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Author(s): Shukla, Amit K.; Prakash, Vishnu; Nath, Rahul; Muhuri, Pranab K.

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Type-2 intuitionistic fuzzy TODIM for intelligent decision-making under uncertainty and hesitancy

Amit K. Shukla¹ · Vishnu Prakash² · Rahul Nath² · Pranab K. Muhuri²

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Abstract

The classical TODIM considers the crisp numbers to handle the information. However, in a real-world applicative context, this information is bounded by noise and vagueness and hence uncertain. There are wide range of works in the literature which utilizes fuzzy sets to handle the uncertainty in the various dimensions. However, there is a constraint of hesitancy in such decision-making problems due to the involvement of various decision-makers. Also, in the TODIM method, decision-maker's bounded rationality and psychological behavior are also taken into consideration which adds up the hesitation and considers the problem with higher dimension of uncertainty. There are various applications of fuzzy TODIM using type-2 fuzzy numbers where uncertainty is being handled in more than one dimensions and also the introduction of intuitionistic fuzzy numbers where hesitancy factor of a decision-maker is taken into account. This paper targets to handle the uncertainty in more than one dimension keeping the hesitancy part into consideration for intelligent decision-making. Therefore, a novel trapezoidal type-2 intuitionistic fuzzy set (TrT2 IFS) is proposed, which is an aggregation of several triangular IFSs having upper and lower membership along with a non-membership value. For this TrT2 IFS, we have defined the generation procedure, operations, comparison and distance between such TrT2 IFSs. In addition, the decision-maker weights and criterion weight computation are also presented with respect to the TODIM approach. Furthermore, we have applied this extended TrT2 IFS-based TODIM method into a renewable energy resource selection problem of multi-criteria decision-making.

Keywords TODIM · Intuitionistic fuzzy set · Intelligent decision-making · Type-2 fuzzy sets · Multi-criteria decision-making

1 Introduction

Decision-making is a procedure for selecting the best alternative between at least two options based on one criterion (Zadeh 1965). This problem turns into a more complex optimization problem when there is more than one criterion. It becomes a critical task to choose one best alternative out of many, based on several criteria. These kinds of problems lie in the domain of multi-criteria

decision-making (MCDM), which are defined as a process to choose an alternative out of more than one alternative based on multiple criteria. Two types of MCDM techniques are defined in the literature (Krohling and Souza 2012): (a) Multiple objective decision-making (MODM), and (b) Multiple attribute decision-making (MADM). The decision space for MODM problems is continuous, as in mathematical programming with multiple objective functions (Fan et al. 2013). On the other hand, MADM problems are related to discrete choice space where the set of alternatives are predetermined (Hanine et al. 2016). MCDM techniques has wide range of application such as green supplier chain management, construction project management, energy planning, economics service quality evaluation, and tourism management engineering management. MCDM techniques work on “expected utility theory” of economics where the decision-maker is

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✉ Amit K. Shukla
amit.k.shukla@jyu.fi; amikshukla@live.com

¹ Faculty of Information Technology, University of Jyväskylä, Box 35 (Agora), 40014 Jyväskylä, Finland

² Department of Computer Science, South Asian University, New Delhi 110021, India

considered as entirely rational, which means they are aware of all alternatives concerning each criterion.

However, in a real-world practical situation, this is not completely feasible. The experts are generally surrounded by limited rationality in real conditions due to ambiguity and uncertainty. The psychological behavior of the expert in decision-making also plays a very vital role. To handle these problems, TODIM was introduced which is an acronym in Portuguese for interactive and multi-criteria decision-making. Developed by Gomes and Lima, TODIM is basically a multi-criteria group decision-making (MCGDM) or MCDM technique where more than one decision-maker take part in selecting the optimal alternative with respect to more than one criterion. Published in 1979, TODIM is most likely the main technique dependent on prospect theory (Krohling and Souza 2012). The research goal was to assess human conduct amid essential leadership at risk situations. In the TODIM method, the decision-maker always tries to find a solution that correlates to the maximum of some global value measure by applying the prospect theory framework. In this manner, the process is focused on an explanation of how people make risk-facing choices, demonstrated by scientific evidence. The TODIM strategy utilizes pair examinations between choice criteria, having technically basic and right assets to take out potential irregularities emerging from these comparisons. It likewise permits judgment esteems to be completed on a verbal scale, utilizing a criteria hierarchy, fluffy esteem decisions, and utilizing relations of reliance among the alternatives.

Although TODIM method can adequately handle the decision-maker's psychological behavior, some serious issues are still left to tackle. To recall, in the classical TODIM method, each alternative is given a crisp numerical value for each criterion, which shows the performance of that alternative with respect to that criteria. However, in a real-world applicative context, there are inherent estimation inaccuracies, incomplete knowledge, and ambiguities, leading to the overall uncertainty in the decision-making process. No one can be sure about the alternative's performance under those criteria. Therefore, the classical TODIM approaches are unable to handle such uncertainty and imprecise information. To overcome these issues, decision-makers usually model their preferences under the framework of fuzzy sets (traditionally referred to as type-1 fuzzy sets).

These type-1 fuzzy sets (T1 FSs) are characterized by membership function which are formed with the help of degree of membership between of each element, set in the range $[0, 1]$. However, recently, extensive range of works on decision-making problems has considered intuitionistic fuzzy sets (IFSs) to handle the uncertainty. Proposed by Atanassov (Wang et al. 2013), IFSs are the generalized

version of fuzzy sets which provides the freedom to also model the hesitancy in the decision-making. They are defined with a membership and a non-membership degree, and the subtraction of both from unity returns the hesitation margin. However, these traditional T1 FSs or the IFSs are often associated with the interpretability issues since their membership values are still crisp in nature. While dealing with these classical intuitionistic fuzzy sets, there is a membership and a non-membership in type-1, it is believed that uncertainty in evaluation can be considered fade away. Despite that, there could be some amount of uncertainty near the membership and non-membership boundaries. And with respect to the real-world applicative context, the ambiguous and imprecise information tends to be higher. This problem can be handled using type-2 membership function as can be seen with type-2 fuzzy sets (T2 FSs) (Shukla et al. 2020; Muhuri and Shukla 2017; Ontiveros et al. 2018; Ontiveros-Robles et al. 2021). In this way, we are trying to introduce another membership function, i.e., secondary membership function to handle uncertainty in another dimension. Therefore, integrating T2 FSs with IFS provides the solution to handle the uncertainty and hesitancy in more than one dimensions for the intelligent decision-making. Moreover, this said integration will provide the freedom of many types of interactions between the various input arguments. Many authors have proposed a higher-order type-2 intuitionistic fuzzy sets to address the multiple opinions of the multiple inputs in this decision-making process.

In this paper, we are introducing the trapezoidal membership functions-based type-2 intuitionistic fuzzy sets which we termed as Trapezoidal Type-2 Intuitionistic Fuzzy Sets (TrT2 IFSs). In a realistic scenario influenced by various decision-makers, the uncertainty may not be represented by a singleton point. Trapezoidal fuzzy numbers are represented by two most likely possible values which is much more relatable situation for the decision-making problems where expert knowledge is involved. Also, a trapezoidal membership function is a more generalized form to represent the linguistic uncertainty from decision-makers. It anyway incorporates triangular membership function in its vicinity. Further, in this paper, we present the generation, operations, comparison, and distance between two TrT2 IFSs. At last, the novel Intuitionistic Type-2 Fuzzy TODIM for multi-criteria decision-making is presented. The major contribution of this paper is as follows:

1. The modeling of uncertainty and hesitancy in the framework of higher dimension fuzzy sets is proposed in this paper and termed as Trapezoidal type-2 Intuitionistic Fuzzy Sets (TrT2 IFSs).

2. Apart from the novel generation technique for TrT2 IFSs, several operations, comparisons and distance computation are also proposed between the two TrT2 IFSs.
3. The decision-maker weights and criterion weight computation are also presented with respect to the TODIM approach.
4. Finally, a novel Intuitionistic Type-2 Fuzzy-based TODIM approach is discussed for the intelligent decision-making in the MCDM problem.
5. For validation, the experiments are performed on a renewable energy resource selection problem.
6. The resulted global values computed from the proposed approach help to rank the renewable energy resources and ultimately complement the decision-making process.

The paper is organized as follow: Sect. 1 presents the introduction about the TODIM approach and the motivation for TrT2 IFSs. The literature background is discussed in Sect. 2. Section 3 includes the basic definitions and the major theoretical framework for the TrT2 IFSs along with the weight computation approach for TODIM with the help of TrT2 IFSs. The complete procedure for the novel TODIM approach for intelligent decision-making is presented in Sect. 4. The validation of the proposed approach with the experimental results is mentioned in Sect. 5. This section is followed by the conclusion in Sect. 6.

2 Literature review

This section highlights the background work on the similar lines of the proposed approach. To start with, Gomes and Lima (1992) introduced a new method called TODIM based upon prospect theory developed by Kahneman and Tversky (2013), which essentially considers the decision-maker's psychological behavior. The TODIM approach became very popular in decision-making since its inception and has been used in various areas such as water management (Zhang and Xu 2019), housing (Uysal and Tosun 2014), energy (Gomes et al. 2009), construction (Chen et al. 2015), energy (Qin et al. 2017b), hotels (Tseng et al. 2015), green supply chain selection (Tseng et al. 2014), and health care (Tolga et al. 2020). There are many more methods proposed by many authors using TODIM method in different ways (Lahdelma and Salminen 2009) (Valdez et al. 2009) (Valdez et al. 2008). The TODIM method essentially deals with crisp numbers where the information about the alternatives is given in the form of numbers which makes it unable to handle uncertainty and vague information. However, if we consider any real-world decision-making problem, there is always lack of

information, ambiguity about the alternatives. This uncertain behavior also holds the same for the decision-makers. And, generally, due to incomplete and imprecise information in real-world problems, the decision-makers are not able to give concrete opinion. Fuzzy sets helps to model such uncertainties and help decision-makers in decision-making problems (Zadeh 1965). Krohling and De Souza (2012) combined prospect theory and fuzzy sets to handle risks and uncertainty in MCDM problem. Fan et al. (2013) proposed an extended TODIM to solve hybrid MADM problems where alternatives are given in the form of crisp numbers, interval numbers and fuzzy numbers. Hanine et al. (2016) did the comparison of fuzzy TODIM and fuzzy AHP in landfill location selection using linguistic terms which were lately converted into triangular fuzzy numbers to represent the criteria. Further, Liang et al. (2019) defined a new fuzzy set called Pythagorean fuzzy set and proposed a new approach to solve MCDM problems in Pythagorean fuzzy situations.

Although fuzzy sets can handle this ambiguity and uncertainties, it ignores the hesitancy of decision-makers, which is generally faced by them. Intuitionistic fuzzy sets developed by Atanassov can handle membership, non-membership as well as hesitation index (Atanassov 1994, 2012). By this capability, it has taken more attention of research community (Kumar et al. 2016; Atanassov 2020). Recently, IFSs-based intercriteria analysis has even been used in the domain of neural networks (Sotirov et al. 2017, 2018). With respect to the MCDM problems, Zhang and Xu (2014) proposed a new method having hesitant fuzzy information. Krohling et al. (2013) have extended the TODIM to solve the MCDM problems having intuitionistic fuzzy information, and Wei et al. (2015) has proposed an extended TODIM to solve MCDM problems with HFLTS (Hesitant fuzzy linguistic term sets). Krohling and Pacheco (2014) proposed the extension of TODIM using interval-valued intuitionistic fuzzy sets developed by Atanassov and Gargov (1989). Li et al. (2015) has also proposed a MCDM technique using extended TODIM represented by interval intuitionistic fuzzy sets. Expressing the information in terms of triangular intuitionistic fuzzy numbers (TIFNs) by decision-makers is more accurate as well as relative to fuzzy concepts (Yu 2013; Li 2010).

