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# VIKOR Method for Interval Neutrosophic Multiple Attribute Group Decision-Making

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**Abstract:** In this paper, we will extend the VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje) method to multiple attribute group decision-making (MAGDM) with interval neutrosophic numbers (INNs). Firstly, the basic concepts of INNs are briefly presented. The method first aggregates all individual decision-makers' assessment information based on an interval neutrosophic weighted averaging (INWA) operator, and then employs the extended classical VIKOR method to solve MAGDM problems with INNs. The validity and stability of this method are verified by example analysis and sensitivity analysis, and its superiority is illustrated by a comparison with the existing methods.

**Keywords:** MAGDM; INNs; VIKOR method

## 1. Introduction

Multiple attribute group decision-making (MAGDM), which has been increasingly investigated and considered by all kinds of researchers and scholars, is one of the most influential parts of decision theory. It aims to provide a comprehensive solution by evaluating and ranking alternatives based on conflicting attributes with respect to decision-makers' (DMs) preferences, and has widely been utilized in engineering, economics, and management. Several traditional MAGDM methods have been developed by scholars in literature, such as the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method [1,2], the VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje) method [3–5], the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method [6], the ELECTRE (ELimination Et Choix Traduisant la Realité) method [7], the GRA (Grey Relational Analysis) method [8–10], and the MULTIMOORA (Multiobjective Optimization by Ratio Analysis plus Full Multiplicative Form) method [11,12].

Due to the fuzziness and uncertainty of the alternatives in different attributes, attribute values in MAGDM are not always represented as real numbers, and they can be described as fuzzy numbers in more suitable occasions [13–15]. Since fuzzy set (FS) was first defined by Zadeh [16], is has been used as a better tool to solve MAGDM [17,18]. Smarandache [19,20] proposed a neutrosophic set (NS). Furthermore, the concepts of single-valued neutrosophic sets (SVNSs) [21] and interval neutrosophic sets(INSs) [22] were presented for actual applications. Ye [23] proposed a simplified neutrosophic set (SNS). Broumi and Smarandache [24] defined the correlation coefficient of INS. Zhang et al. [25] gave the correlation coefficient of interval neutrosophic numbers (INNs) in MAGDM. Zhang et al. [26] gave an outranking approach for INN MAGDM. Tian et al. [27] defined a cross-entropy in INN MAGDM. Zhang et al. [28] proposed some INN aggregating. Some other INN operators are proposed in References [29–32]. Ye [33] proposed two similarity measures between INNs. The SVNS and INS have received more and more attention since their appearance [34–42].

Opricovic [3] proposed the VIKOR method for a MAGDM problem with conflicting attributes [43–45]. Some scholars proposed fuzzy VIKOR models [46], intuitionistic fuzzy VIKOR models [47–49], the linguistic VIKOR method [50], the interval type-2 fuzzy VIKOR model [51], the hesitant fuzzy linguistic VIKOR method [52], the dual hesitant fuzzy VIKOR method [53], the linguistic intuitionistic fuzzy [54], and the single-valued neutrosophic number (SVNN) VIKOR method [38]. However, there has not yet been an academic investigation of the VIKOR method for MAGDM problems with INNs. Therefore, it is necessary to pay great attention to this novel and worthy research issue. The purpose of our paper is to use the VIKOR idea to solve MAGDM with INNs, to fill this vacancy of knowledge. In Section 2, we give the definition of INNs. We propose the VIKOR method for INN MAGDM. In Section 3, an example is provided, and the comparative analysis is proposed in Section 4. We finish with our conclusions in Section 5.

## 2. Preliminaries

The concepts of SVNSs and INSs are introduced.

*SVNSs and INSs*

NSs [19,20] are not easy to apply to real applications. Wang et al. [21] developed SNSs. Furthermore, Wang et al. [22] defined INSs.

