An Extended Intuitionistic Fuzzy Multi-Attributive Border Approximation Area Comparison Approach for Smartphone Selection Using Discrimination Measures

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Abstract. The objective of the paper is to introduce a novel approach using the multi-attribute border approximation area comparison (MABAC) approach under intuitionistic fuzzy sets (IFSs) to solve the smartphone selection problem with incomplete weights or completely unknown weights. A novel discrimination measure of IFSs is proposed to calculate criteria weights. In view of the fact that the ambiguity is an unavoidable feature of multiple-criteria decision-making (MCDM) problems, the proposed approach is an innovative process in the decision-making under uncertain settings. To express the utility and strength of the developed approach for solving problems in the area of MCDM, a smartphone selection problem is demonstrated. To validate the IF-MABAC approach, a comparative discussion is made between the outcomes of the developed and those of the existing methods. The outcomes of analysis demonstrate that the introduced method is well-ordered and effective with the existing ones.

Key words: discrimination measure, intuitionistic fuzzy sets, MABAC, smartphone selection, multiple criteria decision making.

1. Introduction

Until now, users’ attentiveness in mobile communication is increasing and is analogous to this concern; Smartphone developers have manufactured various latest models. As per the survey report of the International Telecommunication Union (ITU) (ITU, 2017), the utilization of communication technologies is increased, while communication costs are
reduced. Due to quick evolution in Smartphone models, the subscribers have faced decision making complexity when acquiring the most desirable Smartphone. Moreover, the young generations are using Smartphones not only for phone calls, but also for numerous functions, viz., internet access, camera, music, and video players, and so on. For that reason, the customers desire to select the Smartphone by considering different qualitative and quantitative criteria. Quantitative criteria contain camera quality, RAM size, battery capacity, built-in memory, screen dimension, processor type, and cost, while qualitative criteria contain durability, user-friendliness, and brand.

Nowadays, MCDM approaches are extensively applied to elucidate the problems, namely Smartphone selection problem. However, MCDM problems differ according to the solution status and the approaches’ implementation. Up until now various MCDM approaches have been proposed in the literature, like the TOPSIS (Akyene, 2012; Mishra, 2016; Mishra et al., 2017a; Büyükozkan and Güleryüz, 2016), VIKOR (Vls Kriteriju miska Optimizacija I Kompromisno Resenje) (Hu et al., 2014; Mishra and Rani, 2019; Rani and Mishra, 2020a; Rani et al., 2019b), ELECTRE (ELimination and Choice Expressing REality) (Chen et al., 2018; Mishra et al., 2020a), WASPAS (Weighted Aggregates Sum Product Assessment) (Mishra et al., 2019a; Rani and Mishra, 2020b), PROMETHEE (Rani and Jain, 2017; Liao et al., 2018), MULTIMOORA (Wu et al., 2018) and GLDS (Wu and Liao, 2019) methods. From the literature, various MCDM approaches have been applied to identify the most desirable Smartphone (Hu et al., 2014; Akyene, 2012; Büyükozkan and Güleryüz, 2016; Wu et al., 2018). Hu et al. (2018) proposed a procedure that can promote mobile-commerce improvement towards attaining the aspiration level in a fuzzy setting. They developed fusion model to conduct the feedback-effect and dependency among criteria, and it combined the DEMATEL, DANP, and GRA methods.

The MABAC is an original MCDM approach pioneered by Pamučar and Ćirović (2015). MABAC has an easy computational process, organized procedure, and an innovative direction that determines the foundation of real-world decision-making problems. Peng and Yang (2016) utilized MABAC method to solve R&D project assessment with Pythagorean fuzzy sets (PFSs). Under IVIFSs (interval-valued intuitionistic fuzzy sets) environment, the MABAC approach is implemented for material evaluation (Xue et al., 2016) and programming language selection (Mishra et al., 2020d). Therefore, it is an attractive explorative way to implement the MABAC in the Smartphone selection. Atanassov (1986) developed the notion of IFSs which extends the fuzzy sets doctrine by accumulating the non-membership degree. As IFSs doctrine has widely been implemented by the researchers in various disciplines for handling uncertainties in the MCDM (Liu and Liao, 2017; Mishra and Rani, 2019), their analogous analysis is significant.

Discrimination and entropy and measures are prominent tools for tackling the ambiguous information in the various fields. Entropy measures, measurement of the degree of fuzziness for FSs and IFSs have gained huge concentration from scholars in various disciplines (Liao et al., 2014; Tang and Liao, 2019). To evaluate the discrimination information between IFSs, first, Vlachos and Sergiadis (2007) proposed IF-discrimination
measure, established relation between them and implemented it in various disciplines. Consequently, various prominent discrimination measures have been introduced for FSs and IFSs (Mishra et al., 2017b; Ansari et al., 2018; Rani et al., 2019a; Jiang et al., 2019; Liang et al., 2019b; Rani et al., 2020; Mishra et al., 2020b, 2020c; Kumari and Mishra, 2020).

Nevertheless, from the literature, it is examined that all the measures do not incorporate the decision expert opinion of the preferences into the measure. In addition, the existing measure is in linear order and does not show the accurate behaviour of alternatives. As a result, by concentrating the standards of flexibility and proficiency of IFSs, this study proposes novel parametric discrimination measures. It has been observed from the literature that the existing discrimination measures are the special cases of the developed one. Next, to estimate the weights criteria, the developed IF-discrimination measures have been applied. Using this procedure for weighting criteria, an intuitionistic fuzzy MABAC (IF-MABAC) approach is developed to deal with MCDM problems. Now, we implement only subjective considerations of options; however, developed method is appropriate for ordinary MCDM circumstances with objective and/or subjective evaluations. Further, a Smartphone selection problem is considered to elucidate the procedure and interpret the performance of IF-MABAC approach in real case decision-making issues. To illustrate the reliability of the results, a comparative discussion between our developed approach and the other current approaches is performed to determine the validity of the results.

However, according to the above motivations, the main contributions of the paper are pointed out as

i. New IF-discrimination measures using the characteristics of IFSs are proposed and compared with other current discrimination measures under IFSs.

ii. Considering the discrimination between alternatives, a procedure to assess the criteria weights is carried out.

iii. After defining the border approximation area (BAA) matrix using the proposed discrimination measure, an integrated MCDM method, IF-MABAC, is developed for MCDM problems under intuitionistic fuzzy environment.

iv. Considering a real-life smartphone selection problem, the IF-MABAC approach is implemented to choose the desirable smartphone. The usefulness of the introduced approach is examined by comparing it with existing approaches.

