i}^+$and ${d_i}^-$ of each alternative from the positive ideal and negative ideal solutions can be calculated using the formula shown below:

$${d_i}^+ = \left(\sum_{j=1}^{n} (w_j(1 - S(F_{ij})))^2 \right)^{\frac{1}{2}} \tag{3}$$

$$d_i{}^{-} = \left(\sum_{j=1}^{n} (w_j S(F_{ij}))^2 \right)^{\frac{1}{2}} \tag{4}$$

Using the entropy-weighted technique described in Section 2.2, the weight vector $w = (w_1, w_2, ..., w_n)$ has been calculated. Next, we determine the relative closeness of m alternatives $A_i,\ i = 1, 2, ..., m$ with respect to the positive ideal solution IDL$^+$ using Eqns. (3) and (4), and the resulting outcomes are presented below:

$$C_i(A_i) = \frac{d_i^-}{d_i^- + d_i^+},\ i = 1, 2, ..., m \tag{5}$$

The closeness coefficient $C_i(A_i), i = 1, 2, ..., m$, determined by (5) can be used to identify the best option from a group of attainable choices and determine the ranking order of all alternatives. The alternatives can be ordered by the closeness coefficient, with the alternative having the highest rank being considered as the best choice.

4 Numerical Example

In today's world, owning a smartphone is a desire for every consumer, but selecting the right one can be challenging due to the numerous manufacturers producing various models with various features. Let's consider a scenario where someone wishes to purchase a smartphone for personal use, and there is a supermarket where they can choose from four available mobile phones, namely M_1, M_2, M_3, and M_4, and may belong to different manufacturers or brands. The person may decide based on one of the following five criteria: (i) C_1 (battery backup-related criteria), (ii) C_2 (camera-related criteria), (iii) C_3 (weight-related criteria), (iv)C_4 (looks and design-related criteria), and (v) C_5 (cost/price-related criteria). There are four alternatives M_1, M_2, M_3, and M_4, which need to be evaluated using IFSs values of the buyer under the mentioned five criteria C_1, C_2, C_3, C_4 and C_5. The decision matrix for this scenario is given below:

$$(F)_{4\times5} = \begin{pmatrix} <0.6, 0.4> & <0.4, 0.5> & <0.5, 0.5> & <0.7, 0.2> & <0.6, 0.3> \\ <0.5, 0.4> & <0.7, 0.2> & <0.4, 0.5> & <0.6, 0.3> & <0.5, 0.3> \\ <0.7, 0.2> & <0.8, 0.1> & <0.4, 0.4> & <0.5, 0.3> & <0.6, 0.2> \\ <0.6, 0.3> & <0.7, 0.3> & <0.6, 0.2> & <0.5, 0.4> & <0.5, 0.3> \end{pmatrix}$$

Here, the notation $C_1(M_4) =< 0.6, 0.3 >$ highlights that the degree to which the alternative M_4 fulfills the criterion C_1 is 0.6, and the level in which the alternative M_4 fails to satisfy the criterion C_1 is 0.3. The decision matrix, which has been determined using the values of the score function by using Eq. (2), is presented below:

$$S(D)_{4\times5} = \begin{pmatrix} 0.60 & 0.45 & 0.50 & 0.75 & 0.65 \\ 0.55 & 0.75 & 0.45 & 0.65 & 0.60 \\ 0.75 & 0.85 & 0.50 & 0.60 & 0.70 \\ 0.65 & 0.70 & 0.70 & 0.55 & 0.60 \end{pmatrix}$$

Using Section 2.2, we have obtained the weight vector for the five criteria $w_1 = 0.12$, $w_2 = 0.45$,$w_3 = 0.28$,$w_4 = 0.12$ and $w_5 = 0.04$. We have computed $d_i{}^+$, $d_i{}^-$and $C_i(M_i)$ using (4), (5), and (6). Table 2 displays the results.

Table 2. Calculated values of $d_i{}^+$, $d_i{}^-$ and $C_i(A_i)$

i	1	2	3	4
d_i^+	0.084	0.041	0.028	0.030
d_i^-	0.075	0.141	0.180	0.149
$C_i\,(M_i)$	0.469	0.773	0.867	0.831

Now, the alternatives have been sorted in descending order based on the calculated closeness coefficient $C_i(M_i)$, $i = 1, 2, 3, 4$, and the highest-ranked alternative will be the best option. The rankings are shown in Table 3 below:

Table 3 shows the ranking of the four mobile phones, and according to the analysis, M_3 is the best option to purchase based on the five criteria given in the example. Figure 1 illustrates the selection of mobile phones by percentage.

Table 4 displays the preferred order of mobile phones in accordance with their ranking based on the five criteria evaluated in the example. M_3 is ranked 1, followed by which M_4 is ranked 2. M_2 is ranked 3, and M_1 is ranked 4.

Table 3. Order of alternative with highest rank

Alternative	A_1	A_2	A_3	A_4
Rank	Rank 4	Rank 3	Rank 1	Rank 2

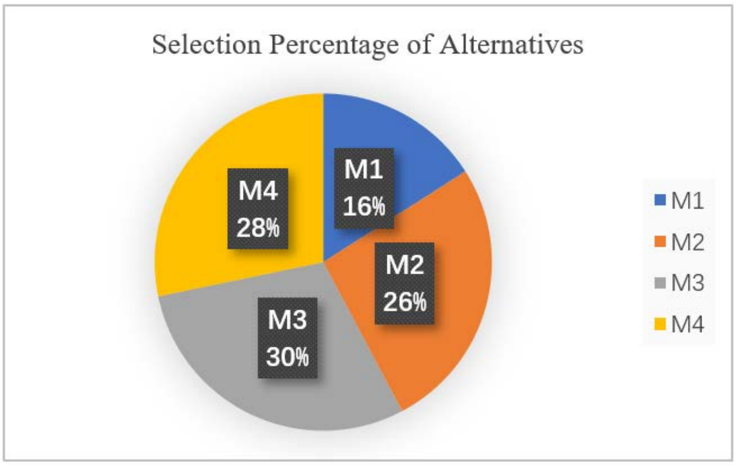

Figure 1. Selection of Mobile phones according to percentage

Note: The figure was prepared by authors

Table 4. Order of preference of alternative (Smart Phone/Mobile phone) according to their rank

Rank	Rank 1	Rank 2	Rank 3	Rank 4
Mobile Selection	M_3	M_4	M_2	M_1

5 Conclusion

Selecting branded electronic devices from the market or making the right electronics product purchases is a vital task, where numerous product characteristics and brand values of the relevant production or manufacturing company are taken into consideration. In this study, we considered five different factors for evaluating smartphones or mobile phones from the market. To choose the best product, a MCDM problem was formulated and solved using the TOPSIS technique. All preference information provided by the decision makers was expressed in terms of intuitionistic fuzzy decision matrices, with each component being represented by an IFS value. The IFS was employed in this work to represent various attributes of electronic products, as it quantifies the measure of satisfaction and dissatisfaction in view of every decision maker.

In this study, the criteria weight vector was generated by employing Shannon's entropy. The distance between each alternative and the positive and negative ideal solutions was quantified to calculate the relative proximity coefficient. The proposed fuzzy sets/operations could be used in future studies in the fields of science, engineering, management science, and other related fields. In our future work, more types of fuzzy data could be considered for solving such problems.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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