**Definition 1 [21].** *Let $X$ be a space of points (objects), a SVNSs $A$ in $X$ is characterized as following:*

$$A = \{(x, \xi_A(x), \psi_A(x), \zeta_A(x)) | x \in X\} \tag{1}$$

*where the truth-membership function $\xi_A(x)$, indeterminacy-membership $\psi_A(x)$ and falsity-membership function $\zeta_A(x)$, $\xi_A(x) \to [0,1], \psi_A(x) \to [0,1]$ and $\zeta_A(x) \to [0,1]$, with the condition $0 \leq \xi_A(x) + \psi_A(x) + \zeta_A(x) \leq 3$.*

**Definition 2 [22].** *Let $X$ be a space of points (objects) with a generic element in fixed set $X$, denoted by $x$, where an INS $\widetilde{A}$ in $X$ is characterized as follows:*

$$\widetilde{A} = \left\{ (x, \xi_{\widetilde{A}}(x), \psi_{\widetilde{A}}(x), \zeta_{\widetilde{A}}(x)) | x \in X \right\} \tag{2}$$

*where truth-membership function $\xi_{\widetilde{A}}(x)$, indeterminacy-membership $\psi_{\widetilde{A}}(x)$, and falsity-membership function $\zeta_{\widetilde{A}}(x)$ are interval values, $\xi_{\widetilde{A}}(x) \subseteq [0,1], \psi_{\widetilde{A}}(x) \subseteq [0,1]$ and $\zeta_{\widetilde{A}}(x) \subseteq [0,1]$, and $0 \leq sup(\xi_{\widetilde{A}}(x)) + sup(\psi_{\widetilde{A}}(x)) + sup(\zeta_{\widetilde{A}}(x)) \leq 3$.*

*An INN can be expressed as $\widetilde{A} = (\xi_{\widetilde{A}}, \psi_{\widetilde{A}}, \zeta_{\widetilde{A}}) = \left(\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right], \left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right], \left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right]\right)$, where $\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right] \subseteq [0,1]$, $\left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right] \subseteq [0,1]$, $\left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right] \subseteq [0,1]$, and $0 \leq \xi^R_{\widetilde{A}} + \psi^R_{\widetilde{A}} + \zeta^R_{\widetilde{A}} \leq 3$.*

**Definition 3 [45].** *Let $\widetilde{A} = \left(\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right], \left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right], \left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right]\right)$ be an INN, then a score function, SF, is:*

$$SF\left(\widetilde{A}\right) = \frac{\left(2 + \xi^L_{\widetilde{A}} - \psi^L_{\widetilde{A}} - \zeta^L_{\widetilde{A}}\right) + \left(2 + \xi^R_{\widetilde{A}} - \psi^R_{\widetilde{A}} - \zeta^R_{\widetilde{A}}\right)}{6}, SF\left(\widetilde{A}\right) \in [0,1] \tag{3}$$

**Definition 4 [45].** *Let $\widetilde{A} = \left(\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right], \left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right], \left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right]\right)$ be an INN, then an accuracy function, $AF\left(\widetilde{A}\right)$, is defined as*:

$$AF\left(\widetilde{A}\right) = \frac{\left(\xi^L_{\widetilde{A}} + \xi^R_{\widetilde{A}}\right) - \left(\zeta^L_{\widetilde{A}} + \zeta^R_{\widetilde{A}}\right)}{2}, AF\left(\widetilde{A}\right) \in [-1,1] \tag{4}$$

**Definition 5 [45].** *Let* $\widetilde{A} = \left(\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right], \left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right], \left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right]\right)$ *and* $\widetilde{B} = \left(\left[\xi^L_{\widetilde{B}}, \xi^R_{\widetilde{B}}\right], \left[\psi^L_{\widetilde{B}}, \psi^R_{\widetilde{B}}\right], \left[\zeta^L_{\widetilde{B}}, \zeta^R_{\widetilde{B}}\right]\right)$ *be two INNs,* $SF\left(\widetilde{A}\right) = \frac{\left(2+\xi^L_{\widetilde{A}}-\psi^L_{\widetilde{A}}-\zeta^L_{\widetilde{A}}\right)+\left(2+\xi^R_{\widetilde{A}}-\psi^R_{\widetilde{A}}-\zeta^R_{\widetilde{A}}\right)}{6}$ *and* $SF\left(\widetilde{B}\right) = \frac{\left(2+\xi^L_{\widetilde{B}}-\psi^L_{\widetilde{B}}-\zeta^L_{\widetilde{B}}\right)+\left(2+\xi^R_{\widetilde{B}}-\psi^R_{\widetilde{B}}-\zeta^R_{\widetilde{B}}\right)}{6}$ *be the score functions, and* $AF\left(\widetilde{A}\right) = \frac{\left(\xi^L_{\widetilde{A}}+\xi^R_{\widetilde{A}}\right)-\left(\zeta^L_{\widetilde{A}}+\zeta^R_{\widetilde{A}}\right)}{2}$ *and* $AF\left(\widetilde{B}\right) = \frac{\left(\xi^L_{\widetilde{B}}+\xi^R_{\widetilde{B}}\right)-\left(\zeta^L_{\widetilde{B}}+\zeta^R_{\widetilde{B}}\right)}{2}$ *be the accuracy functions, then if* $SF\left(\widetilde{A}\right) < SF\left(\widetilde{B}\right)$*, then* $\widetilde{A} < \widetilde{B}$*; if* $SF\left(\widetilde{A}\right) = SF\left(\widetilde{B}\right)$*, then (1) if* $AF\left(\widetilde{A}\right) = AF\left(\widetilde{B}\right)$*, then* $\widetilde{A} = \widetilde{B}$*; (2) if* $AF\left(\widetilde{A}\right) < AF\left(\widetilde{B}\right)$*, then* $\widetilde{A} < \widetilde{B}$*.*