There are many arithmetic operators described for TIFNs (Wang et al. 2013; He et al. 2014). However, there were still some deficiencies. Later, Qin et al. (2017a) has proposed a novel MCGDM method using TIFN into TODIM and also defined a weighted arithmetic interaction averaging operator of TIFNs. Qin also developed a novel distance measure of TIFNs. Although traditional IFS can handle hesitancy factor very easily, it is unable to deal with the uncertainty near its membership and non-membership boundary as these traditional fuzzy set is considered to be

very precise. On the other hand, type-2 fuzzy sets developed by Zadeh (1975) can handle these uncertainties by blurring the membership function boundaries called footprint of uncertainty (FOU). After introduction of Type-2 MF into existing TODIM (Qin et al. 2017a), we can get a new degree of freedom to manage uncertainties in a new way. Castillo et al. (2015) discussed the study of special types of IFSs which can handle certain type of uncertainty and is inspired by the concepts of FSs and general T2 FSs. Another study of specific types of IFSs and their generalized version was presented by Atanassov and Vassilev (2020). This work covers the gap in the higher-order IFSs to the problem of MCDM, with the help of trapezoidal type-2 fuzzy sets. A trapezoidal FS represents the more generalized form to represent the linguistic uncertainty.

3 Trapezoidal type-2 intuitionistic fuzzy sets: generation, operations, comparison, distance, and weight computation for TODIM

This section presents the necessary definitions and mathematical foundations for the trapezoidal type-2 intuitionistic fuzzy sets (TrT2 FSs). It includes the generation of a TrT2 IFN from triangular T1 IFN (TT1 IFN), some operations (addition and scalar multiplications), comparison between two TrT2 FSs, a distance measure and weight computation approach for the TODIM.

3.1 Trapezoidal type-2 intuitionistic fuzzy number

A trapezoidal type-2 intuitionistic fuzzy number (TrT2 IFN) is a special T2 IFS on a real number set R , denoted by

$$\tilde{A} = (\underline{a}, \underline{b}, \bar{b}, \bar{a}; \mu_{a_u}^{\sim}, \nu_{a_u}^{\sim}) (\underline{b}, \underline{c}, \bar{c}, \bar{b}; \mu_{a_l}^{\sim}, \nu_{a_l}^{\sim})$$

whose upper membership is as follows:

$$\mu_{A_u}^{\sim}(x) = \begin{cases} \frac{\mu_u(x - \underline{a})}{(b_1 - \underline{a})} & \underline{a} \leq x \leq \underline{b} \\ \mu_u & \underline{b} \leq x \leq \bar{b} \\ \frac{\mu_u(\bar{b} - x)}{(\bar{b} - b_2)} & \bar{b} \leq x \leq \bar{a} \\ 0 & \text{otherwise} \end{cases}$$

Lower membership is as follows:

$$\mu_{A_l}^{\sim}(x) = \begin{cases} \frac{\mu_u(x - \underline{b})}{(\underline{c} - \underline{b})} & \underline{b} \leq x \leq \underline{c} \\ \mu_u & \underline{c} \leq x \leq \bar{c} \\ \frac{\mu_u(\bar{b} - x)}{(\bar{b} - \bar{c})} & \bar{c} \leq x \leq \bar{b} \\ 0 & \text{otherwise} \end{cases}$$

Upper non-membership is defined as follows:

$$\nu_{A_u}^{\sim}(x) = \begin{cases} \frac{(c_1 - x) + (x - \underline{b})v_u}{(c - a_1)} & \underline{b}, \leq x \leq \underline{c} \\ v_u & \underline{c} \leq x \leq \bar{c} \\ \frac{(x - \bar{c}) + v_u(\bar{b} - x)}{(\bar{b} - \bar{c})} & \bar{c} \leq x \leq \bar{b} \\ 1 & \text{otherwise} \end{cases}$$

and lower non-membership is defined as follows:

$$\nu_{A_l}^{\sim}(x) = \begin{cases} \frac{(\underline{b} - x) + (x - \underline{a})v_u}{(b_1 - \underline{a})} & \underline{a} \leq x \leq \underline{b} \\ v_u & \underline{b} \leq x \leq \bar{b} \\ \frac{(x - \bar{b}) + v_l(\bar{a} - x)}{(\bar{a} - \bar{b})} & \bar{b} \leq x \leq \bar{a} \\ 1 & \text{otherwise} \end{cases}$$

where $0 \leq \mu_{a_u}^{\sim}, \mu_{a_l}^{\sim}, \nu_{a_u}^{\sim}, \nu_{a_l}^{\sim} \leq 1$, $0 \leq \mu_{a_u}^{\sim} + \nu_{a_u}^{\sim} \leq 1$, $0 \leq \mu_{a_l}^{\sim} + \nu_{a_l}^{\sim} \leq 1$.

The upper hesitancy and lower hesitancy of element x to \tilde{a} are defined as $h_{a_u}^{\sim}(x) = 1 - (\mu_{a_u}^{\sim} + \nu_{a_u}^{\sim})$, and $h_{a_l}^{\sim}(x) = 1 - (\mu_{a_l}^{\sim} + \nu_{a_l}^{\sim})$, respectively. Figure 1 shows the pictorial representation of the TrT2 IFS.

3.2 Generation of trapezoidal type-2 intuitionistic fuzzy number from triangular type-1 intuitionistic fuzzy numbers

For the solution of our selection problem, the input will be taken in the form of triangular intuitionistic fuzzy numbers as evaluation given by more than one advisor to a decision-maker. There are three advisors giving their evaluation to one decision-maker in the form of decision matrix of triangular IFNs. Let $\tilde{a}_{ij}^k = ((\underline{a}_{ij}^k, a_{ij}^k, \bar{a}_{ij}^k); \mu_{a_{ij}^k}^{\sim}, \nu_{a_{ij}^k}^{\sim})$ be the evaluation value given by k th advisor for i th alternative with respect to j th criterion. And p th decision-maker will form a decision matrix of TrT2 IFNs in the form of $\tilde{A}^k = [\tilde{d}_{ij}^p]_{m \times n}$ where $\tilde{d}_{ij}^p = ((\underline{d}_{ij}^p, \underline{b}_{ij}^p, \bar{b}_{ij}^p, \bar{d}_{ij}^p); \mu_{d_{ij}^p}^{\sim}, \nu_{d_{ij}^p}^{\sim})$ $\left((\underline{b}_{ij}^p, \underline{c}_{ij}^p, \bar{c}_{ij}^p, \bar{b}_{ij}^p); \mu_{l_{d_{ij}^p}^{\sim}}, \nu_{l_{d_{ij}^p}^{\sim}} \right)$ where $\underline{d}_{ij}^p = \min(\underline{a}_{ij}^1, \underline{a}_{ij}^2, \dots, \underline{a}_{ij}^k)$, $\underline{b}_{ij}^p = \min(a_{ij}^k)$, $\bar{b}_{ij}^p = \max(a_{ij}^k)$, $\bar{d}_{ij}^p = \max(\underline{a}_{ij}^1, \underline{a}_{ij}^2, \dots, \underline{a}_{ij}^k)$, $\underline{c}_{ij}^p = \underline{b}_{ij}^k + \frac{\sigma_{a_{ij}^k}}{2}$, $\bar{c}_{ij}^p = \bar{b}_{ij}^k - \frac{\sigma_{a_{ij}^k}}{2}$ where $\sigma_{a_{ij}^k}$ = standard deviation of a_{ij}^k

$$\mu_{d_{ij}^p}^{\sim} = \max(\mu_{a_{ij}^1}^{\sim}, \mu_{a_{ij}^2}^{\sim}, \mu_{a_{ij}^3}^{\sim}, \dots, \mu_{a_{ij}^k}^{\sim}), \mu_{l_{d_{ij}^p}^{\sim}} = \min(\mu_{a_{ij}^1}^{\sim}, \mu_{a_{ij}^2}^{\sim}, \mu_{a_{ij}^3}^{\sim}, \dots, \mu_{a_{ij}^k}^{\sim}), \nu_{d_{ij}^p}^{\sim} = \min(\nu_{a_{ij}^1}^{\sim}, \nu_{a_{ij}^2}^{\sim}, \nu_{a_{ij}^3}^{\sim}, \dots, \nu_{a_{ij}^k}^{\sim}), \nu_{l_{d_{ij}^p}^{\sim}} = \max(\nu_{a_{ij}^1}^{\sim}, \nu_{a_{ij}^2}^{\sim}, \nu_{a_{ij}^3}^{\sim}, \dots, \nu_{a_{ij}^k}^{\sim}) (i = 1, 2, 3, \dots, m; j = 1, 2, 3, \dots, n; k = 1, 2, \dots, p).$$

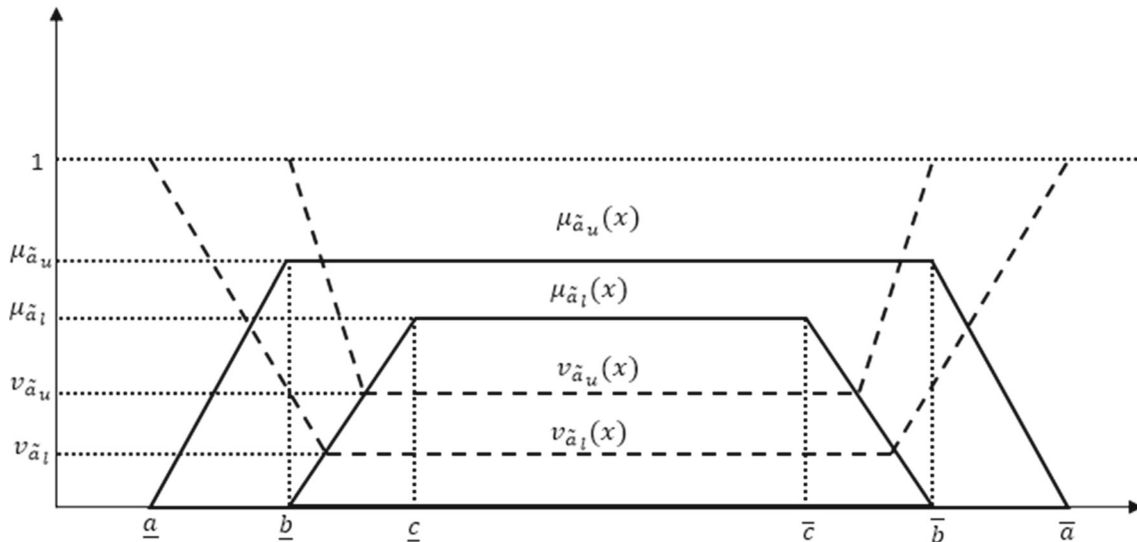


Fig. 1 Trapezoidal type-2 IFS

3.3 Operation on TrT2 IFNs

3.3.1 Sum of two T2 trapezoidal TIFNs

$$\begin{aligned} \tilde{a} + \tilde{d} = & (\underline{a} + \underline{d}, \underline{b} + \underline{e}, \bar{b} + \bar{e}, \bar{a} + \bar{d}; \\ & 1 - (1 - \mu_{\tilde{a}_u})(1 - \mu_{\tilde{d}_u}), (1 - \mu_{\tilde{a}_u})(1 - \mu_{\tilde{d}_u}) \\ & - (1 - (\mu_{\tilde{a}_u} + \nu_{\tilde{a}_i}))(1 - (\mu_{\tilde{d}_u} + \nu_{\tilde{d}_i})), \\ & (\underline{b} + \underline{e}, \underline{c} + \underline{f}, \bar{c} + \bar{f}, \bar{b} + \bar{e}; 1 - (1 - \mu_{\tilde{a}_l})(1 - \mu_{\tilde{d}_l}), \\ & (1 - \mu_{\tilde{a}_l})(1 - \mu_{\tilde{d}_l}) - (1 - (\mu_{\tilde{a}_l} + \nu_{\tilde{a}_u}))(1 - (\mu_{\tilde{d}_l} + \nu_{\tilde{d}_u}))) \end{aligned} \quad (1)$$