The organization of this paper is as follows. In Section 2, we discuss the review of the MABAC method and existing discriminations measures for IFSs. Section 3 illustrates the research method based on the basic information of IFSs, and the recent related works about IF-discrimination measures. In Section 4, the novel IF-discrimination measures are presented, and some attractive properties of proposed measures are conferred. Section 5 presents the IF-MABAC approach for MCDM problem. In Section 6, we discuss the application of smartphone selection of IF-MABAC approach and compare it with currents works. In the last section, the conclusion of this paper is provided.
2. Literature Review

2.1. An Overview of MABAC Method

For the first time, Pamučar and Ćirović (2015) proposed the MABAC as an original MCDM approach. This approach provided an easy computational process, organized procedure, and an innovative direction that determines the foundation of practical MCDM problems. Over the past years, the MABAC approach is used by many scholars in different application areas. Peng and Yang (2016) extended a MABAC procedure with Pythagorean fuzzy Choquet integral. Liang et al. (2019a) introduced MABAC technique to assess rockburst risks under triangular fuzzy numbers (TFNs). Xue et al. (2016) proposed IVIF-MABAC approach to assess the material selection. Gigović et al. (2017) presented a combined method with DEMATEL, MABAC, Geographic Information Systems (GIS) and ANP to select the location for the wind farms. Peng and Dai (2018) established a new model on single-valued neutrosophic (SVN) and similarity measure and distance measure to solve MADM problem based on MABAC and TOPSIS procedures. Yu et al. (2017) proposed a method based on MABAC under interval type-2 fuzzy numbers (IT2FNs) for selecting the best hotel on a tourism website. Sun et al. (2018) established a projection-based MABAC approach under hesitant fuzzy linguistic term sets (HFLTSs) to select and evaluate patients. The summary of other related papers is presented in Table 1.

2.2. Review of Discrimination Measures of IFSs

In the current decade, the applications of IFSs and information measures, namely, discrimination, entropy, and similarity, have been investigated by various scholars in different regions (Deng et al., 2015; Bao et al., 2017; Cavallaro et al., 2018, 2019; Kong et al., 2018; Lohrmann et al., 2018; Luo and Zhao, 2018; Ngan et al., 2018; Shen et al., 2018). Jia et al. (2019) introduced a new IF-similarity measure of pattern recognition problem based on isosceles triangles. Bao et al. (2017) presented a new approach according to evidential reasoning and prospect theory and extended new measures for IF-entropy and discrimination measure in the field of international shipping market. Shen et al. (2018) generalized the IF-TOPSIS approach derived from similarity and distance measures for handling the risk assessment of MCDM issue. Luo and Zhao (2018) developed an IF-distance measure-based on a strictly increasing binary function and matrix norm for evaluating the medical diagnosis. Deng et al. (2015) investigated monotonic similarity and geometrical relation measures under IFSs based on inclusion and entropy measures. Cavallaro et al. (2018) and Cavallaro et al. (2019) extended an IFs based on fuzzy Shannon entropy measure and extended IF-TOPSIS based on circular entropy weights vector for evaluating of the concentrated solar power (CSP).

3. Intuitionistic Fuzzy Sets and Existing Discrimination Measures

This part of the paper presents some basic information of IFSs and the IF-discrimination measures.
Table 1
Summary of the related works of MABAC method.

| Authors                  | Method                          | Fuzzy and conventional environment                     | Application area                      |
|--------------------------|---------------------------------|--------------------------------------------------------|----------------------------------------|
| Roy et al. (2016)        | MABAC                           | Type-2 trapezoidal fuzzy sets                          | System analysis engineer selection     |
|                          |                                 | environment                                           | Software development project          |
| Peng and Dai (2017)      | MABAC, COPRAS, WASPAS,           | HFSSs                                                 | Investment company                     |
|                          | ELECTRE, MABAC                   | IVIFSs                                                | Outsourcing provider selection         |
| Peng et al. (2017)       | MABAC, EDAS                      | SVN linguistic sets                                    | Manufacturer PVC carpentry             |
| Ji et al. (2018)         | ELECTRE, MABAC                   | Conventional MCDM                                     |                                        |
| Nunić (2018)             | MABAC, WASPAS, ARAS, FUCOM       |                                                        |                                        |
| Vesković et al. (2018)   | Delphi, MABAC SWARA              | Conventional MCDM                                     | Railway management                     |
| Bozanic et al. (2018)    | Fuzzy MABAC, fuzzy AHP, MABAC    | Saaty’s fuzzy sets                                    | Deep wading location selection         |
|                         |                                 | Hierarchy Process (AHP)                                |                                        |
| Bojanic et al. (2018)    | Fuzzy AHP, MABAC                | Interval of fuzzy numbers                             | Military decision-making process       |
| Hu et al. (2019)         | MABAC                           | Interval type-2 fuzzy numbers (IT2FNs)                | Patient care assessment                |
| Jia et al. (2019)        | MABAC                           | Intuitionistic fuzzy rough numbers                     | Medical devices supplier selection     |
| Božanić et al. (2019)    | Full Consistency Method. (FUCOM),| Triangular fuzzy number                                | Location selection for bridge          |
|                         | fuzzy MABAC                      |                                                        | construction                           |
| Biswas and Das (2019)    | MABAC, fuzzy AHP                | Fuzzy sets                                            | Commercially available electric vehicle|
| Majchrzycka and Poniszewska-Maranda (2018) | MABAC | Conventional MCDM                                    | Mobile access control                 |
| Biswas and Das (2018)    | MABAC                           | Conventional MCDM                                     | Hybrid vehicle selection               |
| Luo and Liang (2019)     | MABAC                           | Linguistic neutrosophic numbers                       | Roadway support schemes                |
| Liu (2019)               | MABAC                           | IVIFSs                                                | Radiation therapy assessment          |
| Božanić et al. (2016)    | MABAC                           | Conventional MCDM                                     | Defensive operation                    |
| Pamučar and Božanić (2019) | MABAC   | SVNSs                                                 | Logistics center selection             |
| Liang et al. (2019a)     | MABAC                           | IFSs                                                  | Human resource management problem     |
| Shen et al. (2020)       | MABAC                           | Z-number                                              | Circular economy development selection |
| Dorfeshan and Mousavi (2020) | MABAC, WASPAS | IT2FSs                                               | Aircraft maintenance planning         |
| Mishra et al. (2020c)    | MABAC                           | IVIFSs                                                | Programming language assessment       |
| Wang et al. (2020)       | MABAC                           | Q-rung orthopair fuzzy sets                            | Construction projects selection        |
| Wei et al. (2020)        | MABAC                           | Uncertain probabilistic linguistic sets (UPLTSs)      | Green supplier selection               |
3.1. The Concepts Related to IFSs

Atanassov (1986) developed the view of the fuzzy sets (FSs) to IFSs by distinguishing belongingness and the non-belongingness functions where the sum of both degrees is equal to one or less than one.