**Definition 6 [22,33].** *Let* $\widetilde{A} = \left(\left[\xi^L_{\widetilde{A}}, \xi^R_{\widetilde{A}}\right], \left[\psi^L_{\widetilde{A}}, \psi^R_{\widetilde{A}}\right], \left[\zeta^L_{\widetilde{A}}, \zeta^R_{\widetilde{A}}\right]\right)$ *and* $\widetilde{B} = \left(\left[\xi^L_{\widetilde{B}}, \xi^R_{\widetilde{B}}\right], \left[\psi^L_{\widetilde{B}}, \psi^R_{\widetilde{B}}\right], \left[\zeta^L_{\widetilde{B}}, \zeta^R_{\widetilde{B}}\right]\right)$ *be two INNs, then*:

$$(1)\ \widetilde{A} \oplus \widetilde{B} = \left([\xi^L_A + \xi^L_B - \xi^L_A\xi^L_B, \xi^R_A + \xi^R_B - \xi^R_A\xi^R_B], [\psi^L_A\psi^L_B, \psi^R_A\psi^R_B], [\zeta^L_A\zeta^L_B, \zeta^R_A\zeta^R_B]\right);$$

$$(2)\ \widetilde{A} \otimes \widetilde{B} = \begin{pmatrix} [\xi^L_A\xi^L_B, \xi^R_A\xi^R_B], [\psi^L_A + \psi^L_B - \psi^L_A\psi^L_B, \psi^R_A + \psi^R_B - \psi^R_A\psi^R_B], \\ [\zeta^L_A + \zeta^L_B - \zeta^L_A\zeta^L_B, \zeta^R_A + \zeta^R_B - \zeta^R_A\zeta^R_B] \end{pmatrix};$$

$$(3)\ \lambda\widetilde{A} = \left(\left[1-(1-\xi^L_A)^\lambda, 1-(1-\xi^R_A)^\lambda\right], \left[(\psi^L_A)^\lambda, (\psi^R_A)^\lambda\right], \left[(\zeta^L_A)^\lambda, (\zeta^R_A)^\lambda\right]\right), \lambda > 0;$$

$$(4)\ \left(\widetilde{A}\right)^\lambda = \left(\left[(\xi^L_A)^\lambda, (\xi^R_A)^\lambda\right], \left[(\psi^L_A)^\lambda, (\psi^R_A)^\lambda\right], \left[1-(1-\zeta^L_A)^\lambda, 1-(1-\zeta^R_A)^\lambda\right]\right), \lambda > 0.$$

**Definition 7 [45].** *Let* $\widetilde{A}$ *and* $\widetilde{B}$ *be two INNs, then the normalized Hamming distance between* $\widetilde{A}$ *and* $\widetilde{B}$ *is defined as follows*:

$$d\left(\widetilde{A}, \widetilde{B}\right) = \frac{1}{6}\begin{pmatrix} |\xi^L_A - \xi^L_B| + |\xi^R_A - \xi^R_B| + |\psi^L_A - I^L_B| \\ +|\psi^R_A - \psi^R_B| + |\zeta^L_A - \zeta^L_B| + |\zeta^R_A - \zeta^R_B| \end{pmatrix} \tag{5}$$