3.3.2 Multiplication with some scalar

$$\begin{aligned} \lambda \tilde{d} = & \left\{ (\lambda \underline{d}, \lambda \underline{e}, \lambda \bar{e}, \lambda \bar{d}); 1 - (1 - \mu_{\tilde{d}_u})^\lambda, (1 - \mu_{\tilde{d}_u})^\lambda \right. \\ & \left. - (1 - (\mu_{\tilde{d}_u} + \nu_{\tilde{d}_i}))^\lambda \right\} \left\{ (\lambda \underline{b}, \lambda \underline{c}, \lambda \bar{c}, \lambda \bar{b}); 1 - (1 - \mu_{\tilde{d}_l})^\lambda, \right. \\ & \left. (1 - \mu_{\tilde{d}_l})^\lambda - (1 - \mu_{\tilde{d}_l} + \nu_{\tilde{d}_u})^\lambda \right\} \end{aligned} \quad (2)$$

3.4 Comparison of two TrT2 TIFNs

Let a TrT2 IFN be $\tilde{d} = ((\underline{a}, \underline{b}, \bar{b}, \bar{a}); \mu_u, \nu_l)$ $((\underline{b}, \underline{c}, \bar{c}, \bar{b}); \mu_l, \nu_u)$, then its score function is defined as follows:

$$S(\tilde{d}) = \frac{(\underline{a} + \underline{b} + \bar{b} + \bar{a})(\mu_u - \nu_l) + (\underline{b} + \underline{c} + \bar{c} + \bar{b})(\mu_l - \nu_u)}{4}$$

And its accuracy function is defined as

$$H(\tilde{d}) = \frac{(\underline{a} + \underline{b} + \bar{b} + \bar{a})(\mu_u + \nu_l) + (\underline{b} + \underline{c} + \bar{c} + \bar{b})(\mu_l + \nu_u)}{4} \quad (3)$$

For two TrT2 IFNs \tilde{d} and \tilde{e} ,

If $S(\tilde{d}) > S(\tilde{e})$, or if $S(\tilde{d}) = S(\tilde{e})$, and $H(\tilde{d}) > H(\tilde{e})$, then $\tilde{a} > \tilde{b}$

If $S(\tilde{d}) = S(\tilde{e})$, and $H(\tilde{d}) > H(\tilde{e})$, then $\tilde{a} = \tilde{b}$

3.5 Calculation of distance between to numbers

The distance measure is a real function d : TrT2 IFN \times TrT2 IFN $\rightarrow [0, 1]$, if d follows the properties stated below:

1. $d(\tilde{D}, \tilde{D}) = 0$;
2. $d(\tilde{D}, \tilde{E}) = d(\tilde{E}, \tilde{D})$;
3. For $\tilde{D}, \tilde{E}, \tilde{F} \in$ Triangular T2 IFN (TT2 IFN), $d(\tilde{D}, \tilde{F}) \leq d(\tilde{D}, \tilde{E}) + d(\tilde{E}, \tilde{F})$.

$$\begin{aligned} \tilde{d} = & ((\underline{a}, \underline{b}, \bar{b}, \bar{a}); \mu_{a_u}, \nu_{a_l}) ((\underline{b}, \underline{c}, \bar{c}, \bar{b}); \mu_{a_l}, \nu_{a_u}) \text{ and} \\ \tilde{e} = & ((\underline{d}, \underline{e}, \bar{e}, \bar{d}); \mu_{d_u}, \nu_{d_l}) ((\underline{e}, \underline{f}, \bar{f}, \bar{e}); \mu_{d_l}, \nu_{d_u}) \end{aligned}$$

be two TT2 IFNs, then the hamming distance between them is defined as follows:

$$d(\tilde{d}, \tilde{e}) = \frac{1}{16} (|\mu_{a_u} \underline{a} - \mu_{d_u} \underline{d}| + |\mu_{a_u} \underline{b} - \mu_{d_u} \underline{e}| + |\mu_{a_u} \bar{b} - \mu_{d_u} \bar{e}| + |\mu_{a_l} \bar{c} - \mu_{d_l} \bar{f}|)$$

$$\begin{aligned}
& |\mu_{a_u}\bar{a} - \mu_{d_u}\bar{d}| + |v_{a_i}\underline{a} - v_{d_i}\underline{d}| + |v_{a_i}\underline{b} - v_{d_i}\underline{e}| + |v_{a_i}\bar{b} - v_{d_i}\bar{e}| \\
& + |v_{a_i}\bar{a} - v_{d_i}\bar{d}| + |\underline{a} - \underline{d}| + 2|\underline{b} - \underline{e}| + 2|\bar{b} - \bar{e}| \\
& + |\bar{a} - \bar{d}| + |\mu_{a_i}\underline{b} - \mu_{d_i}\underline{e}| + |\mu_{a_i}\underline{c} - \mu_{d_i}\underline{f}| + |\mu_{a_i}\bar{c} - \mu_{d_i}\bar{f}| \\
& + |\mu_{a_i}\bar{b} - \mu_{d_i}\bar{e}| + |v_{a_u}\underline{b} - v_{d_u}\underline{e}| + |v_{a_u}\underline{c} - v_{d_u}\underline{f}| \\
& + |v_{a_u}\bar{c} - v_{d_u}\bar{f}| + |v_{a_u}\bar{b} - v_{d_u}\bar{e}| + |\underline{c} - \underline{f}| + |\bar{c} - \bar{f}|.
\end{aligned}$$

(4)

Proof $d(\tilde{d}, \tilde{f}) = \frac{1}{16} (|\mu_{a_u}\underline{a} - \mu_{d_u}\underline{d} + \mu_{d_u}\underline{d} - \mu_{d_u}\underline{g}| + |\mu_{a_u}\underline{b} - \mu_{d_u}\underline{e} + \mu_{d_u}\underline{e} - \mu_{d_u}\underline{h}| + |\mu_{a_u}\bar{b} - \mu_{d_u}\bar{e} + \mu_{d_u}\bar{e} - \mu_{d_u}\bar{h}| + |\mu_{a_u}\bar{a} - \mu_{d_u}\bar{d} + \mu_{d_u}\bar{d} - \mu_{d_u}\bar{g}| + |v_{a_i}\underline{a} - v_{d_i}\underline{d} + v_{d_i}\underline{d} - v_{d_i}\underline{g}| + |v_{a_i}\underline{b} - v_{d_i}\underline{e} + v_{d_i}\underline{e} - v_{d_i}\underline{h}| + |v_{a_i}\bar{b} - v_{d_i}\bar{e} + v_{d_i}\bar{e} - v_{d_i}\bar{h}| + |v_{a_i}\bar{a} - v_{d_i}\bar{d} + v_{d_i}\bar{d} - v_{d_i}\bar{g}| + |\mu_{a_i}\underline{b} - \mu_{d_i}\underline{e} + \mu_{d_i}\underline{e} - \mu_{d_i}\underline{h}| + |\mu_{a_i}\underline{c} - \mu_{d_i}\underline{f} + \mu_{d_i}\underline{f} - \mu_{d_i}\underline{i}| + |\mu_{a_i}\bar{c} - \mu_{d_i}\bar{f} + \mu_{d_i}\bar{f} - \mu_{d_i}\bar{i}| + |\mu_{a_i}\bar{b} - \mu_{d_i}\bar{e} + \mu_{d_i}\bar{e} - \mu_{d_i}\bar{h}| + |v_{a_u}\underline{b} - v_{d_u}\underline{e} + v_{d_u}\underline{e} - v_{d_u}\underline{h}| + |v_{a_u}\underline{c} - v_{d_u}\underline{f} + v_{d_u}\underline{f} - v_{d_u}\underline{i}| + |v_{a_u}\bar{c} - v_{d_u}\bar{f} + v_{d_u}\bar{f} - v_{d_u}\bar{i}| + |v_{a_u}\bar{b} - v_{d_u}\bar{e} + v_{d_u}\bar{e} - v_{d_u}\bar{h}|)$

$$\begin{aligned}
& \leq \frac{1}{16} (|\mu_{a_u}\underline{a} - \mu_{d_u}\underline{d}| + |\mu_{a_u}\underline{b} - \mu_{d_u}\underline{e}| + |\mu_{a_u}\bar{b} - \mu_{d_u}\bar{e}| \\
& + |\mu_{a_u}\bar{a} - \mu_{d_u}\bar{d}| + |v_{a_i}\underline{a} - v_{d_i}\underline{d}| + |v_{a_i}\underline{b} - v_{d_i}\underline{e}| \\
& + |v_{a_i}\bar{b} - v_{d_i}\bar{e}| + |v_{a_i}\bar{a} - v_{d_i}\bar{d}| + |\mu_{a_i}\underline{b} - \mu_{d_i}\underline{e}| \\
& + |\mu_{a_i}\underline{c} - \mu_{d_i}\underline{f}| + |\mu_{a_i}\bar{c} - \mu_{d_i}\bar{f}| + |\mu_{a_i}\bar{b} - \mu_{d_i}\bar{e}| \\
& + |v_{a_u}\underline{b} - v_{d_u}\underline{e}| + |v_{a_u}\underline{c} - v_{d_u}\underline{f}| + |v_{a_u}\bar{c} - v_{d_u}\bar{f}| \\
& + |v_{a_u}\bar{b} - v_{d_u}\bar{e}|) + \frac{1}{16} (|\mu_{a_u}\underline{d} - \mu_{d_u}\underline{g}| + |\mu_{a_u}\underline{e} - \mu_{d_u}\underline{h}| \\
& + |\mu_{a_u}\bar{e} - \mu_{d_u}\bar{h}| + |\mu_{a_u}\bar{d} - \mu_{d_u}\bar{g}| + |v_{a_i}\underline{d} - v_{d_i}\underline{g}| \\
& + |v_{a_i}\underline{e} - v_{d_i}\underline{h}| + |v_{a_i}\bar{e} - v_{d_i}\bar{h}| + |v_{a_i}\bar{d} - v_{d_i}\bar{g}| \\
& + |\mu_{a_i}\underline{e} - \mu_{d_i}\underline{h}| + |\mu_{a_i}\underline{f} - \mu_{d_i}\underline{i}| + |\mu_{a_i}\bar{f} - \mu_{d_i}\bar{i}| \\
& + |\mu_{a_i}\bar{e} - \mu_{d_i}\bar{h}| + |v_{a_u}\underline{e} - v_{d_u}\underline{h}| + |v_{a_u}\underline{f} - v_{d_u}\underline{i}| \\
& + |v_{a_u}\bar{f} - v_{d_u}\bar{i}| + |v_{a_u}\bar{e} - v_{d_u}\bar{h}|) \\
& = d(\tilde{d}, \tilde{e}) + d(\tilde{e}, \tilde{f})
\end{aligned}$$

3.6 Determination of decision-maker weight and criterion weight

Decision-maker weight and criterion weight are calculated on the same principles of the traditional fuzzy TODIM method. And they are defined as follows:

Suppose $\tilde{d}_{ij}^p (i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n)$ is the evaluation value of alternative A_i with respect to the criterion C_j given by decision-maker D_p . We will denote the mean

values for alternatives A_i with respect to the criterion C_j provided by p decision-makers as

$$\tilde{d}_{ij}^{\sim} = ((\underline{d}_{ij}, \underline{b}_{ij}, \bar{b}_{ij}, \bar{d}_{ij}); \mu'_{u_{\tilde{d}_{ij}}}, \nu'_{l_{\tilde{d}_{ij}}}) ((\underline{b}_{ij}, \underline{c}_{ij}, \bar{c}_{ij}, \bar{b}_{ij}); \mu'_{l_{\tilde{d}_{ij}}}, \nu'_{u_{\tilde{d}_{ij}}})$$

And it can be calculated by using the equation as follows:

$$\tilde{d}_{ij}^{\sim} = \frac{1}{p} (\tilde{d}_{ij}^1 + \tilde{d}_{ij}^2 + \tilde{d}_{ij}^3 \dots \tilde{d}_{ij}^p), (i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n)$$

The similarity degree between \tilde{d}_{ij}^p and \tilde{d}_{ij}^{\sim} is defined as $s(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})$:

where $d(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})$ is the distance between \tilde{d}_{ij}^k and \tilde{d}_{ij}^{\sim} .

$$s(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim}) = 1 - \frac{d(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})}{\sum_{p=1}^p d(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})}, (p = 1, 2, 3 \dots p; i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n)$$

Then, the weight for the decision-maker D_p for the alternative A_i w.r.t. criterion C_j is defined as follows:

$$\lambda_{ij}^p = \frac{s(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})}{\sum_{p=1}^p s(\tilde{d}_{ij}^k, \tilde{d}_{ij}^{\sim})}, (p = 1, 2, 3 \dots p; i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n)$$

Aggregation of individual decision matrices $\tilde{A}^k = [\tilde{d}_{ij}^p]_{m \times n}$ into group decision matrix $G = [\tilde{g}_{ij}]_{m \times n}$ as follows:

$$\tilde{g}_{ij} = ((\underline{g}_{ij}, \underline{h}_{ij}, \bar{h}_{ij}, \bar{g}_{ij}); \mu_{u_{\tilde{g}_{ij}}}, \nu_{l_{\tilde{g}_{ij}}}) ((\underline{h}_{ij}, \underline{i}_{ij}, \bar{i}_{ij}, \bar{h}_{ij}); \mu_{l_{\tilde{g}_{ij}}}, \nu_{u_{\tilde{g}_{ij}}})$$

$$\begin{aligned}
& = \sum_{p=1}^p \lambda_{ij}^p \tilde{d}_{ij}^p = \left\{ \left(\sum_{p=1}^p \lambda_{ij}^p \underline{a}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \underline{b}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \bar{b}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \bar{a}_{ij}^p \right); \right. \\
& 1 - \prod_{p=1}^p (1 - \mu_{u_{\tilde{d}_{ij}^p}})^{\lambda}, \prod_{p=1}^p (1 - \mu_{u_{\tilde{d}_{ij}^p}})^{\lambda} \\
& \left. - \prod_{p=1}^p (1 - (\mu_{u_{\tilde{d}_{ij}^p}} + \nu_{l_{\tilde{d}_{ij}^p}}))^{\lambda} \right\} \\
& \left\{ \left(\sum_{p=1}^p \lambda_{ij}^p \underline{b}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \underline{c}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \bar{c}_{ij}^p, \sum_{p=1}^p \lambda_{ij}^p \bar{b}_{ij}^p \right); \right. \\
& 1 - \prod_{p=1}^p (1 - \mu_{l_{\tilde{d}_{ij}^p}})^{\lambda}, \prod_{p=1}^p (1 - \mu_{l_{\tilde{d}_{ij}^p}})^{\lambda} - \left(1 - (\mu_{l_{\tilde{d}_{ij}^p}} + \nu_{u_{\tilde{d}_{ij}^p}}) \right)^{\lambda} \left. \right\}
\end{aligned}$$

The mean of the evaluation under criterion C_j is calculated to determine the criterion weight for the collective decision matrix $G = [\tilde{g}_{ij}]_{m \times n}$ in the following way:

$$\begin{aligned} \tilde{g}'_{ij} &= \left((g'_{ij}, l'_{ij}, \bar{h}'_{ij}, \bar{g}'_{ij}); \mu'_{u_{\tilde{g}'_{ij}}}, \nu'_{l_{\tilde{g}'_{ij}}} \right) \left((l'_{ij}, \underline{l}'_{ij}, \bar{l}'_{ij}, \bar{h}'_{ij}); \mu'_{l_{\tilde{g}'_{ij}}}, \nu'_{u_{\tilde{g}'_{ij}}} \right) \\ \tilde{g}^k_{ij} &= \frac{1}{m} (\tilde{g}_{1j} + \tilde{g}_{2j} + \tilde{g}_{3j} \dots \tilde{g}_{mj}), (i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n) \end{aligned} \quad (9)$$

Then, we will calculate the weight for the criterion C_j :

$$w_j = \frac{d(\tilde{g}^k_{ij}, \tilde{g}'_{ij})}{\sum_{j=1}^n \sum_{i=1}^m d(\tilde{g}^k_{ij}, \tilde{g}'_{ij})} \quad (10)$$

The distance between \tilde{g}^k_{ij} and \tilde{g}'_{ij} is denoted by $d(\tilde{g}^k_{ij}, \tilde{g}'_{ij})$.

4 Proposed intuitionistic type-2 fuzzy TODIM for multi-criteria decision-making

We present the algorithm for the proposed intuitionistic Type-2 Fuzzy sets-based TODIM for intelligent decision-making for the MCDM problems.

Step 1. Aggregate the individual decision matrix $E^k = [\tilde{a}^k_{ij}]_{m \times n}$ ($\tilde{a}^k_{ij} = (a^k_{ij}, \underline{a}^k_{ij}, \bar{a}^k_{ij}); \mu_{a^k_{ij}}, \nu_{a^k_{ij}}$) given by advisors of the decision-makers in the form of triangular TIFNs into the combined decision matrix for decision-maker D^p represented by

$$\begin{aligned} \tilde{A}^p &= [\tilde{a}^p_{ij}]_{m \times n} \\ &= \left((a^p_{ij}, \underline{a}^p_{ij}, \bar{a}^p_{ij}, \bar{a}^p_{ij}); \mu_{a^p_{ij}}, \nu_{l^p_{a^p_{ij}}} \right) \left((b^p_{ij}, \underline{c}^p_{ij}, \bar{c}^p_{ij}, \bar{b}^p_{ij}); \mu_{l^p_{a^p_{ij}}}, \nu_{u^p_{a^p_{ij}}} \right) \end{aligned}$$

Step 2. Normalize the combined decision matrix \tilde{A}^k into the normalized decision matrix

$$\begin{aligned} R^k &= [\tilde{r}^k_{ij}]_{m \times n} \\ &= \left(\left((l^p_{ij}, \underline{l}^p_{ij}, \bar{l}^p_{ij}, \bar{r}^p_{ij}); \mu_{u^p_{d^p_{ij}}}, \nu_{l^p_{d^p_{ij}}} \right) \left((s^p_{ij}, \underline{l}^p_{ij}, \bar{l}^p_{ij}, \bar{s}^p_{ij}); \mu_{l^p_{d^p_{ij}}}, \nu_{u^p_{d^p_{ij}}} \right) \right) \end{aligned}$$

using the following expression:

$$\begin{aligned} \tilde{r}^k_{ij} &= \left(\left(\frac{a^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{b^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{\bar{b}^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{\bar{a}^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}} \right); \mu_{u^p_{d^p_{ij}}}, \nu_{l^p_{d^p_{ij}}} \right) \\ &\left(\left(\frac{b^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{c^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{\bar{c}^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}}, \frac{\bar{b}^p_{ij} - \min_j a^p_{ij}}{\max_j a^p_{ij} - \min_j a^p_{ij}} \right); \mu_{l^p_{d^p_{ij}}}, \nu_{u^p_{d^p_{ij}}} \right) \end{aligned} \quad (11)$$

Step 3. Calculate the decision-makers' weight vector $\lambda^p_{ij} = \{\lambda^1_{ij}, \lambda^2_{ij}, \lambda^3_{ij} \dots \lambda^p_{ij}\}$ of decision-maker D_k for the alternatives A_i w.r.t. criterion C_j using Eqs. (5) and (6).

Step 4. Aggregate the individual decision matrices $R^k = [\tilde{r}^k_{ij}]_{m \times n}$ into group decision matrix $G = [\tilde{g}_{ij}]_{m \times n}$ using Eq. (8).

Step 5. The criterion weight vector $w = (w_1, w_2, w_3 \dots w_n)$ is calculated using Eq. (10).

Step 6. Find the relative weight w_{jr} of criterion C_j to the reference criterion C_r , which is defined as follows:

$$w_{jr} = \frac{w_j}{w_r}, \text{ where } w_r = \max\{w_j | j = 1, 2, 3 \dots n\}$$

Step 7. On the basis of classical TODIM method, the dominance of each alternative A_i over each alternative A_k under the criterion C_j can be calculated by using the following expression:

$$\varnothing_j(A_i, A_k) = \begin{cases} \sqrt{\frac{w_{jr}}{\sum_{j=1}^n w_{jr}}} d(\tilde{g}_{ij}, \tilde{g}_{kj}) & \text{if } (\tilde{g}_{ij} > \tilde{g}_{kj}) \\ 0 & \text{if } (\tilde{g}_{ij} = \tilde{g}_{kj}) \\ -\frac{1}{\theta} \sqrt{\frac{\sum_{j=1}^n w_{jr}}{w_{jr}}} d(\tilde{g}_{ij}, \tilde{g}_{kj}) & \text{if } (\tilde{g}_{ij} < \tilde{g}_{kj}) \end{cases} \quad (12)$$

Step 8. With respect to criterion C_j , the dominance degree matrix can be calculated as follows:

$$\varnothing_j = [\varnothing^j_{ik}]_{m \times n} = \begin{matrix} & A1 & A2 & \dots & Am \\ \begin{matrix} A1 \\ A2 \\ \vdots \\ Am \end{matrix} & \left| \begin{array}{cccc} \varnothing^j_{11} & \varnothing^j_{12} & \dots & \varnothing^j_{1m} \\ \varnothing^j_{21} & \varnothing^j_{22} & \dots & \varnothing^j_{2m} \\ \vdots & \vdots & \dots & \vdots \\ \varnothing^j_{m1} & \varnothing^j_{m2} & \dots & \varnothing^j_{mm} \end{array} \right| \end{matrix}$$

where diagonal elements $\varnothing^j_{ii} = 0$, $i, k = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n$

Step 9. For an alternative A_i over each alternative A_k , their global dominance degree is calculated as follows:

$$\delta(A_i, A_k) = \sum_{j=1}^n \varnothing_j(A_i, A_k) \quad (13)$$

Step 10. By normalizing the global dominance degree matrix, we can calculate the global value for the alternative A_i by the following expression:

$$\varepsilon_i = \frac{\sum_{k=1}^m \delta(A_i, A_k) - \min_{i \in m} \{\sum_{k=1}^m \delta(A_i, A_k)\}}{\max_{i \in m} \{\sum_{k=1}^m \delta(A_i, A_k)\} - \min_{i \in m} \{\sum_{k=1}^m \delta(A_i, A_k)\}} \quad (14)$$

Step 11. Rank all the alternatives and select the best one. The higher the value ε_i , the better the alternative A_i .