**Definition 1** (Intuitionistic fuzzy sets, see Atanassov, 1986). An IFS $E$ on universe set $U = \{u_1, u_2, \ldots, u_n\}$ is described by

$$E = \{\langle u_i, \mu_E(u_i), \nu_E(u_i) \rangle: u_i \in U\},$$

(1)

where $\mu_E : U \to [0, 1]$ and $\nu_E : U \to [0, 1]$ symbolize the non-belongingness and belongingness degrees of $u_i$ to $E$ in $U$, correspondingly, under the condition

$$0 \leq \mu_E(u_i), \nu_E(u_i) \leq 1, \quad \text{and} \quad 0 \leq \mu_E(u_i) + \nu_E(u_i) \leq 1, \quad \forall u_i \in U.$$  

(2)

The hesitancy degree of an element $u_i \in U$ to $E$ is defined by

$$\pi_E(u_i) = 1 - \mu_E(u_i) - \nu_E(u_i) \quad \text{and} \quad 0 \leq \pi_E(u_i) \leq 1, \quad \forall u_i \in U.$$  

For effortlessness, an intuitionistic fuzzy number (IFN) is characterized by $\theta = (\mu_\theta, \nu_\theta)$ where it holds $\mu_\theta, \nu_\theta \in [0, 1]$ and $0 \leq \mu_\theta + \nu_\theta \leq 1$. Let $\theta_j = (\mu_j, \nu_j) \in \text{IFN}(U)$, $j = 1(1)n$, then,

$$S(\theta_j) = (\mu_j - \nu_j), \quad \sigma(\theta_j) = (\mu_j + \nu_j),$$

(3)

are said to be score and accuracy functions of an IFN $\theta_j$ (Xu, 2007) such that $S(\theta_j) \in [-1, 1]$ and $\sigma(\theta_j) \in [0, 1]$. Since $S(\theta_j) \in [-1, 1]$, thus we need to normalize it. As a result, Xu et al. (2015) modified a concept of score values for IFN and given by

$$S^*(\theta_j) = \frac{1}{2} (S(\theta_j) + 1), \quad \sigma^*(\theta_j) = 1 - \sigma(\theta_j),$$

(4)

are mentioned to be the normalized score value and uncertainty function like $S^*(\theta_j) \in [0, 1]$ and $\sigma^*(\theta_j) \in [0, 1]$.

Let $\theta_j = (\mu_j, \nu_j) \in \text{IFNs}(U)$. Then, the IF-Weighted Average (IFWA) is described as Xu (2007):

$$\text{IFWA}_w(\theta_1, \theta_2, \ldots, \theta_n) = \left[1 - \prod_{j=1}^{n} (1 - \mu_j)^{\sigma_j}, \prod_{j=1}^{n} \nu_j \right]^n,$$

(5)

where $\sigma_j$ is a significant weight of IFNs such that $\sum_{j=1}^{n} \sigma_j = 1$ and $\sigma_j \in [0, 1]$.

The discrimination measure is a recognized device to measure the discrimination degree in IFSs. Later on, Montes et al. (2015) demonstrated the discrimination measure is the more restrictive way when the comparison is performed with other measures and necessary for avoiding counter-intuitive situations.
**Definition 2 (Discrimination measure, see Montes et al., 2015).** A mapping $L : IFS(U) \times IFS(U) \rightarrow \mathbb{R}$ is entitled discrimination measure if $L$ satisfies the following postulates:

(D1). $L(E, F) = L(F, E), \quad \forall E, F \in IFS_s(U)$,

(D2). $L(E, F) = 0 \iff E = F$,

(D3). $L(E \cap P, E \cap P) \leq L(E, F)$ \ for every $P \in IFS(U)$,

(D4). $L(E \cup P, F \cup P) \leq L(E, F)$ \ for every $P \in IFS(U)$.

### 3.2. Existing Discrimination Measures for IFSs

Various existing IF-discrimination measures are analysed from the literature. The details of recent discrimination measures are listed as follows:

**Maheshwari and Srivastava (2015):**

$$L_{MS_1}(E, F) = \frac{1}{n(\sqrt{2} - 1)} \sum_{i=1}^{n} \left[ \sqrt{\frac{(\mu_E(u_i))^2 + (\mu_F(u_i))^2}{2}} - \frac{\mu_E(u_i) + \mu_F(u_i)}{2} ight] + \sqrt{\frac{(v_E(u_i))^2 + (v_F(u_i))^2}{2}} - \frac{v_E(u_i) + v_F(u_i)}{2} + \sqrt{\frac{(\pi_E(u_i))^2 + (\pi_F(u_i))^2}{2}} - \frac{\pi_E(u_i) + \pi_F(u_i)}{2}.$$  

**Verma and Sharma (2014):**

$$L_{VS_2}(E, F) = -\frac{1}{n} \sum_{i=1}^{n} \left[ \mu_E(u_i) \log \frac{\mu_E(u_i) + \mu_F(u_i)}{2} + v_E(u_i) \log \frac{v_E(u_i) + v_F(u_i)}{2} + \pi_E(u_i) \log \frac{\pi_E(u_i) + \pi_F(u_i)}{2} - \pi_E(u_i) \log \pi_E(u_i) - (1 - \pi_E(u_i)) \log (1 - \pi_E(u_i)) - \pi_E(u_i) \right].$$

**Garg (2016):**

$$L_G(E, F) = \frac{\alpha}{n(2 - \beta)} \sum_{i=1}^{n} \left[ \mu_E^{\alpha\beta}(u_i) \log \left( \frac{\mu_E^{\alpha\beta}(u_i)}{\lambda \mu_E^{\alpha\beta}(u_i) + (1 - \lambda) \mu_F^{\alpha\beta}(u_i)} \right) + v_E^{\alpha\beta}(u_i) \log \left( \frac{v_E^{\alpha\beta}(u_i)}{\lambda v_E^{\alpha\beta}(u_i) + (1 - \lambda) v_F^{\alpha\beta}(u_i)} \right) + \pi_E^{\alpha\beta}(u_i) \log \left( \frac{\pi_E^{\alpha\beta}(u_i)}{\lambda \pi_E^{\alpha\beta}(u_i) + (1 - \lambda) \pi_F^{\alpha\beta}(u_i)} \right) \right].$$
Srivastava and Maheshwari (2016):

\[
L_{MS_2}(E, F) = 1 - \log_2 \left[ 1 + \frac{1}{n} \sum_{i=1}^{n} \left( \min(\mu_E(u_i), \mu_F(u_i)) + \min(v_E(u_i), v_F(u_i)) + \min(\pi_E(u_i), \pi_F(u_i)) \right) \right].
\]

Ohlan (2016):

\[
L_O(E, F) = \sum_{i=1}^{n} \left[ 1 - \left( \frac{v_E(u_i) + 1 - \mu_E(u_i)}{2} \right)^2 e^{\frac{\left( \mu_E(u_i) - \mu_F(u_i) - (v_E(u_i) - v_F(u_i)) \right)}{2}} - \left( \frac{\mu_E(u_i) + 1 - v_E(u_i)}{2} \right)^2 e^{\frac{\left( \mu_F(u_i) - \mu_E(u_i) - (v_F(u_i) - v_E(u_i)) \right)}{2}} \right].
\]