## 3. VIKOR Method for INN MAGDM Problems

Let $\phi = \{\phi_1, \phi_2, \cdots, \phi_m\}$ be alternatives and $\varphi = \{\varphi_1, \varphi_2, \cdots, \varphi_n\}$ be attributes. Let $\tau = (\tau_1, \tau_2, \cdots, \tau_n)$ be the weight of $\varphi_j$, $0 \le \tau_j \le 1$, $\sum_{j=1}^{n} \tau_j = 1$. Let $D = \{D_1, D_2, \cdots, D_t\}$ be the set of DMs, $\sigma = (\sigma_1, \sigma_2, \cdots, \sigma_t)$ be the weighting of DMs, with $0 \le \sigma_k \le 1$, $\sum_{k=1}^{t} \sigma_k = 1$. Suppose that $\widetilde{R}_k = \left(\widetilde{r}^{(k)}_{ij}\right)_{m\times n} = \left(\left[\xi^{L(k)}_{ij}, \xi^{R(k)}_{ij}\right], \left[\psi^{L(k)}_{ij}, \psi^{R(k)}_{ij}\right], \left[\zeta^{L(k)}_{ij}, \zeta^{R(k)}_{ij}\right]\right)_{m\times n}$ is the INN decision matrix $\left[\xi^{L(k)}_{ij}, \xi^{R(k)}_{ij}\right] \subseteq [0,1]$, $\left[\psi^{L(k)}_{ij}, \psi^{R(k)}_{ij}\right] \subseteq [0,1]$, $\left[\zeta^{L(k)}_{ij}, \zeta^{R(k)}_{ij}\right] \subseteq [0,1]$, $0 \le \xi^{R(k)}_{ij} + \psi^{R(k)}_{ij} + \zeta^{R(k)}_{ij} \le 3$, $i = 1, 2, \cdots, m$, $j = 1, 2, \cdots, n$, $k = 1, 2, \cdots, t$.

To cope with the MAGDM with INNs, we develop the INN VIKOR model.

**Step 1.** Utilize the $\widetilde{R}_k$ and the interval neutrosophic number weighted averaging (INNWA) operator

$$\begin{array}{l} \widetilde{r}_{ij} = \left(\left[\xi^L_{ij}, \xi^R_{ij}\right], \left[\psi^L_{ij}, \psi^R_{ij}\right], \left[\zeta^L_{ij}, \zeta^R_{ij}\right]\right) = \mathrm{INNWA}_\sigma\left(\widetilde{r}^{(1)}_{ij}, \widetilde{r}^{(2)}_{ij}, \cdots, \widetilde{r}^{(t)}_{ij}\right) \\ i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \end{array} \tag{6}$$

to get $\widetilde{R} = (\widetilde{r}_{ij})_{m\times n}$.

**Step 2.** Define the positive ideal solutions $\widetilde{R}^+$ and negative ideal solutions $\widetilde{R}^-$.

$$\widetilde{R}^+ = \left(\left[\xi^{L+}_j, \xi^{R+}_j\right], \left[\psi^{L+}_j, \psi^{R+}_j\right], \left[\zeta^{L+}_j, \zeta^{R+}_j\right]\right) \tag{7}$$

$$\widetilde{R}^- = \left(\left[\xi^{L-}_j, \xi^{R-}_j\right], \left[\psi^{L-}_j, \psi^{R-}_j\right], \left[\zeta^{L-}_j, \zeta^{R-}_j\right]\right) \tag{8}$$

For the benefit attribute:

$$\begin{aligned}&\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right)\\&=\left(\left[\max_i \xi_{ij}^L,\max_i \xi_{ij}^R\right],\left[\min_i \psi_{ij}^L,\min_i \psi_{ij}^R\right],\left[\min_i \zeta_{ij}^L,\min_i \zeta_{ij}^R\right]\right)\end{aligned} \tag{9}$$

$$\begin{aligned}&\left(\left[\xi_j^{L-},\xi_j^{R-}\right],\left[\psi_j^{L-},\psi_j^{R-}\right],\left[\zeta_j^{L-},\zeta_j^{R-}\right]\right)\\&=\left(\left[\min_i \xi_{ij}^L,\min_i \xi_{ij}^R\right],\left[\max_i \psi_{ij}^L,\max_i \psi_{ij}^R\right],\left[\max_i \zeta_{ij}^L,\max_i \zeta_{ij}^R\right]\right)\end{aligned} \tag{10}$$