5 Experimental results

The experiments are performed on the renewable energy resource selection problem. An alarming number of pollutants are released in atmosphere due to the enormous use of fossil fuels in the past few decades. The renewable energy resources, on the other hand, do not produce such pollutants and hence are very effective in reduction in pollutants in the atmosphere. Therefore, it is necessary to develop such energy resources which will also help in mitigating the future energy crises. For example, according to the Chinese “long-term renewable energy development plan,” they are going to heavily invest in renewable energy (hydropower, wind, biomass, solar and geothermal energy, etc. (Qin et al. 2017a).

In this case, we chose five renewable energy resources as alternative solutions, geothermal (A1), solar (A2), wind (A3), hydropower (A4) and biomass (A5). Each type of renewable energy source has its advantages and disadvantages depending on the local environment, so it is important to select the most appropriate source among them to achieve the optimal benefit. The alternatives will be evaluated based on five (5) criteria such as Energy Source Quality (C1), Socio-Political (C2), Economic (C3), Technological (C4), and Environmental (C5). Then, according to their performance with respect to each criterion, three experts (D1, D2, D3) provide their preference for each renewable energy source after aggregating the evaluation given by the three advisors. The advisors will

evaluate each alternative with respect to each criterion and provide a decision matrix in the form of triangular IFNs. It is assumed that the experts are aware of the problem domain, hence, they can directly provide the values of the decision matrix based on their understanding. After considering all these three decision matrices, decision-makers (DMs) will give their assessment in the form of TrT2 IFNs. The criterion values are stated in the form of TIFNs, in which performance ratings range from 1 to 10. The relatively larger value refers to better performance on this criterion. There are nine advisors (A, B, C, D, E, F, G, H, I) out of which advisors A, B, and C will be under DM D1, advisors D, E, and F will be under DM D2 and advisors G, H, and I will be under DM D3. The choice of number of advisors is subjective and can be adjusted according to the designers. We chose the mentioned number of experts as it is easier to present the numerical computations in the paper.

5.1 Methodology and empirical results

The evaluation values provided by the advisors A, B, C, D, E, F, G, H, I are shown in Tables 1, 2, 3, 4, 5, 6, 7, 8 and 9.

Next step is to determine the decision matrix for decision-makers D1, D2, D3, which is listed in Tables 10, 11 and 12.

After these three TrIFN, we will normalize the decision matrices using Eq. (11). The resulted tables are listed from Tables 13, 14 and 15.

Now, we calculate the decision weight vector of decision-maker D_p using Eqs. (5)–(7) for alternatives A_i with respect to the criterion C_j . The resulted tables are shown in Tables 16, 17 and 18.

These individual decision matrices $\tilde{A}^k = [\tilde{a}_{ij}^k]_{m \times n}$ are aggregated into the group decision matrix $G = [\tilde{g}_{ij}]_{m \times n}$ using Eq. 8. The corresponding group decision matrix is shown in Table 19.

We use Eq. (10) to compute the relative criterion weight w_{jr} , which is shown in Table 20 as follows:

Over each alternative A_k under the criterion C_j , the dominance of each alternative A_i is calculated using Eq. 12

Table 1 Decision matrix of A

	C1	C2	C3	C4	C5
A1	((4,5,8,7,3);0,5,0,5)	((2,6,7,8,9,6);0,8,0,1)	((1,9,3,7,6,9);0,5,0,3)	((4,1,6,5,8,6);0,6,0,1)	((5,9,6,6,8,6);0,5,0,1)
A2	((3,7,6,6,8,3);0,6,0,3)	((1,9,3,8,8,5);0,6,0,2)	((2,8,3,9,5,7);0,6,0,2)	((1,6,3,9,5,8);0,8,0,1)	((0,9,5,3,6,8);0,5,0,2)
A3	((1,1,2,5,7,6);0,7,0,1)	((1,2,3,2,4,9);0,4,0,2)	((1,3,3,7,4,3);0,8,0,1)	((1,4,3,1,5,9);0,6,0,3)	((1,5,4,4,5,6);0,7,0,3)
A4	((4,1,5,6,7,4);0,6,0,2)	((6,7,7,1,8,9);0,6,0,2)	((4,3,6,7,8,9);0,5,0,1)	((4,2,6,1,7,3);0,7,0,2)	((0,8,2,6,3,9);0,8,0,1)
A5	((1,9,3,5,4,8);0,8,0,1)	((3,8,4,7,6,6);0,7,0,2)	((0,6,1,8,2,9);0,7,0,2)	((2,8,3,3,4,3);0,6,0,1)	((0,3,2,5,3,1);0,7,0,1)

Table 2 Decision matrix of B

	C1	C2	C3	C4	C5
A1	((2,4,8,3,6);0,6,0,1)	((3,2,4,8,7,2);0,7,0,1)	((3,6,6,3,7,4);0,4,0,1)	((3,2,6,3,7,4);0,4,0,1)	((0,1,5,4,7,8);0,6,0,2)
A2	((4,8,5,2,7,8);0,5,0,2)	((3,7,2,9,5);0,5,0,1)	((5,6,6,3,7,9);0,4,0,2)	((5,6,6,3,7,9);0,4,0,2)	((2,5,8);0,7,0,1)
A3	((3,6,4,9,8,1);0,6,0,1)	((3,7,5,6,8,1);0,5,0,1)	((3,8,6,9,8,4);0,6,0,2)	((3,8,6,9,8,4);0,6,0,2)	((4,5,5,9,7);0,7,0,2)
A4	((6,6,7,1,8,6);0,8,0,1)	((1,7,2,5,6,6);0,4,0,2)	((6,8,8,1,9,2);0,6,0,1)	((6,8,8,1,9,2);0,6,0,1)	((2,3,4,8,6,9);0,6,0,2)
A5	((2,1,4,6,8);0,4,0,3)	((4,8,6,7,6);0,6,0,2)	((1,7,3,4,5,1);0,5,0,3)	((1,7,3,4,5,1);0,5,0,3)	((0,4,2,7,9);0,6,0,1)

Table 3 Decision matrix of C

	C1	C2	C3	C4	C5
A1	((5,7,6,8,7);0,7,0,2)	((4,6,7,3,8,6);0,6,0,2)	((5,7,8,3,9,2);0,7,0,2)	((6,7,8,9,9,6);0,5,0,3)	((4,6,6,3,9,7);0,8,0,1)
A2	((0,5,4,3,6,9);0,4,0,1)	((5,7,6,6,9);0,3,0,1)	((6,4,7,8,8,9);0,7,0,2)	((5,6,7,2,8,9);0,6,0,2)	((3,1,4,6,7,2);0,8,0,1)
A3	((6,1,7,6,8,4);0,8,0,1)	((6,2,7,1,9,6);0,6,0,2)	((6,3,7,5,9,2);0,8,0,1)	((6,4,7,5,9,3);0,6,0,1)	((6,5,8,8,9,9);0,5,0,2)
A4	((1,6,3,5,9,3);0,7,0,2)	((4,2,6,9,8,5);0,5,0,3)	((1,8,3,8,6,3);0,6,0,2)	((3,1,4,9,8,3);0,7,0,1)	((3,3,4,6,6,9);0,6,0,3)
A5	((2,8,5,7,8,9);0,2,0,1)	((2,1,3,2,4,3);0,8,0,1)	((2,1,6,3,8,4);0,8,0,1)	((4,6,7,1,8);0,8,0,1)	((3,9,8,6,9,1);0,8,0,2)

Table 4 Decision matrix of D

	C1	C2	C3	C4	C5
A1	((1,2,3,5,4,8);0,8,0,1)	((2,5,3,9,5,9);0,8,0,1)	((2,3,4,9,5,6);0,6,0,1)	((0,8,1,6,2,9);0,8,0,1)	((3,6,4,7,7,9);0,4,0,2)
A2	((3,2,4,7,6,9);0,6,0,3)	((4,5,5,6,8,9);0,6,0,1)	((4,2,5,2,9,9);0,8,0,1)	((2,2,3,7,4,5);0,7,0,2)	((1,6,2,5,4,2);0,8,0,1)
A3	((1,9,2,5,3,1);0,5,0,4)	((2,5,3,9,8,9);0,7,0,1)	((3,5,4,1,8,8);0,5,0,2)	((2,2,3,8,4,9);0,8,0,1)	((3,7,5,7,9,6);0,7,0,2)
A4	((6,8,2,6,3,8);0,6,0,2)	((4,8,5,9,8,7);0,5,0,3)	((1,6,2,9,4,7);0,7,0,1)	((2,4,3,8,4,6);0,9,0,1)	((4,7,5,3,8,8);0,9,0,1)
A5	((0,4,4,9,7,3);0,5,0,3)	((2,7,3,5,4,9);0,6,0,3)	((0,8,1,5,2,8);0,6,0,2)	((1,7,2,6,3,9);0,6,0,3)	((1,1,2,8,3,7);0,7,0,2)

Table 5 Decision matrix of E

	C1	C2	C3	C4	C5
A1	((3,1,4,6,5,9);0,7,0,2)	((4,2,5,7);0,7,0,2)	((3,5,6,7,3);0,5,0,3)	((2,1,4,6,3);0,7,0,1)	((1,5,3,7,6,2);0,8,0,1)
A2	((5,2,6,8,8,6);0,7,0,1)	((6,7,3,9,1);0,8,0,2)	((5,7,8);0,6,0,2)	((5,7,8);0,6,0,2)	((0,8,3,8,5,2);0,7,0,1)
A3	((4,9,5,3,7,5);0,4,0,1)	((3,2,6,1,7,5);0,6,0,1)	((4,1,6,7,7,5);0,7,0,1)	((4,1,6,7,7,5);0,7,0,1)	((1,8,3,9,8,6);0,5,0,3)
A4	((7,8,3,9,5,6);0,7,0,1)	((5,7,1,9,2);0,4,0,2)	((2,6,3,1,5,1);0,6,0,3)	((2,6,3,1,5,1);0,6,0,3)	((1,3,2,9,7,6);0,6,0,2)
A5	((2,1,3,6,8,2);0,4,0,2)	((1,2,6,2,7,8);0,5,0,1)	((1,9,2,7,3,5);0,5,0,4)	((1,9,2,7,3,5);0,5,0,4)	((2,9,4,9,5,6);0,6,0,4)

Table 6 Decision matrix of F

	C1	C2	C3	C4	C5
A1	((2.1,5.5,6.5);0.6,0.3)	((1.8,2.8,3.6);0.6,0.3)	((4.6,3.5,3.9);0.7,0.2)	((1.4,2.2,4.7);0.6,0.2)	((2.7,5.2,8.1);0.6,0.4)
A2	((2.8,3.9,5.9);0.6,0.2)	((3.8,4.8,6.7);0.7,0.1)	((2.7,3.8,5.9);0.5,0.3)	((1.8,2.9,5.5);0.7,0.1)	((2.1,4.2,6.3);0.6,0.3)
A3	((2.8,3.8,4.9);0.6,0.2)	((1.9,2.8,5.6);0.5,0.3)	((1.9,3.2,6.3);0.4,0.3)	((1.7,4.2,8.8);0.6,0.3)	((2.9,4.1,7.2);0.6,0.1)
A4	((1.6,5.6,7.8);0.8,0.1)	((3.5,4,5.9);0.6,0.1)	((0.7,5.1,6.9);0.5,0.4)	((1.9,2.8,3.8);0.6,0.3)	((3.8,2.8,6.1);0.5,0.3)
A5	((3.5,5.8,9.1);0.7,0.1)	((3.5,4.8,9.2);0.7,0.2)	((2.5,3.4,4);0.8,0.1)	((3.6,4.2,7.8);0.8,0.1)	((3.2,5.3,7.2);0.5,0.2)