Mishra et al. (2019b):

\[
L_{M_1}(E, F) = \frac{1}{n(\sqrt{e} - 1)} \sum_{i=1}^{n} \left[ \begin{array}{c}
\left\{ \mu_E(u_i) + \frac{1}{2} - \frac{1}{2} (v_E(u_i) + v_F(u_i)) \right\} \\
\times \exp\left\{ \frac{v_E(u_i) + v_F(u_i) + 2 - (\mu_E(u_i) + (v_E(u_i)))}{4} \right\} \\
+ \left\{ \frac{v_E(u_i) + v_F(u_i) + 2 - (\mu_E(u_i) + (v_F(u_i)))}{4} \right\} \\
\times \exp\left\{ \frac{\mu_E(u_i) + \mu_F(u_i) + 2 - (v_E(u_i) + (v_F(u_i)))}{4} \right\} \\
\end{array} \right].
\]

\[
L_{M_2}(E, F) = \frac{1}{n\sqrt{e}(\sqrt{e} - 1)} \sum_{i=1}^{n} \left[ \begin{array}{c}
\left\{ \mu_E(u_i) + \frac{1}{2} - \frac{1}{2} (v_E(u_i) + v_F(u_i)) \right\} \\
\times \exp\left\{ \frac{v_E(u_i) + v_F(u_i) + 2 - (\mu_E(u_i) + (v_E(u_i)))}{4} \right\} \\
+ \left\{ \frac{v_E(u_i) + v_F(u_i) + 2 - (\mu_E(u_i) + (v_F(u_i)))}{4} \right\} \\
\times \exp\left\{ \frac{\mu_E(u_i) + \mu_F(u_i) + 2 - (v_E(u_i) + (v_F(u_i)))}{4} \right\} \\
\end{array} \right].
\]
Mishra et al. (2020d):

\[ L_{A_{\alpha}}(E, F) = CE_{\alpha}(E, F) + CE_{\alpha}(F, E) \]
\[ = \frac{1}{2^{\alpha - 1}} - 1 \left\{ \exp\left\{ (\alpha - 1) \sum_{i=1}^{n} \left( \mu_E(u_i) \ln\left( \frac{\mu_E(u_i)}{(1/2)(\mu_E(u_i) + \mu_F(u_i))} \right) \right. \right. \]
\[ + v_E(u_i) \ln\left( \frac{v_E(u_i)}{(1/2)(v_E(u_i) + v_F(u_i))} \right) \right\} \right\] \]
\[ + \left[ \exp\left\{ (\alpha - 1) \sum_{i=1}^{n} \left( \mu_F(u_i) \ln\left( \frac{\mu_F(u_i)}{(1/2)(\mu_E(u_i) + \mu_F(u_i))} \right) \right. \right. \]
\[ + v_F(u_i) \ln\left( \frac{v_F(u_i)}{(1/2)(v_E(u_i) + v_F(u_i))} \right) \right\} \right\} - 2 \].

\[ L_{G_{\beta}}(E, F) = \sum_{i=1}^{n} \left\{ \left( \frac{(\mu_E(u_i) + 1 - v_E(u_i))}{2} \right) e^{\beta\left( \frac{\mu_F(u_i) + 1 - v_E(u_i)}{(1/2)(\mu_E(u_i) + \mu_F(u_i))} \right) - v_E(u_i)} \right\} \]
\[ + \left( \frac{v_F(u_i) + \mu_F(u_i)}{2} \right) e^{\beta\left( \frac{v_E(u_i) + 1 - v_F(u_i)}{(1/2)(\mu_E(u_i) + \mu_F(u_i))} \right) - v_F(u_i)} \].

From the above discussions, it has been examined that all measures do not incorporate decision experts’ preferences into the measure. Keeping in mind the flexibility and efficiency of criteria for IFSs, this paper develops generalized discrimination measure to evaluate the fuzziness degree of a set.

4. New IF-Discrimination Measure and Comparison

In the following sub-section, to evade the drawbacks of current discrimination measures, novel IF-discrimination measures are developed.

4.1. New Discrimination Measure for IFSs

Here, we have proposed some flexible and generalized parametric IF-discrimination measures. Various attractive properties of developed ones are being studied.

Let \( E, F \in IFSs(U) \), then an IF-discrimination measure is based on Parkash and Kumar (2017); we can define the following measure:

**Definition 3.** Let \( E, F \in IFSs(U) \). Then, an IF-discrimination measure is defined as

\[ L_1(E, F) = \frac{1}{2n \ln 2} \sum_{i=1}^{n} \left[ \left( (\mu_E(u_i) + \mu_F(u_i)) \right) \ln\left\{ \frac{\mu_E(u_i) + \mu_F(u_i)}{2(\sqrt{\mu_E(u_i)} + \sqrt{\mu_F(u_i)})} \right\} \right. \]
\[ + \left( (v_E(u_i) + v_F(u_i)) \right) \ln\left\{ \frac{v_E(u_i) + v_F(u_i)}{2(\sqrt{v_E(u_i)} + \sqrt{v_F(u_i)})} \right\} \].

\[ (6) \]
$L_2(E, F) = \frac{1}{2n \ln 2} \sum_{i=1}^{n} \left[ \frac{(\mu_E(u_i) + \mu_F(u_i)) + 2 - (v_E(u_i) + v_F(u_i))}{2} \right] \times \ln \left\{ \frac{1}{2} \left( \sqrt{\mu_E(u_i)} + 1 - v_E(u_i) + \sqrt{\mu_F(u_i)} + 1 - v_F(u_i) \right) \right\} + \left( \frac{(v_E(u_i) + v_F(u_i)) + 2 - (\mu_E(u_i) + \mu_F(u_i))}{2} \right) \times \ln \left\{ \frac{1}{2} \left( \sqrt{\mu_E(u_i)} + 1 - v_E(u_i) + \sqrt{\mu_F(u_i)} + 1 - v_F(u_i) \right) \right\}$. (7)

**Definition 4.** A parametric symmetric IF-discrimination measure between IFSs $E$ and $F$ with $\gamma > 0$ ($\gamma \neq 1$) is proposed as follows:

$L_3(E, F) = \frac{1}{n(2^{1-\gamma/2} - 1)} \sum_{i=1}^{n} \left[ \frac{\left( (\mu_E(u_i))^2 + (\mu_F(u_i))^2 \right)^{\gamma/2}}{2} - \frac{\mu^\gamma_E(u_i) + \mu^\gamma_F(u_i)}{2} + \frac{\left( (v_E(u_i))^2 + (v_F(u_i))^2 \right)^{\gamma/2}}{2} - \frac{v^\gamma_E(u_i) + v^\gamma_F(u_i)}{2} + \frac{\left( (\pi_E(u_i))^2 + (\pi_F(u_i))^2 \right)^{\gamma/2}}{2} - \frac{\pi^\gamma_E(u_i) + \pi^\gamma_F(u_i)}{2} \right]$. (8)

**Theorem 1.** The functions $L_\alpha(E, F); \alpha = 1, 2, 3$, given by (6)–(8) are IF-discrimination measures:

(P1). $L_\alpha(E, F) = L_\alpha(F, E); \alpha = 1, 2, 3$.

(P2). $L_\alpha(E, F) = 0$ iff $E = F$.

(P3). $L_\alpha(E \cup P, F \cup P) \leq L_\alpha(E, F)$ for every $P \in IFS(Z)$.

(P4). $L_\alpha(E \cap P, F \cap P) \leq L_\alpha(E, F)$ for every $P \in IFS(Z)$.

(P5). $L_\alpha(E, E \cup F) + L_\alpha(E, E \cap F) = L_\alpha(E, F)$.

(P6). $L_\alpha(E, E \cap F) = L_\alpha(E, E \cup F)$.

(P7). $L_\alpha(E, F) = L_\alpha(E^c, F^c)$.