For the cost attribute:

$$\begin{aligned}&\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right)\\&=\left(\left[\min_i \xi_{ij}^L,\min_i \xi_{ij}^R\right],\left[\max_i \psi_{ij}^L,\max_i \psi_{ij}^R\right],\left[\max_i \zeta_{ij}^L,\max_i \zeta_{ij}^R\right]\right)\end{aligned} \tag{11}$$

$$\begin{aligned}&\left(\left[\xi_j^{L-},\xi_j^{R-}\right],\left[\psi_j^{L-},\psi_j^{R-}\right],\left[\zeta_j^{L-},\zeta_j^{R-}\right]\right)\\&=\left(\left[\max_i \xi_{ij}^L,\max_i \xi_{ij}^R\right],\left[\min_i \psi_{ij}^L,\min_i \psi_{ij}^R\right],\left[\min_i \zeta_{ij}^L,\min_i \zeta_{ij}^R\right]\right)\end{aligned} \tag{12}$$

**Step 3.** Compute the $\Gamma_i$ and $Z_i$.

$$\Gamma_i=\sum_{j=1}^{n}\frac{\tau_j\times d\begin{pmatrix}\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right),\\\left(\left[\xi_{ij}^{L},\xi_{ij}^{R}\right],\left[\psi_{ij}^{L},\psi_{ij}^{R}\right],\left[\zeta_{ij}^{L},\zeta_{ij}^{R}\right]\right)\end{pmatrix}}{d\begin{pmatrix}\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right),\\\left(\left[\xi_j^{L-},\xi_j^{R-}\right],\left[\psi_j^{L-},\psi_j^{R-}\right],\left[\zeta_j^{L-},\zeta_j^{R-}\right]\right)\end{pmatrix}} \tag{13}$$

$$Z_i=\max_j\left\{\frac{\tau_j\times d\begin{pmatrix}\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right),\\\left(\left[\xi_{ij}^{L},\xi_{ij}^{R}\right],\left[\psi_{ij}^{L},\psi_{ij}^{R}\right],\left[\zeta_{ij}^{L},\zeta_{ij}^{R}\right]\right)\end{pmatrix}}{d\begin{pmatrix}\left(\left[\xi_j^{L+},\xi_j^{R+}\right],\left[\psi_j^{L+},\psi_j^{R+}\right],\left[\zeta_j^{L+},\zeta_j^{R+}\right]\right),\\\left(\left[\xi_j^{L-},\xi_j^{R-}\right],\left[\psi_j^{L-},\psi_j^{R-}\right],\left[\zeta_j^{L-},\zeta_j^{R-}\right]\right)\end{pmatrix}}\right\} \tag{14}$$

where $\tau_j$ is weight of $\varphi_j$.

**Step 4.** Compute the $\Theta_i$ by the following formula:

$$\Theta_i=\theta\frac{(\Gamma_i-\Gamma_i^*)}{(\Gamma_i^- -\Gamma_i^*)}+(1-\theta)\frac{(Z_i-Z_i^*)}{(Z_i^- -Z_i^*)} \tag{15}$$

where

$$\Gamma_i^*=\min_i\Gamma_i,\ \ \Gamma_i^-=\max_i\Gamma_i \tag{16}$$

$$Z_i^*=\min_i Z_i,\ \ Z_i^-=\max_i\Gamma_i \tag{17}$$

where $\theta$ depicts the decision-making mechanism coefficient. If $\theta>0.5$, it is for "the maximum group utility"; If $\theta<0.5$, it is "the minimum regret"; and it is both if $\theta=0.5$.

**Step 5.** Rank the alternatives by $\Theta_i$, $\Gamma_i$ and $Z_i$ according to the selection rule of the traditional VIKOR method.

## 4. Numerical Example

### 4.1. Numerical Example

In this section, a numerical example is given with INNs. Five possible emerging technology enterprises (ETEs) $\phi_i (i = 1, 2, 3, 4, 5)$ are selected. Four attributes are selected to evaluate the five possible ETEs: ① $\varphi_1$ is the employment creation; ② $\varphi_2$ is the development of science and technology; ③ $\varphi_3$ is the technical advancement; ④ $\varphi_4$ is the industrialization infrastructure. The five ETEs are to be evaluated by using INNs under the attributes ($\tau = (0.2, 0.1, 0.3, 0.4)^T$) by the DMs ($\sigma = (0.2, 0.5, 0.3)^T$), as listed in Tables 1–3.