Table 7 Decision matrix of G

	C1	C2	C3	C4	C5
A1	((4.2,5.7,6.8);0.7,0.2)	((0.3,1.8,3.7);0.5,0.4)	((1.9,2.5,3.7);0.7,0.2)	((0.2,1.9,2.7);0.7,0.2)	((2.6,3.5,4.7);0.8,0.1)
A2	((2.1,3.7,4.9);0.8,0.1)	((2.2,3.9,4.8);0.8,0.1)	((2.1,3.8,7.2);0.6,0.2)	((1.8,2.9,3.9);0.8,0.1)	((1.6,2.8,3.9);0.7,0.2)
A3	((3.2,4.3,6.7);0.6,0.3)	((1.8,2.7,4.6);0.7,0.1)	((1.2,2.5,3.8);0.7,0.1)	((2.1,3.1,4.9);0.8,0.1)	((0.6,1.8,2.9);0.8,0.1)
A4	((1.8,2.7,4.2);0.7,0.2)	((2.9,4.5,6.5);0.8,0.1)	((2.5,3.9,4.7);0.9,0.1)	((1.7,2.9,4.3);0.6,0.3)	((1.8,2.7,4.8);0.7,0.2)
A5	((1.2,3.7,4.9);0.8,0.1)	((2.7,3.7,4.9);0.5,0.2)	((2.6,3.9,4.9);0.8,0.1)	((2.1,3.9,5);0.7,0.2)	((1.2,2.3,5);0.4,0.3)

Table 8 Decision matrix of H

	C1	C2	C3	C4	C5
A1	((3.7,4.3,7.7);0.6,0.1)	((1.4,2.5,4.6);0.8,0.1)	((0.3,1.8,4.5);0.5,0.3)	((1.3,2.8,3.9);0.6,0.3)	((1.6,2.9,3.5);0.6,0.3)
A2	((1.8,2.8,5.6);0.5,0.3)	((0.7,4.5,6.7);0.5,0.3)	((1.9,4.2,5.8);0.7,0.1)	((2.2,3.5,5.3);0.6,0.3)	((2.1,3.1,4.9);0.8,0.1)
A3	((2.2,3.8,5.7);0.8,0.2)	((2.9,3.5,5.8);0.6,0.3)	((0.9,1.5,4.7);0.5,0.4)	((3.2,4.2,5.7);0.7,0.2)	((1.2,2.5,3.9);0.5,0.4)
A4	((2.7,4.7,5.1);0.6,0.3)	((1.8,3.7,5.7);0.6,0.2)	((1.5,2.9,3.9);0.5,0.3)	((0.8,3.8,5.3);0.4,0.1)	((0.9,2.5,3);0.5,0.4)
A5	((2.7,4.9,5.9);0.6,0.2)	((1.8,4.3,5.9);0.8,0.1)	((1.1,2.5,5.9);0.7,0.2)	((3.2,4.9,6.8);0.7,0.1)	((2.9,3.5,5.2);0.6,0.2)

Table 9 Decision matrix of I

	C1	C2	C3	C4	C5
A1	((2.8,3.7,5.5);0.4,0.3)	((1.9,3.1,5.7);0.6,0.2)	((1.1,3.5,5.7);0.8,0.1)	((2.5,3.3,4.5);0.5,0.4)	((0.5,1.8,2.8);0.5,0.4)
A2	((3.7,4.5,6.8);0.7,0.2)	((3.8,5.8,7.8);0.7,0.1)	((2.7,5.3,6.9);0.7,0.1)	((0.7,4.3,6.8);0.4,0.2)	((0.7,4.3,6.9);0.5,0.3)
A3	((1.8,5.7,7.8);0.5,0.4)	((0.3,4.3,6.7);0.6,0.3)	((2.3,3.9,5.5);0.6,0.3)	((1.5,4.5,6.9);0.6,0.3)	((2.3,3.7,5.3);0.6,0.3)
A4	((0.7,3.5,7.2);0.8,0.1)	((3.7,5.2,7.1);0.5,0.4)	((0.5,1.6,5.8);0.6,0.2)	((2.1,4.3,6.9);0.5,0.4)	((2.3,1.5,6.9);0.8,0.1)
A5	((1.8,2.9,6.7);0.5,0.3)	((0.7,2.8,6.1);0.4,0.3)	((0.9,4.3,6.7);0.6,0.3)	((3.8,5.6,7.3);0.5,0.4)	((0.3,4.3,6.8);0.7,0.1)

Table 10 TrIFN decision matrix formed of D1

	C1	C2
A1	((2,4,8,7,6,8,7);0,7,0,1)((4,8,5,509,6,890,7,6);0,5,0,5)	((2,6,4,8,7,8,9,6);0,8,0,1)((4,8,5,603,6,996,7,8);0,6,0,2)
A2	((0,5,4,3,6,6,8,3);0,6,0,1)((4,3,4,879,6,020,6,6);0,4,0,3)	((1,9,3,8,7,2,9,5);0,6,0,1)((3,8,4,662,6,337,7,2);0,3,0,2)
A3	((1,1,2,5,7,6,8,4);0,8,0,1)((2,5,3,775,6,324,7,6);0,6,0,1)	((1,2,3,2,7,1,9,6);0,6,0,1)((3,2,4,183,6,116,7,1);0,40,2)
A4	((1,6,3,5,7,1,9,3);0,8,0,1)((3,5,4,404,6,195,7,1);0,6,0,2)	((1,7,2,5,7,1,8,9);0,6,0,2)((2,5,3,8,5,8,7,1);0,4,0,3)
A5	((1,9,3,5,5,7,8,9);0,8,0,1)((3,5,4,05,5,15,5,7);0,2,0,3)	((2,1,3,2,6,7,6);0,8,0,1)((3,2,3,9,5,2994,6);0,6,0,2)
	C3	C4
A1	((1,9,3,7,8,3,9,2);0,7,0,1)((3,7,4,853,7,146,8,3);0,4,0,3)	((3,2,6,3,8,9,9,6);0,6,0,1)((6,3,7,023,8,176,8,9);0,4,0,3)
A2	((2,8,3,9,7,8,8,9);0,7,0,2)((3,9,4,883,6,816,7,8);0,4,0,2)	((1,6,3,9,7,2,8,9);0,8,0,1)((3,9,4,752,6,347,7,2);0,40,2)
A3	((1,3,3,7,7,5,9,2);0,8,0,1)((3,7,4,721,6,478,7,5);0,6,0,2)	((1,4,3,1,7,5,9,3);0,6,0,1)((3,1,4,293,6,306,7,5);0,6,0,3)
A4	((1,8,3,8,8,1,9,2);0,6,0,1)((3,8,4,896,7,003,8,1);0,5,0,2)	((3,1,4,9,8,1,9,2);0,7,0,1)((4,9,5,708,7,291,8,1);0,6,0,2)
A5	((0,6,1,8,6,3,8,4);0,8,0,1)((1,8,2,940,5,159,6,3);0,5,0,3)	((1,7,3,3,7,1,8);0,8,0,1)((3,3,4,382,6,0171,7,1);0,5,0,3)
	C5	
A1	((0,1,5,4,6,6,9,7);0,8,0,1) ((5,4,5,712,6,287,6,6);0,5,0,2)	
A2	((0,9,4,6,5,3,8);0,8,0,1)((4,6,4,775,5,124,5,3);0,5,0,2)	
A3	((1,5,4,4,8,8,9,9);0,7,0,2) ((4,4,5,544,7,655,8,8);0,5,0,3)	
A4	((0,8,2,6,4,8,6,9);0,8,0,1) ((2,6,3,208,4,191,4,8);0,6,0,3)	
A5	((0,2,5,8,6,9,1);0,8,0,1)((2,5,4,074,7,025,8,6);0,6,0,2)	

Table 11 TrIFN decision matrix formed of D2

	C1	C2
A1	((1,2,3,5,5,5,6,5);0,8,0,1)((3,5,4,000,4,999,5,5);0,6,0,3)	((1,8,2,8,5,7);0,8,0,1)((2,8,3,35,4,45,5);0,6,0,3)
A2	((2,8,3,9,6,8,8,6);0,70,1)((3,9,4,648,6,051,6,8);0,6,0,3)	((3,8,4,8,7,3,9,1);0,8,0,1)((4,8,5,438,6,661643,7,3);0,6,0,2)
A3	((1,9,2,5,5,3,7,5);0,6,0,1)((2,5,3,200,4,599,5,3);0,4,0,4)	((1,9,2,8,6,1,8,9);0,7,0,1)((2,8,3,640,5,259,6,1);0,5,0,3)
A4	((1,6,2,6,5,6,7,8);0,8,0,1)((2,6,3,352,4,847,5,6);0,6,0,2)	((3,5,4,7,1,9,2);0,6,0,1)((4,4,781,6,318,7,1);0,4,0,3)
A5	((0,4,3,6,5,8,9,1);0,7,0,1)((3,6,4,153,5,246,5,8);0,4,0,3)	((1,2,3,5,6,2,9,2);0,7,0,1)((3,5,4,175,5,524,6,2);0,5,0,3)
	C3	C4
A1	((2,3,3,5,6,7,3);0,7,0,1)((3,5,4,126,5,373,6);0,5,0,3)	((0,8,1,4,2,2,6,3);0,8,0,1)((1,4,1,608,1,991,2,2);0,6,0,2)
A2	((2,7,3,8,7,9,9);0,8,0,1)((3,8,4,602,6,197,7);0,5,0,3)	((1,8,2,9,7,8);0,7,0,1)((2,9,3,986,5,913,7);0,6,0,2)
A3	((1,9,3,2,6,7,8,8);0,7,0,1)((3,2,4,108,5,791,6,7);0,4,0,3)	((1,7,3,8,6,7,8,8);0,8,0,1)((3,8,4,585,5,9141,6,7);0,6,0,3)
A4	((0,7,2,9,5,1,6,9);0,7,0,1)((2,9,3,508,4,491,5,1);0,5,0,4)	((1,9,2,8,3,8,5,1);0,9,0,1)((2,8,3,056,3,543,3,8);0,6,0,3)
A5	((0,8,1,5,3,4,4);0,8,0,1)((1,5,1,980,9,19,3,4);0,5,0,4)	((1,7,2,6,4,2,7,8);0,8,0,1)((2,6,3,0481,3,751,4,2);0,5,0,4)
	C5	
A1	((1,5,3,7,5,2,8,1);0,8,0,1) ((3,7,4,081,4,818,5,2);0,4,0,4)	
A2	((0,8,2,5,4,2,6,3);0,8,0,1) ((2,5,2,944,3,755,4,2);0,6,0,3)	
A3	((1,8,3,9,5,7,9,6);0,7,0,1) ((3,9,4,393,5,206,5,7);0,5,0,3)	
A4	((1,3,2,8,5,3,8,8);0,9,0,1) ((2,8,3,507,4,592,5,3);0,5,0,3)	
A5	((1,1,2,8,5,3,7,2);0,7,0,2) ((2,8,3,471,4,628,5,3);0,5,0,4)	

