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RESEARCH ARTICLE

VIKOR-Based MAGDM Strategy Revisited in Bipolar Neutrosophic Set Environment

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Abstract: VIKOR strategy was proposed to solve Multi-Attribute Group Decision-Making (MAGDM) in bipolar neutrosophic set (BNS) environment, where compromise solutions (CSs) were not identified. To overcome the shortcomings, the VIKOR strategy is revisited by incorporating CSs in the BNS environment. Using the revisited VIKOR strategy, an MAGDM problem is solved. Sensitivity analysis is presented to reflect the impact of the decision-making mechanism coefficient on ranking of the alternatives.

Keywords: neutrosophic set, bipolar neutrosophic set, MADM, MAGDM, VIKOR, compromise solution

1. Introduction

Smarandache (1998) introduced the neutrosophic set (NS) that extended fuzzy set (FS) (Zadeh, 1965), and intuitionistic FS (Atanassov, 1983; Atanassov & Stoeva, 1983). New trends in neutrosophic research have been documented by many researchers (Broumi et al., 2022; El-Hefenawy et al., 2016; Muzaffar et al., 2020; Nguyen et al., 2019; Otay, & Kahraman, 2019; Peng, & Dai, 2018; Zhang et al., 2020).

Deli et al. (2015) grounded the bipolar NS (BNS) by hybridizing the bipolar FS (BFS) (Zhang, 1994; Zhang, 1998) and the NS (Smarandache, 1998). Pramanik et al. (2017) presented the projection-based MADM strategy under the BNS environment. Uluçay et al. (2018) presented the outranking approach for MADM in the BNS setting. Wang et al. (2018) developed the MADM strategy using "Frank Choquet Bonferroni operators" under the BNS setting. Pramanik et al. (2018a) developed the TODIM strategy under the BNS environment. Abdel-Basset et al. (2019) defined cosine similarity measures and established their properties to develop MADM strategies in BNS and interval BN (IBNS) environments. Many researchers contributed to the development of BNSs (Akram & Sarwar, 2017; Chakraborty et al., 2019). Akram and Shum (2017) developed a new graph theory on the BNS environment. Chakraborty et al. (2019) presented the MADM strategy for the triangular BNS setting. Ali et al. (2017) grounded the bipolar neutrosophic soft set (BNSS) by combining soft sets (Molodtsov, 1999) and BNSs (Deli et al., 2015) and developed the MADM strategy using the aggregation operator under the BNSS setting. Hashim et al. (2020) presented the gray relational analysis-based MADM strategy in the neutrosophic bipolar FS setting.

Opricovic (1998) proposed the "VlseKriterijuska Optimizacija I Komoromisno Resenje" (VIKOR) strategy with conflicting criteria. Opricovic and Tzeng (2003) presented the VIKOR strategy using FSs in analyzing land-use techniques to deal with natural hazards. Chen and Wang (2009) presented the fuzzy VIKOR strategy to present the optimal compromise solution (CS). Chang (2010) presented the modified VIKOR strategy that has a logical judgment to improve the conventional VIKOR strategy. Vahdani et al. (2010) proposed the VIKOR strategy under interval FS assessment having unequal weights of criteria. Devi (2011) presented the VIKOR strategy in the intuitionistic fuzzy (IF) setting where the rating values and the weights of the criteria are presented in the form of triangular IF numbers. Park et al. (2011) presented the VIKOR strategy for Multi-Attribute Group Decision-Making (MAGDM) in interval-valued IF (IVIF) setting where ratings are presented in terms of IVIF numbers. Zhang and Wei (2013) presented the VIKOR and TOPSIS to deal with MADM problems under the hesitant FS environment. Mardani et al. (2016) documented a systematic review of the VIKOR strategy dealing with its methodologies and applications.

Rani et al. (2019) presented the VIKOR strategy in Pythagorean FS setting. VIKOR strategy under the trapezoidal BFS environment was presented by Shumaiza et al. (2019). Pouresmaeil et al. (2017) presented the VIKOR and TOPSIS for MAGDM in SVNS setting. VIKOR strategy under the interval NS (INS) (Wang et al., 2005) environment was studied by Bausys and Zavadskas (2015) and Huang et al. (2017). Hu et al. (2017) discussed the VIKOR strategy based on projection measures under the INS setting. Ünver et al. (2022) presented the VIKOR strategy for MAGDM in IF-valued neutrosophic setting.

Pramanik et al. (2018b) presented the VIKOR strategy under the BNS environment where CSs are not identified. So there exists a research gap.

Motivation: To deal with the research gap, the VIKOR strategy is modified by defining CSs under the BNS environment.

The structure of the remaining part of the paper is presented in Table 1.

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Table 1
Outline of the paper

Sections	Contents
2	Some basic concepts and operations related to BNSs.
3	The modified VIKOR strategy is developed by incorporating CS.
4	Illustration of the developed VIKOR strategy.
5	Sensitivity analysis
6	The conclusion and direction of further research

2. Preliminaries

The basics of the BNS are recalled in this section.