**Table 1.** The decision matrix $\widetilde{R}_1$.

| | $\varphi_1$ | $\varphi_2$ |
|---|---|---|
| $\phi_1$ | ([0.3, 0.4], [0.6, 0.7], [0.3, 0.5]) | ([0.4, 0.5], [0.2, 0.3], [0.1, 0.2]) |
| $\phi_2$ | ([0.5, 0.7], [0.6, 0.8], [0.2, 0.4]) | ([0.5, 0.6], [0.3, 0.5], [0.2, 0.3]) |
| $\phi_3$ | ([0.4, 0.5], [0.5, 0.6], [0.2, 0.3]) | ([0.3, 0.4], [0.5, 0.6], [0.1, 0.2]) |
| $\phi_4$ | ([0.6, 0.7], [0.2, 0.3], [0.1, 0.2]) | ([0.4, 0.5], [0.1, 0.2], [0.2, 0.3]) |
| $\phi_5$ | ([0.4, 0.5], [0.2, 0.3], [0.2, 0.3]) | ([0.2, 0.3], [0.6, 0.7], [0.2, 0.3]) |
| | $\varphi_3$ | $\varphi_4$ |
| $\phi_1$ | ([0.1, 0.2], [0.4, 0.5], [0.1, 0.2]) | ([0.3, 0.4], [0.5, 0.6], [0.2, 0.3]) |
| $\phi_2$ | ([0.5, 0.7], [0.4, 0.6], [0.2, 0.3]) | ([0.6, 0.7], [0.3, 0.4], [0.2, 0.3]) |
| $\phi_3$ | ([0.3, 0.4], [0.1, 0.2], [0.2, 0.3]) | ([0.4, 0.5], [0.1, 0.2], [0.3, 0.4]) |
| $\phi_4$ | ([0.4, 0.5], [0.2, 0.3], [0.1, 0.2]) | ([0.3, 0.4], [0.4, 0.5], [0.2, 0.3]) |
| $\phi_5$ | ([0.5, 0.6], [0.4, 0.5], [0.2, 0.3]) | ([0.3, 0.4], [0.6, 0.7], [0.3, 0.4]) |

**Table 2.** The decision matrix $\widetilde{R}_2$.

| | $\varphi_1$ | $\varphi_2$ |
|---|---|---|
| $\phi_1$ | ([0.4, 0.6], [0.5, 0.7], [0.3, 0.4]) | ([0.6, 0.7], [0.5, 0.6], [0.5, 0.6]) |
| $\phi_2$ | ([0.6, 0.9], [0.4, 0.5], [0.3, 0.4]) | ([0.7, 0.8], [0.6, 0.7], [0.4, 0.5]) |
| $\phi_3$ | ([0.8, 0.9], [0.8, 0.9], [0.4, 0.5]) | ([0.7, 0.8], [0.5, 0.6], [0.5, 0.6]) |
| $\phi_4$ | ([0.6, 0.7], [0.3, 0.4], [0.5, 0.6]) | ([0.8, 0.9], [0.5, 0.6], [0.6, 0.7]) |
| $\phi_5$ | ([0.4, 0.5], [0.6, 0.7], [0.6, 0.7]) | ([0.6, 0.7], [0.3, 0.4], [0.3, 0.4]) |
| | $\varphi_3$ | $\varphi_4$ |
| $\phi_1$ | ([0.5, 0.6], [0.4, 0.5], [0.3, 0.4]) | ([0.6, 0.7], [0.4, 0.5], [0.3, 0.4]) |
| $\phi_2$ | ([0.7, 0.8], [0.3, 0.4], [0.3, 0.4]) | ([0.8, 0.9], [0.4, 0.5], [0.3, 0.4]) |
| $\phi_3$ | ([0.7, 0.8], [0.1, 0.2], [0.3, 0.4]) | ([0.8, 0.9], [0.5, 0.6], [0.2, 0.3]) |
| $\phi_4$ | ([0.5, 0.6], [0.2, 0.3], [0.4, 0.5]) | ([0.5, 0.6], [0.7, 0.9], [0.3, 0.4]) |
| $\phi_5$ | ([0.9, 1.0], [0.4, 0.5], [0.3, 0.4]) | ([0.7, 0.8], [0.8, 0.9], [0.1, 0.2]) |