Table 12 TrIFN decision matrix formed of D3

	C1	C2
A1	((2.8,3.7,5.7,7.7);0.7,0.1)((3.7,4.213,5.186,5.7);0.4,0.3)	((0.3,1.8,3.1,5.7);0.8,0.1)((1.8,2.125,2.774,3.1);0.5,0.4)
A2	((1.8,2.8,4.5,6.8);0.8,0.1)((2.8,3.225,4.074,4.5);0.5,0.3)	((0.7,3.9,5.8,7.8);0.8,0.1)((3.9,4.385,5.314,5.8);0.5,0.3)
A3	((1.8,3.8,5.7,7.8);0.8,0.2)((3.8,4.292,5.207,5.7);0.5,0.4)	((0.3,2.7,4.3,6.7);0.7,0.1)((2.7,3.1,3.9,4.3);0.6,0.3)
A4	((0.7,2.7,4.7,7.2);0.8,0.1)((2.7,3.203,4.196,4.7);0.6,0.3)	((1.8,3.7,5.2,7.1);0.8,0.1)((3.7,4.075,4.824,5.2);0.5,0.4)
A5	((1.2,2.9,4.9,6.7);0.8,0.1)((2.9,3.403,4.396,4.9);0.5,0.3)	((0.7,2.8,4.3,6.1);0.8,0.1)((2.8,3.177,3.922,4.3);0.4,0.3)
	C3	C4
A1	((0.3,1.8,3.5,5.7);0.8,0.1)((1.8,2.227,3.0728,3.5)0.5,0.3)	((0.2,1.9,3.3,4.5);0.7,0.2)((1.9,2.254,2.945,3.3);0.5,0.4)
A2	((1.9,3.8,5.3,7.2);0.7,0.1)((3.8,4.188,4.911,5.3);0.6,0.2)	((0.7,2.9,4.3,6.8);0.8,0.1)((2.9,3.251,3.948,4.3);0.4,0.3)
A3	((0.9,1.5,3.9,5.5);0.7,0.1)((1.5,2.102,3.297,3.9);0.5,0.4)	((1.5,3.1,4.5,6.9);0.8,0.1)((3.1,3.468,4.131,4.5);0.6,0.3)
A4	((0.5,1.6,3.9,5.8);0.9,0.1)((1.6,2.176,3.323,3.9);0.5,0.3)	((0.8,2.9,4.3,6.9);0.6,0.1)((2.9,3.254,3.945,4.3);0.4,0.4)
A5	((0.9,2.5,4.3,6.7);0.8,0.1)((2.5,2.972,3.827,4.3);0.6,0.3)	((2.1,3.9,5.6,7.3);0.7,0.1)((3.9,4.327,5.172,5.6);0.5,0.4)
	C5	
A1	((0.5,1.8,3.5,4.7);0.8,0.1)((1.8,2.231,3.068,3.5);0.5,0.4)	
A2	((0.7,2.8,4.3,6.9);0.8,0.1)((2.8,3.196,3.903,4.3);0.5,0.3)	
A3	((0.6,1.8,3.7,5.3);0.8,0.1)((1.8,2.280,3.219,3.7);0.5,0.4)	
A4	((0.9,1.5,2.7,6.9);0.8,0.1)((1.5,1.801,2.398,2.7);0.5,0.4)	
A5	((0.3,2.2,4.3,6.8);0.7,0.1)((2.2,2.729,3.770,4.3);0.4,0.3)	

Table 13 Normalized decision matrix of D1

	C1	C2
A1	((0.170,0.488,0.806,0.931);0.7,0.1) ((0.488,0.569,0.726,0.806);0.5,0.5)	((0.166,0.428,0.785,1);0.8,0.1) ((0.428,0.524,0.690,0.785);0.6,0.2)
A2	((0.0,0.431,0.693,0.886);0.6,0.1) ((0.431,0.497,0.627,0.693);0.4,0.3)	((0.0833,0.309,0.714,0.988);0.6,0.1) ((0.309,0.412,0.611,0.7142);0.3,0.2)
A3	((0.068,0.227,0.806,0.897);0.8,0.1) ((0.227,0.372,0.661,0.806);0.6,0.1)	((0.0,0.238,0.702,1);0.6,0.1) ((0.238,0.355,0.585,0.702);0.4,0.2)
A4	((0.125,0.340,0.75,1);0.8,0.1) ((0.340,0.443,0.647,0.75);0.6,0.2)	((0.059,0.154,0.702,0.916);0.6,0.2) ((0.154,0.309,0.547,0.702);0.4,0.3)
A5	((0.159091,0.340,0.590,0.954);0.8,0.1) ((0.340,0.403,0.528,0.590);0.2,0.3)	((0.107,0.238,0.571,0.761);0.8,0.1) ((0.238,0.321,0.488,0.571);0.6,0.2)
	C3	C4
A1	((0.1510,0.36,0.895,1);0.7,0.1) ((0.36,0.494,0.761,0.895);0.4,0.3)	((0.219,0.597,0.914,1);0.6,0.1) ((0.597,0.685,0.826,0.914);0.4,0.3)
A2	((0.255,0.383,0.837,0.965);0.7,0.2) ((0.383,0.498,0.722,0.837);0.4,0.2)	((0.024,0.304,0.707,0.914);0.8,0.1) ((0.304,0.408,0.603,0.707);0.4,0.2)
A3	((0.0813,0.360,0.8026,1);0.8,0.1) ((0.360,0.479,0.683,0.802);0.6,0.2)	((0.0,0.207,0.743,0.963);0.6,0.1) ((0.207,0.352,0.598,0.743);0.6,0.3)
A4	((0.139,0.372,0.872,1);0.6,0.1) ((0.372,0.499,0.744,0.872);0.5,0.2)	((0.207,0.426,0.817,0.951);0.7,0.1) ((0.4268,0.525,0.718,0.817);0.6,0.2)
A5	((0.0,0.139,0.662,0.906);0.8,0.1) ((0.139,0.272,0.530,0.662);0.5,0.3)	((0.0365,0.231,0.6951,0.804);0.8,0.1) ((0.231,0.363,0.563,0.695);0.5,0.3)
	C5	
A1	((0.010,0.545,0.666,0.979);0.8,0.1)((0.545,0.576,0.635,0.666);0.5,0.2)	
A2	((0.090,0.464,0.535,0.808);0.8,0.1)((0.464,0.482,0.517,0.535);0.5,0.2)	
A3	((0.1515,0.444,0.888,1);0.7,0.2)((0.444,0.560,0.773,0.888);0.5,0.3)	
A4	((0.080,0.262,0.484,0.696);0.8,0.1)((0.262,0.324,0.423,0.484);0.6,0.3)	
A5	((0.0,0.252,0.868,0.919);0.8,0.1)((0.252,0.411,0.709,0.868);0.6,0.2)	

Table 14 Normalized decision matrix of D2

	C1	C2
A1	((0.091,0.356,0.586,0.701);0.8,0.1) ((0.356,0.413,0.528,0.586);0.6,0.3)	((0.075,0.2,0.475,0.725);0.8,0.1) ((0.2,0.268,0.406,0.475);0.6,0.3)
A2	((0.275,0.402,0.735,0.942);0.7,0.1) ((0.402,0.488,0.649,0.735);0.6,0.3)	((0.325,0.45,0.7625,0.9875);0.8,0.1) ((0.45,0.5295,0.682,0.762);0.6,0.2)
A3	((0.172,0.241,0.563,0.816);0.6,0.1) ((0.241,0.321,0.482,0.563);0.4,0.4)	((0.087,0.2,0.612,0.962);0.7,0.1) ((0.2,0.305,0.507,0.612);0.5,0.3)
A4	((0.137,0.252,0.597,0.850);0.8,0.1) ((0.252,0.339,0.511,0.597);0.6,0.2)	((0.287,0.35,0.737,1);0.6,0.1) ((0.35,0.447,0.639,0.737);0.4,0.3)
A5	((0.0367,0.620,1);0.7,0.1) ((0.367,0.431,0.557,0.620);0.4,0.3)	((0,0.287,0.625,1);0.7,0.1) ((0.287,0.371,0.540,0.625);0.5,0.3)
	C3	C4
A1	((0.173,0.304,0.576,0.717);0.7,0.1) ((0.304,0.372,0.507,0.576);0.5,0.3)	((0,0.075,0.175,0.687);0.8,0.1) ((0.075,0.101,0.148,0.175);0.6,0.2)
A2	((0.217,0.336,0.684,1);0.8,0.1) ((0.336,0.424,0.597,0.684);0.5,0.3)	((0.125,0.262,0.775,0.9);0.7,0.1) ((0.2625,0.398,0.639,0.775);0.6,0.2)
A3	((0.130,0.271,0.652,0.880);0.7,0.1) ((0.271,0.370,0.553,0.652);0.4,0.3)	((0.112,0.375,0.7375,1);0.8,0.1) ((0.375,0.473,0.639,0.737);0.6,0.3)
A4	((0,0.239,0.478,0.673);0.7,0.10) ((0.239,0.305,0.412,0.478);0.5,0.4)	((0.137,0.25,0.375,0.5375);0.9,0.1) ((0.25,0.282,0.342,0.375);0.6,0.3)
A5	((0.010,0.086,0.293,0.358);0.8,0.1) ((0.086,0.139,0.241,0.293);0.5,0.4)	((0.112,0.225,0.425,0.875);0.8,0.1) ((0.225,0.281,0.368,0.425);0.5,0.4)
	C5	
A1	((0.079,0.329,0.5,0.829);0.8,0.1)((0.329,0.372,0.456,0.5);0.4,0.4)	
A2	((0,0.193,0.386,0.625);0.8,0.1)((0.193,0.243,0.335,0.386);0.6,0.3)	
A3	((0.113,0.3522,0.556,1);0.7,0.1)((0.352,0.408,0.500,0.556);0.5,0.3)	
A4	((0.056,0.227,0.511,0.909);0.9,0.1)((0.227,0.307,0.430,0.511);0.5,0.3)	
A5	((0.034,0.227,0.511,0.727);0.7,0.2)((0.227,0.303,0.435,0.511);0.5,0.4)	

Table 15 Normalized decision matrix of D3

	C1	C2
A1	((0.295,0.422,0.704,985;0.7,0.1) ((0.422,0.494,0.631,0.704);0.4,0.3)	((0,0.2,0.373,0.72);0.8,0.1) ((0.2,0.243,0.329,0.373);0.5,0.4)
A2	((0.154,0.295,0.535,0.859);0.8,0.1) ((0.295,0.355,0.475,0.535);0.5,0.3)	((0.0533,0.48,0.733,1);0.8,0.1) ((0.48,0.544,0.668,0.733);0.5,0.3)
A3	((0.154,0.436,0.704,1);0.8,0.2) ((0.436,0.505,0.634,0.704);0.5,0.4)	((0,0.32,0.533,0.853);0.7,0.1) ((0.32,0.373,0.48,0.533);0.6,0.3)
A4	((0,0.281,0.563,0.915);0.8,0.1) ((0.281,0.352,0.492,0.563);0.6,0.3)	((0.2,0.453,0.653,0.906);0.8,0.1) ((0.453,0.503,0.603,0.653);0.5,0.4)
A5	((0.070,0.309,0.591,0.845);0.8,0.1) ((0.309,0.380,0.520,0.591);0.5,0.3)	((0.0533,0.333,0.533,0.773);0.8,0.1) ((0.333,0.383,0.483,0.533);0.4,0.3)
	C3	C4
A1	((0,0.217,0.463,0.782);0.8,0.1) ((0.217,0.279,0.401,0.463);0.5,0.3)	((0,0.239,0.436,0.605);0.7,0.2) ((0.239,0.289,0.386,0.436);0.5,0.4)
A2	((0.231,0.507,0.724,1);0.7,0.1) ((0.507,0.563,0.668,0.724);0.6,0.2)	((0.070,0.380,0.577,0.929);0.8,0.1) ((0.380,0.429,0.528,0.577);0.4,0.3)
A3	((0.086,0.173,0.521,0.753);0.7,0.1) ((0.173,0.261,0.434,0.521);0.5,0.4)	((0.183,0.408451,0.605,0.943);0.8,0.1) ((0.408,0.460,0.553,0.605);0.6,0.3)
A4	((0.028,0.188,0.521,0.797);0.9,0.1) ((0.188,0.271,0.438,0.521);0.5,0.3)	((0.084,0.380,0.577,0.943);0.6,0.1) ((0.380,0.430,0.527,0.577);0.4,0.4)
A5	((0.086,0.318,0.579,0.927);0.8,0.1) ((0.318,0.387,0.511,0.579);0.6,0.3)	((0.267,0.521,0.760,1);0.7,0.1) ((0.521,0.581,0.700,0.760);0.5,0.4)
	C5	
A1	((0.030,0.227,0.484,0.666);0.8,0.1)((0.227,0.292,0.419,0.484);0.5,0.4)	
A2	((0.060,0.378,0.606,1);0.8,0.1)((0.378,0.438,0.545,0.606);0.5,0.3)	
A3	((0.0454,0.227,0.515,0.757);0.8,0.1)((0.227,0.300,0.442,0.515);0.5,0.4)	
A4	((0.090,0.181,0.363,1);0.8,0.1)((0.181,0.227,0.317,0.363);0.5,0.4)	
A5	((0,0.287,0.606,0.984);0.7,0.1)((0.287,0.368,0.525,0.606);0.4,0.3)	