(P8). $L_\alpha(E, F^c) = L_\alpha(E^c, F)$.

(P9). $L_\alpha(E, E^c) = 1$ iff $E$ is a crisp set.

4.2. Comparison with the Existing IF-Discrimination Measures

To indicate the superiority of the developed IF-discrimination measures, we compared the developed IF-discrimination and the current discrimination measures. A comparison is employed based on the extensively utilized counter-intuitive cases. Table 2 demonstrates the result of the proposed and existing IF-discrimination measures.

From Table 2, $L_{ZJ}(E, F) = L_O(E, F) = L_1(E, F) = 0$ for two different IFSs $E = (0.3, 0.3)$ and $F = (0.4, 0.4)$. This demonstrates that the second postulate of IF-discrimination measure (D2) is not fulfilled by $L_{ZJ}(E, F), L_O(E, F)$ and $L_1(E, F)$. 
Table 2
Comparison of IF-discrimination measures (counter-intuitive cases are in bold type).

| Case 1  | Case 2  | Case 3  | Case 4  | Case 5  |
|---------|---------|---------|---------|---------|
| $E = (\mu_E, \nu_E)$ | $E = (0.3, 0.3)$ | $E = (0.3, 0.4)$ | $E = (0.5, 0.5)$ | $E = (0.4, 0.2)$ | $E = (0.4, 0.2)$ |
| $F = (\mu_F, \nu_F)$ | $F = (0.4, 0.4)$ | $F = (0.4, 0.3)$ | $F = (0.0, 0.0)$ | $F = (0.5, 0.3)$ | $F = (0.5, 0.2)$ |
| $L_{ZJ}(E, F)$ | 0.0000 | 0.0050 | 0.0000 | 0.0000 | 0.0013 |
| $L_{WY}(E, F)$ | 0.0226 | 0.0072 | NaN | 0.0233 | 0.0063 |
| $L_{VS_1}(E, F)$ | 0.0078 | 0.0026 | NaN | 0.0081 | 0.0023 |
| $L_{VS_2}(E, F)$ | 0.8385 | 0.7852 | NaN | 0.8052 | 0.7882 |
| $L_{MS_2}(E, F)$ | 0.4122 | 0.3581 | 1.0000 | 0.4122 | 0.3581 |
| $L_O(E, F)$ | 0.0000 | 0.0050 | 0.0000 | 0.0000 | 0.0013 |
| $L_1(E, F)$ | 0.0000 | 0.0017 | NaN | 0.0000 | 0.0005 |
| $L_2(E, F)$ | 0.0025 | 0.0025 | 0.2402 | 0.0027 | 0.0010 |
| $L_3(E, F)$ | 0.0555 | 0.0173 | 0.9353 | 0.0565 | 0.0157 |

This also can be illustrated by $L_{ZJ}(E, F) = L_O(E, F) = L_1(E, F) = 0$ when $E = (0.5, 0.5)$, $F = (0.0, 0.0)$, while $L_{WY}(E, F)$, $L_{VS_1}(E, F)$ and $L_{VS_2}(E, F)$ are not defined when $E = (0.5, 0.5)$, $F = (0.0, 0.0)$. Therefore, the proposed IF-discrimination measure $L_3(E, F)$ is in agreement with this analysis. The developed IF-discrimination is the best reasonable discrimination measure without any counterintuitive examples.

5. The IF-MABAC Approach for MCDM Problem

Here, the MABAC method is explored for solving the MCDM issues under IFSs.

5.1. The Extended IF-MABAC Method-Based on the Discrimination Measures

Let $M = \{M_1, M_2, \ldots, M_m\}$ and $F = \{F_1, F_2, \ldots, F_n\}$ be a set of options and criteria, respectively. The outline of the introduced IF-MABAC framework is demonstrated in the following stages (see Fig. 1):

**Stage 1:** Determine weights of decision experts’ (DEs)

Construct a group $\ell$ DEs to include decision making concerning various perspectives. Suppose the rating specified for each DE through experts is $E_k = (\mu_k, \nu_k, \pi_k)$, $\forall k$. According to Boran et al. (2009), DEs weight is calculated by

$$
\lambda_k = \frac{(\mu_k + \pi_k (\frac{\mu_k}{\mu_k + \nu_k}))}{\sum_{k=1}^{\ell} (\mu_k + \pi_k (\frac{\mu_k}{\mu_k + \nu_k}))}, \quad k = 1, 2, \ldots, \ell,
$$

(9)

where $\lambda_k > 0$, $\sum_{k=1}^{\ell} \lambda_k = 1$.

**Stage 2:** Construct IF-aggregation decision matrix (IF-ADM) over DEs weights

Aggregate the individual DEs assessment matrices $Z = (\xi_{ij})_{m \times n}$ generated by experts in linguistic terms mapped into IFNs by using Eq. (5) over the DEs weight $\lambda_k$ such that $\sum_{k=1}^{\ell} \lambda_k = 1$, $\lambda_k \in [0, 1]$ and we construct IF-ADM as $Z = [\xi_{ij}]_{m \times n}$. 
Stage 3: Evaluate the criteria weights based on the IF-discrimination measures

Let \( w = (w_1, w_2, \ldots, w_n)^T \), where \( \sum_{j=1}^{n} w_j = 1, w_j \in [0, 1] \) be a criterion weight vector. Here, criteria weights are determined using the developed IF-discrimination measure as follows:

\[
    w_j = \frac{\sum_{i=1}^{m} \sum_{k=1}^{m} L_\alpha(\xi_{ij}, \xi_{kj})}{\sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{m} L_\alpha(\xi_{ij}, \xi_{kj})}, \quad \forall j, \alpha = 1, 2, 3.
\]
Stage 4: Build the normalized IF-ADM
The normalized IF-ADM $N = [\xi_{ij}]_{m \times n}$ for a set of options is defined by

$$\xi_{ij} = \begin{cases} \xi_{ij} = \langle \mu_{ij}, \nu_{ij} \rangle, & \text{for beneficial criterion,} \\ (\xi_{ij})^c = \langle \nu_{ij}, \mu_{ij} \rangle, & \text{for non-beneficial criterion.} \end{cases}$$

Stage 5: Evaluate the weighted IF-ADM
When the weight $w_j$ of criteria $F_j$ is constructed, the weighted IF-ADM $R = [\varsigma_{ij}]_{m \times n}$ is calculated by:

$$\varsigma_{ij} = w_j \xi_{ij} = \left[ 1 - (1 - \mu_{ij}) w_j \right], \left[ (\nu_{ij}) w_j \right],$$

where $\varsigma_{ij} = \langle \hat{\mu}_{ij}, \hat{\nu}_{ij} \rangle$ is a weighted IFN.

Stage 6: Compute the border approximation area (BAA) matrix
The matrix for BAA $G = [\hat{g}_j]_{1 \times n}$ is showed in terms of IFNs by applying the IFGO and is given by

$$\hat{g}_j = \prod_{i=1}^{m} (\varsigma_{ij})^{1/m} = \left[ \prod_{i=1}^{m} (\hat{\mu}_{ij})^{1/m} \right], \left[ 1 - \prod_{i=1}^{m} (1 - \hat{\nu}_{ij})^{1/m} \right],$$

where $\hat{g}_j = \langle \hat{\mu}_j, \hat{\nu}_j \rangle$ is an IFN.