**Table 3.** The decision matrix $\widetilde{R}_3$.

| | $\varphi_1$ | $\varphi_2$ |
|---|---|---|
| $\phi_1$ | ([0.7, 0.8], [0.4, 0.5], [0.4, 0.5]) | ([0.7, 0.8], [0.3, 0.4], [0.6, 0.7]) |
| $\phi_2$ | ([0.6, 0.7], [0.5, 0.6], [0.4, 0.5]) | ([0.7, 0.8], [0.6, 0.7], [0.5, 0.6]) |
| $\phi_3$ | ([0.7, 0.8], [0.3, 0.4], [0.5, 0.6]) | ([0.8, 0.9], [0.2, 0.4], [0.6, 0.7]) |
| $\phi_4$ | ([0.7, 0.8], [0.4, 0.5], [0.6, 0.7]) | ([0.6, 0.9], [0.1, 0.2], [0.7, 0.8]) |
| $\phi_5$ | ([0.6, 0.7], [0.7, 0.8], [0.2, 0.3]) | ([0.7, 0.8], [0.3, 0.5], [0.4, 0.5]) |
| | $\varphi_3$ | $\varphi_4$ |
| $\phi_1$ | ([0.6, 0.7], [0.3, 0.4], [0.4, 0.5]) | ([0.5, 0.6], [0.4, 0.5], [0.4, 0.5]) |
| $\phi_2$ | ([0.8, 0.9], [0.2, 0.3], [0.7, 0.8]) | ([0.6, 0.7], [0.3, 0.4], [0.4, 0.6]) |
| $\phi_3$ | ([0.8, 0.9], [0.2, 0.4], [0.4, 0.5]) | ([0.9, 1.0], [0.1, 0.2], [0.5, 0.6]) |
| $\phi_4$ | ([0.6, 0.7], [0.1, 0.2], [0.5, 0.6]) | ([0.6, 0.7], [0.3, 0.4], [0.4, 0.5]) |
| $\phi_5$ | ([0.7, 0.9], [0.3, 0.4], [0.4 0.5]) | ([0.8, 0.9], [0.5, 0.6], [0.5, 0.6]) |

Then, we use the proposed model to select the best ETE.

**Step 1.** Utilize $\widetilde{R}_k (k = 1, 2, 3)$ and the INNWA operator, in order to obtain matrix $\widetilde{R} = (\widetilde{r}_{ij})_{5\times 4}$ by Equation (6) which is listed in Table 4.

**Table 4.** The decision matrix $\widetilde{R}$.

| | $\varphi_1$ | $\varphi_2$ |
|---|---|---|
| $\phi_1$ | ([0.4974, 0.6477], [0.4850, 0.6328], [0.3270, 0.4472]) | ([0.6021, 0.7058], [0.3571, 0.4625], [0.3828, 0.5044]) |
| $\phi_2$ | ([0.5817, 0.8268], [0.4638, 0.5802], [0.3016, 0.4277]) | ([0.6677, 0.7703], [0.5223, 0.6544], [0.3723, 0.4768]) |
| $\phi_3$ | ([0.7186, 0.8301], [0.5426, 0.6507], [0.3723, 0.4768]) | ([0.6853, 0.7976], [0.3798, 0.5313], [0.3828, 0.5044]) |
| $\phi_4$ | ([0.6331, 0.7344], [0.3016, 0.4038], [0.3828, 0.5044]) | ([0.6933, 0.8620], [0.2236, 0.3464], [0.5044, 0.6150]) |
| $\phi_5$ | ([0.4687, 0.5710], [0.5044, 0.6150], [0.3464, 0.4583]) | ([0.5785, 0.6853], [0.3446, 0.4783], [0.3016, 0.4083]) |
| | $\varphi_3$ | $\varphi_4$ |
| $\phi_1$ | ([0.4740, 0.5785], [0.3669, 0.4676], [0.2625, 0.3723]) | ([0.5127, 0.6243], [0.4183, 0.5186], [0.3016, 0.4038]) |
| $\phi_2$ | ([0.7058, 0.8238], [0.2814, 0.3979], [0.3567, 0.4649]) | ([0.7172, 0.8268], [0.3464, 0.4472], [0.3016, 0.4265]) |
| $\phi_3$ | ([0.6853, 0.7976], [0.1231, 0.2462], [0.3016, 0.4038]) | ([0.7976, 1.0000], [0.2236, 0.3464], [0.2855, 0.3912]) |
| $\phi_4$ | ([0.5150, 0.6163], [0.1625, 0.2656], [0.3241, 0.4397]) | ([0.4998, 0.6021], [0.4854, 0.6274], [0.3016, 0.4038]) |
| $\phi_5$ | ([0.8082, 1.0000], [0.3669, 0.4676], [0.3016, 0.4038]) | ([0.6853, 0.7976], [0.6559, 0.7579], [0.2019, 0.3194]) |