Table 16 Weight matrix of D1

	C1	C2	C3	C4	C5
A1	0.295	0.287	0.280	0.233	0.273
A2	0.3178	0.382	0.300	0.324	0.324
A3	0.311	0.351	0.287	0.299	0.242
A4	0.283	0.342	0.316	0.288	0.341
A5	0.336	0.315	0.321	0.320	0.289

Table 17 Weight matrix of D2

	C1	C2	C3	C4	C5
A1	0.353	0.353	0.374	0.380	0.362
A2	0.330	0.297	0.341	0.340	0.333
A3	0.336	0.310	0.343	0.351	0.387
A4	0.351	0.328	0.336	0.350	0.327
A5	0.313	0.344	0.326	0.326	0.349

Table 18 Weight matrix of D3

	C1	C2	C3	C4	C5
A1	0.350	0.358	0.344	0.385	0.363
A2	0.351	0.320	0.358	0.335	0.342
A3	0.352	0.337	0.368	0.348	0.370
A4	0.364	0.328	0.347	0.360	0.331
A5	0.350	0.339	0.352	0.352	0.361

Table 20 Relative weight of criterion

	C1	C2	C3	C4	C5
W _{jr}	0.9547	1	0.700	0.633	0.772

Table 19 The group decision matrix

	C1	C2
A1	((0.186,0.418,0.692,0.869);0.694,0.305) ((0.418,0.488,0.623,0.692);0.465,0.534)	((0.145,0.374,0.651,0.895);0.694,0.305) ((0.374,0.444,0.581,0.651);0.4902,0.509)
A2	((0.145,0.374,0.651,0.895);0.694,0.305) ((0.374,0.444,0.581,0.651);0.490,0.509)	((0.145,0.405,0.734,0.991);0.794,0.205) ((0.405,0.489,0.651,0.734);0.528,0.470)
A3	((0.133,0.305,0.688,0.906);0.724,0.275) ((0.305,0.402,0.592,0.688);0.483,0.516)	((0.027,0.253,0.617,0.938);0.689,0.310) ((0.253,0.345,0.525,0.617);0.525,0.474)
A4	((0.084,0.288,0.628,0.916);0.745,0.254) ((0.288,0.373,0.543,0.628);0.541,0.458)	((0.180,0.317,0.697,0.940);0.692,0.307) ((0.317,0.418,0.596,0.697);0.444,0.555)
A5	((0.078,0.338,0.600,0.930);0.773,0.225) ((0.338,0.404,0.534,0.600);0.381,0.617)	((0.051,0.287,0.576,0.847);0.752,0.247) ((0.287,0.359,0.504,0.576);0.488,0.511)
	C3	C4
A1	((0.107,0.290,0.626,0.819);0.675,0.324) ((0.290,0.374,0.542,0.626);0.412,0.587)	((0.051,0.260,0.448,0.7285);0.581,0.418) ((0.260,0.310,0.398,0.448);0.390,0.609)
A2	((0.234,0.412,0.744,0.989);0.700,0.299) ((0.412,0.496,0.660,0.744);0.470,0.528)	((0.074,0.315,0.6868,0.914);0.761,0.238) ((0.315,0.412,0.590,0.686);0.466,0.532)
A3	((0.100,0.261,0.647,0.868);0.685,0.314) ((0.261,0.361,0.547,0.647);0.456,0.542)	((0.103,0.336,0.693,0.969);0.709,0.290) ((0.336,0.432,0.597,0.693);0.560,0.439)
A4	((0.054,0.263,0.618,0.819);0.753,0.246) ((0.263,0.355,0.526,0.618);0.482,0.517)	((0.138,0.348,0.575,0.803);0.721,0.278) ((0.348,0.405,0.518,0.575);0.491,0.507)
A5	((0.034,0.185,0.512,0.735);0.788,0.211) ((0.185,0.269,0.429,0.512);0.522,0.477)	((0.142,0.331,0.629,0.896);0.758,0.241) ((0.331,0.413,0.548,0.629);0.486,0.513)
	C5	
A1	((0.042,0.351,0.540,0.811);0.732,0.267) ((0.351,0.399,0.491,0.540);0.404,0.595)	
A2	((0.050,0.344,0.509,0.812);0.791,0.208) ((0.344,0.387,0.466,0.509);0.526,0.473)	
A3	((0.097,0.328,0.621,0.910);0.621,0.378) ((0.328,0.404,0.545,0.621);0.395,0.604)	
A4	((0.076,0.224,0.453,0.866);0.847,0.152) ((0.224,0.286,0.390,0.453);0.544,0.455)	
A5	((0.011,0.256,0.649,0.875);0.687,0.312) ((0.256,0.358,0.547,0.649);0.458,0.541)	

Table 21 Dominance degree matrix for criterion C_1

\varnothing_1	A1	A2	A3	A4	A5
A1	0	-0.081	-0.124	0.047	-0.191
A2	0.018	0	-0.082	0.030	-0.143
A3	0.027	0.017	0	0.020	-0.135
A4	-0.181	-0.107	-0.075	0	-0.122
A5	0.037	0.026	0.026	0.026	0

Table 22 Dominance degree matrix for criterion C_2

\varnothing_2	A1	A2	A3	A4	A5
A1	0	-0.321	-0.081	-0.185	-0.065
A2	0.080	0	-0.246	-0.137	-0.268
A3	0.029	0.068	0	0.036	0.020
A4	0.056	0.043	-0.154	0	-0.169
A5	0.017	0.065	-0.050	0.032	0

Table 23 Dominance degree matrix for criterion C_3

\varnothing_3	A1	A2	A3	A4	A5
A1	0	0.050	0.011	0.018	0.044
A2	-0.305	0	-0.300	0.060	0.094
A3	-0.066	0.049	0	0.013	0.043
A4	-0.074	-0.303	-0.042	0	-0.196
A5	-0.193	-0.473	-0.185	0.029	0

Table 24 Dominance degree matrix for criterion C_4

\varnothing_4	A1	A2	A3	A4	A5
A1	0	-0.391	0.063	-0.293	0.057
A2	0.055	0	0.013	-0.173	0.013
A3	-0.404	-0.117	0	-0.189	-0.130
A4	0.040	0.027	0.024	0	0.014
A5	-0.330	-0.085	0.014	-0.088	0

Table 25 Dominance degree matrix for criterion C_5

\varnothing_5	A1	A2	A3	A4	A5
A1	0	0.020	-0.078	0.046	-0.139
A2	-0.081	0	-0.135	0.035	-0.150
A3	0.026	0.042	0	0.057	0.0271
A4	-0.199	-0.164	-0.1941	0	-0.181
A5	0.032	0.039	-0.113	0.049	0

Table 26 Global dominance degree

	A1	A2	A3	A4	A5
A1	0	-1.076	-0.252	-0.693	-0.303
A2	-0.266	0	-0.833	-0.280	-0.535
A3	-0.577	-0.012	0	-0.116	-0.185
A4	-0.329	-0.494	-0.540	0	-0.724
A5	-0.683	-0.480	-0.336	-0.011	0

Table 27 Global value of alternatives

	δ	ε	Ranking
A1		0	5
A2		0.285	3
A3		1	1
A4		0.164	4
A5		0.567	2

(attenuation coefficient θ is assumed to be 1 (Krohling et al. 2013)) and listed from Tables 21, 22, 23, 24 and 25.

Next step is to compute the global dominance degree of alternative A_i over A_k , which is obtained using Eq. 13 and listed in Table 26.

Finally, the global value and ranking of each alternative A_i are obtained using Eq. 14 and shown in the following Table 27.

We can see that after defining our resource selection problem in new way and following our new defined algorithm based on TrT2 IFSs, we found that alternative A_3 is having global dominance value (ε), i.e., 1 so it would be the best alternative among the all five. We have taken the attenuation factor of loss θ as 1 (Krohling et al. 2013). Its range may vary from 1 to 2.5, however, it totally depends on the physiological behavior of the decision-maker.

6 Discussion and conclusion

There are several types of fuzzy sets available in the literature which are utilized for various purposes depending on the attributes. Some of the most widely used fuzzy sets are T1 FSs, IFSs, T2 FSs. In this paper, we introduce a novel variant of fuzzy sets termed as trapezoidal type-2 intuitionistic fuzzy set (TrT2 IFS). Table 28 presents the comparison among all these fuzzy sets with respect to several characteristics. All of them have graded

Table 28 Several characteristics with respect to the different types of fuzzy sets

Characteristics	Type of fuzzy sets			
	T1FS	IFS	T2 FS	T2 IFS
1. Graded membership value	Yes	Yes	Yes	Yes
2. Parameters used to model/define uncertainty	Membership	Membership, non-membership and hesitancy	Primary membership and secondary membership	Primary membership, secondary membership, non-memberships and hesitancy
3. Parameter uncertainties	Not considered	Not considered	Yes, considered	Yes, Considered along with hesitancy
4. Multi-attribute modeling capability	Yes	Yes	Yes	Yes
5. Multi-source/higher-order uncertainty modeling	No	No	Yes	Yes
6. Consideration of hesitancy in decision-making	No	Yes	No	Yes
7. Explainability and interpretability	No	No	Yes	Yes
8. Capabilities of handling multi-dimensional uncertainties and hesitancy	No	No	No	Yes

membership value and ability of model multi-attribute uncertainty. However, only T2 FS and T2 IFS have the potential to model the multi-source or higher-order uncertainty. Along with uncertainty, hesitancy is only modeled by IFSs and T2 IFS. T1 FS and IFS suffer from interpretability issues, thus, T2 FS and T2 IFS are used as they have the capability to model parameter uncertainty with primary and secondary membership. Among all, only T2 IFS can handle multi-dimensional uncertainties and hesitancy.

One of the major purposes of this paper is to study the effectiveness of fuzzy sets in handling hesitancy and uncertainties for intelligent decision-making in the MCDM problems. Considering the real-life situation with multiple decision-makers, an extended intuitionistic fuzzy set-based TODIM is proposed. Note that, in the considered problem, the weights of criteria and the decision-makers are completely unknown. Hence, we introduce some new arithmetic operations along with generation procedure for TrT2 IFS. The comparison and a modified distance measure between two TrT2 TIFNs are also defined. In addition, the procedure for converting the triangular IFNs to the TrT2 IFNs is also presented. Later, a novel TODIM method is introduced using TrT2 IFNs with unknown weight of criteria and decision-makers. A technique is designed to use the variance of the assessment values and the mean value to calculate the weight of each assessment by the decision-maker in the decision matrix and the weight of each criterion. Finally, a ranking is generated for our considered selection problem to find the optimal alternative. The future work shall focus on presenting a more generalized framework for higher-order IFSs in solving MCDM

problems. Further, we shall extend the proposed work in the domain of Industry 4.0 systems.

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Declarations

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