Stage 7: Compute the discrimination values from the BAA
With the proposed IF-discrimination measure, the degree of discriminations of the alternative from the BAA are determined by

$$\vartheta_{ij} = \begin{cases} L(\varsigma_{ij}, \hat{g}_j), & \text{if } \varsigma_{ij} \geq \hat{g}_j, \\ 0, & \text{if } \varsigma_{ij} = \hat{g}_j, \\ -L(\varsigma_{ij}, \hat{g}_j), & \text{if } \varsigma_{ij} \leq \hat{g}_j \end{cases}$$

with the discrimination measure $L$ being demonstrated by Eq. (7).

Stage 8: Derive the ranking order
The degrees of performance function for an alternative are determined to add the discriminations from the BAA for each alternative and are specified by

$$C_i = \sum_{j=1}^{n} \vartheta_{ij}.$$ 

Next, the preference order of their degree of performance function for the alternative is evaluated and the desirable Smartphone for the given SPS problem can be demonstrated.
6. Application of Smartphone Selection of IF-MABAC Method

In the present section, the developed IF-MABAC approach is implemented to solve SPS problem. Seven Smartphones as alternatives are considered as follows: Apple (M1), Xiaomi (M2), Nokia (M3), HTC (M4), OPPO (M5), VIVO (M6) and Samsung (M7), by a user who needs to purchase a smartphone and three DEs who have thorough knowledge on Smartphones (to construct DEs committee), consequently, a study of the relevant websites and the technology markets is conducted. To select a desirable Smartphone, the following 8 criteria are characterized into three main groups according to the DEs opinions, namely, technical specifications (e.g. storage capacity & RAM, camera, battery power, processor type, operating system), physical specifications (viz., screen size), and user-oriented features (viz., ease of use, price). The operational parameters are given as follows: Price (F1), Battery Power (F2), Camera (F3), Storage Capacity and RAM (F4), Processor Type (F5), Screen Size (F6), Ease of Use (F7) and Operating System (F8) (see Fig. 2).

Here, Table 3 and Table 4 describe the linguistic terms (LTs) in the forms of IFNs for the criteria and DEs importance. According to these two tables and Eq. (9), the DEs’
weights are calculated and presented in Table 5. The linguistic values illustrated in Table 6 by three DEs under the criteria parameters of specified SPSs.

According to DEs weights obtained by Eq. (9), and Eq. (5), IF-ADM regarding SPSs is constructed and shown in Table 7. Since one criterion is non-benefit type and the remaining are benefit type, by Eq. (11), Table 8 depicts the normalized decision matrix for SPSs.

Using Eqs. (7) and (10), the objective weights of the criteria is computed as: \( w_j = (0.2726, 0.0388, 0.1222, 0.1479, 0.1638, 0.0446, 0.1718, 0.0383)^T \). In the following, the weighted IF-ADM is made and provided in Table 9.

The BAA (\( \tilde{G} \)) is obtained based on Table 10 and Eq. (14), which is \( \tilde{G} = \{(0.0719, 0.9009), (0.0622, 0.9307), (0.1564, 0.8219), (0.1716, 0.8011), (0.1802, 0.7755), (0.0730, 0.9185), (0.1899, 0.7702), (0.0440, 0.9181)\} \).

Next, the discrimination matrix of SPSs option from BAA is evaluated by Eq. (7) and Eq. (15). The corresponding discrimination matrix is established and revealed in Table 10. The closeness degree of the BAA for each Smartphone is computed by Eq. (15) and shown in Table 10. Finally, all Smartphones ranks are shown based on the values which are depicted in Table 10. As a result, Smartphone \( M_7 \) (Samsung) is preferred as the most desirable Smartphone among the seven SPSs.
Table 6
The linguistic variable for Smartphones rating.

| Parameters                     | Smartphone       | Experts |
|-------------------------------|------------------|---------|
|                               | $E_1$ | $E_2$ | $E_3$ |
| Price ($F_1$)                 | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | H     | H     | H     |
| $M_2$                         | L     | L     | A     |
| $M_3$                         | H     | H     | H     |
| $M_4$                         | H     | VH    | H     |
| $M_5$                         | VL    | H     | H     |
| $M_6$                         | VL    | A     | VH    |
| $M_7$                         | H     | VH    | H     |
| Battery power ($F_2$)         | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | H     | VH    | VH    |
| $M_2$                         | A     | VH    | H     |
| $M_3$                         | VH    | VH    | A     |
| $M_4$                         | VH    | H     | H     |
| $M_5$                         | A     | VH    | H     |
| $M_6$                         | H     | A     | VH    |
| $M_7$                         | H     | VH    | H     |
| Camera ($F_3$)                | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | A     | VH    | VH    |
| $M_2$                         | H     | A     | A     |
| $M_3$                         | A     | A     | H     |
| $M_4$                         | A     | VH    | VH    |
| $M_5$                         | L     | VH    | H     |
| $M_6$                         | L     | VH    | H     |
| $M_7$                         | A     | VH    | VH    |
| Storage capacity and RAM ($F_4$) | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | L     | A     | VH    |
| $M_2$                         | VH    | A     | VH    |
| $M_3$                         | L     | H     | VH    |
| $M_4$                         | L     | H     | H     |
| $M_5$                         | L     | H     | VH    |
| $M_6$                         | H     | L     | H     |
| $M_7$                         | VH    | A     | VH    |
| Processor type ($F_5$)        | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | A     | H     | H     |
| $M_2$                         | A     | H     | H     |
| $M_3$                         | H     | H     | A     |
| $M_4$                         | H     | H     | A     |
| $M_5$                         | A     | H     | A     |
| $M_6$                         | H     | H     | A     |
| $M_7$                         | VH    | VH    | VH    |
| Screen size ($F_6$)           | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | VH    | VH    | H     |
| $M_2$                         | H     | VH    | A     |
| $M_3$                         | H     | H     | VH    |
| $M_4$                         | H     | H     | VH    |
| $M_5$                         | H     | VH    | A     |
| $M_6$                         | VH    | VH    | H     |
| $M_7$                         | VH    | VH    | H     |
| Ease of use ($F_7$)           | $E_1$ | $E_2$ | $E_3$ |
| $M_1$                         | A     | H     | VH    |
| $M_2$                         | A     | H     | VH    |
| $M_3$                         | H     | L     | A     |
| $M_4$                         | H     | L     | A     |
| $M_5$                         | L     | H     | H     |
| $M_6$                         | L     | VH    | H     |
| $M_7$                         | VH    | H     | VH    |

(continued on next page)
Table 6  
(continued)  
| Parameters            | Smartphone | Experts |
|-----------------------|------------|---------|
|                       |            | E₁      | E₂      | E₃      |
| Operating system (F₈) | M₁         | A       | A       | H       |
|                       | M₂         | H       | A       | H       |
|                       | M₃         | A       | A       | H       |
|                       | M₄         | A       | VH      | A       |
|                       | M₅         | A       | VH      | A       |
|                       | M₆         | H       | A       | H       |
|                       | M₇         | A       | A       | VH      |