**Step 2.** Define the $\widetilde{R}^+$ and $\widetilde{R}^-$ by Equations (7) and (8).

$$\widetilde{R}^+ = \left\{ \begin{array}{c} ([0.7186, 0.8301], [0.3016, 0.4038], [0.3016, 0.4277]), \\ ([0.6933, 0.8620], [0.2236, 0.3464], [0.3016, 0.4038]), \\ ([0.8082, 1.0000], [0.1231, 0.2462], [0.2625, 0.3723]), \\ ([0.7976, 1.1000], [0.2236, 0.3464], [0.2019, 0.3194]) \end{array} \right\}$$

$$\widetilde{R}^- = \left\{ \begin{array}{c} ([0.4687, 0.5710], [0.5426, 0.6507], [0.3828, 0.5044]), \\ ([0.5785, 0.6853], [0.5223, 0.6544], [0.5044, 0.6150]), \\ ([0.4740, 0.5785], [0.3669, 0.4676], [0.3567, 0.4649]), \\ ([0.4998, 0.6021], [0.6559, 0.7579], [0.3016, 0.4265]) \end{array} \right\}$$

**Step 3.** Compute the $\Gamma_i$ and $Z_i$ by Equation (14).

$$\begin{array}{c} \Gamma_1 = 0.6507, \Gamma_2 = 0.4182, \Gamma_3 = 0.2416, \Gamma_4 = 0.5261, \Gamma_5 = 0.5195 \\ Z_1 = 0.2386, Z_2 = 0.1515, Z_3 = 0.0921, Z_4 = 0.2765, Z_5 = 0.2252 \end{array}$$

**Step 4.** Compute the $\Theta_i$ (let $\theta = 0.5$) by Equation (15).

$$\Theta_1 = 0.8974, \Theta_2 = 0.3772, \Theta_3 = 0.0000, \Theta_4 = 0.8477, \Theta_5 = 0.7006$$

**Step 5.** The order of ETEs is determined by $\Theta_i$ $(i = 1, 2, 3, 4, 5)$: $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$, and thus the most desirable ETE is $\phi_3$.

### *4.2. Comparative Analysis*

In what follows, we compare with the interval neutrosophic number weighted averaging (INNWA) operator and interval neutrosophic number weighted geometric (INNWG) operator [28], INN similarity [33], and INN VIKOR [55]. The results are shown in Table 5.

From the above analysis, it can be seen that the five methods have the same best emerging technology enterprise $\phi_3$, and the ranking results of Method 1 and Method 2 are slightly different. The proposed INN VIKOR method can reasonably focus a MAGDM problem with INNs. At the same time, compared with Method 5 based on the INN VIKOR method in Reference [55], our proposed method avoids the interval numbers' comparison.

**Table 5.** The orders by utilizing five methods.

| Methods | Ranking Orders | Best Alternatives |
|---|---|---|
| Method 1 with INNWA operator in [28] | $\phi_3 \succ \phi_5 \succ \phi_2 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |
| Method 2 with INNWG operator in [28] | $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |
| Method 3 based on similarity in [33] | $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |
| Method 4 based on similarity in [33] | $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |
| Method 5 based on INN VIKOR in [55] | $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |
| The proposed method | $\phi_3 \succ \phi_2 \succ \phi_5 \succ \phi_4 \succ \phi_1$ | $\phi_3$ |

## 5. Conclusions

The VIKOR method for a MAGDM presents some conflicting attributes. We extended the VIKOR method to MAGDM with INNs. Firstly, the basic concepts of INNs were briefly presented. The method first aggregates all individual decision-makers' assessment information based on an INNWA operator, and then employs the extended classical VIKOR method for MAGDM problems with INNs. The validity and stability of this method were verified by example analysis and comparative analysis, and its superiority was illustrated by a comparison with the existing methods. In the future, many other methods of INSs need to be explored in for MAGDM, risk analysis, and many other uncertain and fuzzy environments [56–78].

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