Table 7  
The IF-ADM for Smartphones.  

|      | M₁       | M₂       | M₃       | M₄       | M₅       | M₆       | M₇       |
|------|----------|----------|----------|----------|----------|----------|----------|
| F₁   | (0.7000, | (0.4648, | (0.7000, | (0.7951, | (0.5684, | (0.6502, | (0.7951, |
|      | 0.2000)  | 0.4329)  | 0.2000)  | 0.1572)  | 0.3183)  | 0.3013)  | 0.1572)  |
| F₂   | (0.8493, | (0.7720, | (0.8521, | (0.8004, | (0.7720, | (0.7568, | (0.8493, |
|      | 0.1293)  | 0.1828)  | 0.1363)  | 0.1547)  | 0.1828)  | 0.1893)  | 0.1293)  |
| F₃   | (0.8328, | (0.6405, | (0.6312, | (0.8328, | (0.7350, | (0.7350, | (0.8328, |
|      | 0.1503)  | 0.2581)  | 0.2676)  | 0.1503)  | 0.2209)  | 0.2209)  | 0.1503)  |
| F₄   | (0.6856, | (0.8382, | (0.7154, | (0.6121, | (0.7154, | (0.6184, | (0.8382, |
|      | 0.2660)  | 0.1464)  | 0.2310)  | 0.2809)  | 0.2310)  | 0.2749)  | 0.1464)  |
| F₅   | (0.6662, | (0.6662, | (0.6746, | (0.6746, | (0.6380, | (0.6746, | (0.9000, |
|      | 0.2325)  | 0.2325)  | 0.2242)  | 0.2242)  | 0.2606)  | 0.2242)  | 0.1000)  |
| F₆   | (0.8637, | (0.7778, | (0.7799, | (0.7799, | (0.7778, | (0.8637, | (0.8637, |
|      | 0.1216)  | 0.1763)  | 0.1645)  | 0.1645)  | 0.1763)  | 0.1216)  | 0.1216)  |
| F₇   | (0.7552, | (0.7552, | (0.5862, | (0.5862, | (0.6121, | (0.7350, | (0.8536, |
|      | 0.1912)  | 0.1912)  | 0.3082)  | 0.3082)  | 0.2000)  | 0.2209)  | 0.1272)  |
| F₈   | (0.6312, | (0.6685, | (0.6312, | (0.7527, | (0.7527, | (0.6685, | (0.7295, |
|      | 0.2676)  | 0.2302)  | 0.2676)  | 0.2049)  | 0.2049)  | 0.2302)  | 0.2201)  |

Table 8  
The normalized IF-ADM for Smartphones.  

|      | M₁       | M₂       | M₃       | M₄       | M₅       | M₆       | M₇       |
|------|----------|----------|----------|----------|----------|----------|----------|
| F₁   | (0.2000, | (0.4329, | (0.2000, | (0.1572, | (0.3183, | (0.3103, | (0.1572, |
|      | 0.7000)  | 0.4648)  | 0.2000)  | 0.7951)  | 0.5684)  | 0.6502)  | 0.7951)  |
| F₂   | (0.8493, | (0.7720, | (0.8521, | (0.8004, | (0.7720, | (0.7568, | (0.8493, |
|      | 0.1293)  | 0.1828)  | 0.1363)  | 0.1547)  | 0.1828)  | 0.1893)  | 0.1293)  |
| F₃   | (0.8328, | (0.6405, | (0.6312, | (0.8328, | (0.7350, | (0.7350, | (0.8328, |
|      | 0.1503)  | 0.2581)  | 0.2676)  | 0.1503)  | 0.2209)  | 0.2209)  | 0.1503)  |
| F₄   | (0.6856, | (0.8382, | (0.7154, | (0.6121, | (0.7154, | (0.6184, | (0.8382, |
|      | 0.2660)  | 0.1464)  | 0.2310)  | 0.2809)  | 0.2310)  | 0.2749)  | 0.1464)  |
| F₅   | (0.6662, | (0.6662, | (0.6746, | (0.6746, | (0.6380, | (0.6746, | (0.9000, |
|      | 0.2325)  | 0.2325)  | 0.2242)  | 0.2242)  | 0.2606)  | 0.2242)  | 0.1000)  |
| F₆   | (0.8637, | (0.7778, | (0.7799, | (0.7799, | (0.7778, | (0.8637, | (0.8637, |
|      | 0.1216)  | 0.1763)  | 0.1645)  | 0.1645)  | 0.1763)  | 0.1216)  | 0.1216)  |
| F₇   | (0.7552, | (0.7552, | (0.5862, | (0.5862, | (0.6121, | (0.7350, | (0.8536, |
|      | 0.1912)  | 0.1912)  | 0.3082)  | 0.3082)  | 0.2000)  | 0.2209)  | 0.1272)  |
| F₈   | (0.6312, | (0.6685, | (0.6312, | (0.7527, | (0.7527, | (0.6685, | (0.7295, |
|      | 0.2676)  | 0.2302)  | 0.2676)  | 0.2049)  | 0.2049)  | 0.2302)  | 0.2201)  |
Table 9

The weighted IF-ADM for Smartphone selection.

|      | $M_1$     | $M_2$     | $M_3$     | $M_4$     | $M_5$     | $M_6$     | $M_7$     |
|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $F_1$| (0.0590,  | (0.1433,  | (0.0590,  | (0.0456,  | (0.0992,  | (0.0963,  | (0.0456,  |
|      | 0.9073)  | 0.8115)  | 0.9073)  | 0.8573)  | 0.8893)  | 0.9394)  | 0.9394)  |
| $F_2$| (0.0708,  | (0.0557,  | (0.0715,  | (0.0606,  | (0.0557,  | (0.0534,  | (0.0709,  |
|      | 0.9237)  | 0.9256)  | 0.9301)  | 0.9362)  | 0.9375)  | 0.9237)  | 0.9237)  |
| $F_3$| (0.1963,  | (0.1175,  | (0.1148,  | (0.1963,  | (0.1498,  | (0.1498,  | (0.1963,  |
|      | 0.7933)  | 0.8475)  | 0.8512)  | 0.7933)  | 0.8315)  | 0.8315)  | 0.7933)  |
| $F_4$| (0.1573,  | (0.2362,  | (0.1696,  | (0.1307,  | (0.1696,  | (0.1328,  | (0.2362,  |
|      | 0.8221)  | 0.7526)  | 0.8052)  | 0.8288)  | 0.8052)  | 0.8261)  | 0.7526)  |
| $F_5$| (0.1645,  | (0.1645,  | (0.1680,  | (0.1680,  | (0.1533,  | (0.1680,  | (0.3142,  |
|      | 0.7874)  | 0.7874)  | 0.7828)  | 0.7828)  | 0.8023)  | 0.7828)  | 0.6858)  |
| $F_6$| (0.0850,  | (0.0649,  | (0.0653,  | (0.0649,  | (0.0850,  | (0.0850,  | (0.0850,  |
|      | 0.9103)  | 0.9255)  | 0.9227)  | 0.9227)  | 0.9255)  | 0.9103)  | 0.9103)  |
| $F_7$| (0.2148,  | (0.2148,  | (0.1407,  | (0.1407,  | (0.1502,  | (0.2040,  | (0.2811,  |
|      | 0.7526)  | 0.7526)  | 0.8169)  | 0.8169)  | 0.7584)  | 0.7715)  | 0.7077)  |
| $F_8$| (0.0375,  | (0.0414,  | (0.0375,  | (0.0521,  | (0.0521,  | (0.0414,  | (0.0488,  |
|      | 0.9508)  | 0.9453)  | 0.9508)  | 0.9411)  | 0.9411)  | 0.9453)  | 0.9437)  |

Table 10

The discrimination matrix of all alternatives from the BAA for Smartphones.

|      | $F_1$     | $F_2$     | $F_3$     | $F_4$     | $F_5$     | $F_6$     | $F_7$     | $F_8$     | $C_i$     | Rank |
|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|------|
| $M_1$| -0.0001   | 0.00004   | -0.0003   | -0.00009  | -0.00005  | 0.0039    | 0.0004    | -0.0003   | 0.00413   | 2    |
| $M_2$| 0.0026    | 0.00002   | 0.0003    | 0.0008    | 0.00005   | 0.00003   | 0.0001    | 0.0001    | 0.00400   | 3    |
| $M_3$| 0.00005   | 0.00003   | 0.0004    | 0.000003  | 0.00002   | 0.00002   | 0.0060    | 0.0003    | 0.001423  | 5    |
| $M_4$| 0.00007   | 0.00000   | 0.0003    | 0.00003   | 0.00002   | 0.00002   | 0.0060    | 0.00004   | 0.00198   | 4    |
| $M_5$| 0.00005   | 0.00002   | 0.00002   | 0.00002   | 0.00005   | 0.00004   | 0.00004   | 0.00008   | 6      |
| $M_6$| 0.0001    | 0.00004   | 0.00002   | 0.00003   | 0.00002   | 0.00005   | 0.00001   | 0.00001   | 0.00064   | 7    |
| $M_7$| 0.0007    | 0.00004   | 0.0003    | 0.00008   | 0.00028   | 0.00005   | 0.0014    | 0.00008   | 0.00617   | 1    |

6.1. Comparison with Other Works

Here, we illustrate a comparative evaluation with the existing method to show the validity and usefulness of the IF-MABAC approach based on IF-discrimination measures. We have implemented the same numerical example applying the developed approach for comparing with the existing approaches.

The above Smartphone selection problem is also solved by the ANP-Generalized Choquet integral method (Yildiz and Ergul, 2015), the fuzzy ELECTRE method (Belbag et al., 2016) and the Shapley discrimination measure VIKOR method (Mishra and Rani, 2019). Outcomes of the different approaches were obtained to certify the outcomes of the developed IF-MABAC method. Moreover, we implement the given case study to investigate the above methods and to show the effectiveness of the proposed approach. Figure 3 and Table 11 demonstrate the preference orders of the SPSs alternatives as achieved by applying the existing methods.

The outcomes show that the optimal preference of SPSs is the same, i.e. $M_7$ (Samsung), based on the introduced framework and the existing models. Further, the correlation values
among the preference orders evaluated by the developed and other methods are 0.964, 0.884, and 0.964, respectively. The analyses express the strength of the introduced IF-MABAC framework.

The key distinctive outcomes of the developed IF-MABAC framework are as follows:

i. To tackle with uncertainty in MCDM problems, all the facets, namely, the alternative on the assessments criteria by various DEs, the DEs weights, and the criteria weights are taken in the form of IFNs.

Table 11
Discussion of the developed method with current methods.

| Methods             | Discipline | Benchmark                          | Criterion weights | Expert weights | Ranking order          | Best Smartphone |
|---------------------|------------|------------------------------------|-------------------|----------------|------------------------|----------------|----------------|
| Yildiz and Ergul (2015) | FSs        | ANP – Generalized choquet integral | ANP               | Assumed        | \( M_7 > M_2 > M_1 > M_4 \) \( M_7 > M_3 > M_5 > M_6 \) |                |
| Belbag et al. (2016)  | FSs        | Fuzzy ELECTRE                      | TFNs              | Assumed        | \( M_7 \approx M_1 > M_4 > M_3 \) \( M_7, M_1 \) \( M_2 > M_5 > M_6 \) |                |
| Mishra and Rani (2019) | IFSs       | IF-VIKOR                           | Shapley function with entropy method | Not considered | \( M_7 > M_1 > M_4 > M_2 \) \( M_7 \) \( M_3 > M_5 > M_6 \) |                |
| Proposed method      | IFSs       | IF-MABAC                           | Discrimination measure | Computed measure | \( M_7 > M_1 > M_2 > M_4 \) \( M_7 \) \( M_3 > M_5 > M_6 \) |                |
ii. The developed approach utilizes IFSs to develop the procedure, different from the methods in Yildiz and Ergul (2015) and Belbag et al. (2016), wherein the FSs are implemented.

iii. The criteria weights of proposed IF-MABAC approach are obtained through the proposed IF-discrimination measure, which gives more precise weights, different from the randomly assumed criteria weights in Belbag et al. (2016).

iv. Multiple DEs have been selected in the developed method whose weights are given in terms of IFNs, while the methodology proposed in Yildiz and Ergul (2015), Belbag et al. (2016) and Mishra and Rani (2019) did not incorporate the group decision making (GDM) procedure.

v. Criteria weights in the developed IF-MABAC method are provided as IFNs, whereas in Belbag et al. (2016) and Mishra and Rani (2019), the crisp weights are assumed, leaving no space to handle the uncertainty.

7. Conclusions

With the use of technology, human life becomes more comfortable, and therefore it becomes a requisite for users. Several brands or products materialize on the business world with fast-growing technology and Smartphones are one of these products. A desirable Smartphone selection from the available options is a complex problem since it has different types of processors, RAM in GB, screens with HD resolution, O/S, etc. Several interesting criteria affect the SPS, as similar to various products. Hence, MCDM approaches can facilitate to evaluate SPS problem. Here, an integrated approach based on MABAC under IFSs was developed to assess the SPS problem. To compute the weight of the vector, new IF-discrimination measures were developed, and some useful properties were presented. The novel developed discrimination measure based on IFSs is verified, it would solve the problem of some current distance measures. The assessment of each SPSs alternative over different criteria was assessed on IFSs, and a new IF-MABAC framework was applied to prefer the most desirable Smartphone. To investigate the usefulness of the IF-MABAC method, comparative analyses with existing approaches were presented. The computational findings found that the ranking outcomes achieved based on the IF-MABAC method were reliable with existing ones; and hence, the developed method was sound to the SPSs under uncertainty. By employing the integrated IF-MABAC approach, a more consistent and best ranking findings of SPS case would be obtained, which help to make the accurate decision for selection of smartphone.

Further, we will integrate the MABAC framework with various other procedures, viz., CRITIC, AHP and SWARA, in the MCDM process. Also, the introduced approach would be employed for deciphering the several real-world problems, namely, supplier or material selection, and electric vehicles charging station selection to elucidate its strength and usefulness.
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