Definition 2.1. BNS (Deli et al., 2015)
Let W be a space of objects and $\omega \in W$ be a generic element. A BNS θ is defined as:

$$\theta = \{< \omega,\ \tau_\theta^+(\omega),\ \iota_\theta^+(\omega),\ \pi_\theta^+(\omega),\ \tau_\theta^-(\omega),\ \iota_\theta^-(\omega),\ \pi_\theta^-(\omega) >:\ \omega \in \Omega\},$$

where, $\tau_\theta^+(\omega),\ \iota_\theta^+(\omega),\ \pi_\theta^+(\omega) : \Omega \rightarrow [0, 1]$ and $\tau_\theta^-(\omega),\ \iota_\theta^-(\omega),\ \pi_\theta^-(\omega) : \Omega \rightarrow [-1, 0]$.

Here, $\theta =< \tau_\theta^+,\ \iota_\theta^+,\ \pi_\theta^+,\ \tau_\theta^-,\ \iota_\theta^-,\ \pi_\theta^- >$ represents a bipolar neutrosophic number (BNN).

Definition 2.2. Containment (Deli et al, 2015)
Assume that
$\theta_1 = \{< \omega,\ \tau_{\theta_1}^+(\omega),\ \iota_{\theta_1}^+(\omega),\ \pi_{\theta_1}^+(\omega),\ \tau_{\theta_1}^-(\omega),\ \iota_{\theta_1}^-(\omega),\ \pi_{\theta_1}^-(\omega) >:\ \omega \in \Omega\}$
and
$\theta_2 = \{< \omega,\ \tau_{\theta_2}^+(\omega),\ \iota_{\theta_2}^+(\omega),\ \pi_{\theta_2}^+(\omega),\ \tau_{\theta_2}^-(\omega),\ \iota_{\theta_2}^-(\omega),\ \pi_{\theta_2}^-(\omega) >:\ \omega \in \Omega\}$
are any two BNSs in Ω. Then $\theta_1 \subseteq \theta_2$, iff $\tau_{\theta_1}^+(\omega) \le \tau_{\theta_2}^+(\omega)$, $\iota_{\theta_1}^+(\omega) \ge \iota_{\theta_2}^+(\omega)$, $\pi_{\theta_1}^+(\omega) \ge \pi_{\theta_2}^+(\omega)$ and $\tau_{\theta_1}^-(\omega) \ge \tau_{\theta_2}^-(\omega)$, $\iota_{\theta_1}^-(\omega) \le \iota_{\theta_2}^-(\omega)$, $\pi_{\theta_1}^-(\omega) \le \pi_{\theta_2}^-(\omega)$, $\forall \omega \in \Omega$.

Definition 2.3. Equality (Deli et al., 2015)
Assume that
$\theta_1 = \{< \omega,\ \tau_{\theta_1}^+(\omega),\ \iota_{\theta_1}^+(\omega),\ \pi_{\theta_1}^+(\omega),\ \tau_{\theta_1}^-(\omega),\ \iota_{\theta_1}^-(\omega),\ \pi_{\theta_1}^-(\omega) >:\ \omega \in \Omega\}$
and
$\theta_2 = \{< \omega,\ \tau_{\theta_2}^+(\omega),\ \iota_{\theta_2}^+(\omega),\ \pi_{\theta_2}^+(\omega),\ \tau_{\theta_2}^-(\omega),\ \iota_{\theta_2}^-(\omega),\ \pi_{\theta_2}^-(\omega) >:\ \omega \in \Omega\}$
are any two BNSs in Ω. Then, $\theta_1 = \theta_2$, iff $\tau_{\theta_1}^+(\omega) = \tau_{\theta_2}^+(\omega)$, $\iota_{\theta_1}^+(\omega) = \iota_{\theta_2}^+(\omega)$, $\pi_{\theta_1}^+(\omega) = \pi_{\theta_2}^+(\omega)$ and $\tau_{\theta_1}^-(\omega) = \tau_{\theta_2}^-(\omega)$, $\iota_{\theta_1}^-(\omega) = \iota_{\theta_2}^-(\omega)$, $\pi_{\theta_1}^-(\omega) = \iota_{\theta_2}^-(\omega), \forall \omega \in \Omega$.

Definition 2.4. Union (Deli et al., 2015)
Assume that
$\theta_1 = \{< \omega,\ \tau_{\theta_1}^+(\omega),\ \iota_{\theta_1}^+(\omega),\ \pi_{\theta_1}^+(\omega),\ \tau_{\theta_1}^-(\omega),\ \iota_{\theta_1}^-(\omega),\ \pi_{\theta_1}^-(\omega) >:\ \omega \in \Omega\}$
and
$\theta_2 = \{< \omega,\ \tau_{\theta_2}^+(\omega),\ \iota_{\theta_2}^+(\omega),\ \pi_{\theta_2}^+(\omega),\ \tau_{\theta_2}^-(\omega),\ \iota_{\theta_2}^-(\omega),\ \pi_{\theta_2}^-(\omega) >:\ \omega \in \Omega\}$

are any two BNSs in Ω. Then,

$$\theta_1(\omega) \cup \theta_2(\omega) = \{< \omega, \max\left(\tau_{\theta_1}^+(\omega),\ \tau_{\theta_2}^+(\omega)\right),$$

$$\min\left(\iota_{\theta_1}^+(\omega),\ \iota_{\theta_2}^+(\omega)\right), \min\left(\pi_{\theta_1}^+(\omega),\ \pi_{\theta_2}^+(\omega)\right),$$
$$\min\left(\tau_{\theta_1}^-(\omega),\ \tau_{\theta_2}^-(\omega)\right), \max\left(\iota_{\theta_1}^-(\omega),\ \iota_{\theta_2}^-(\omega)\right),$$
$$\max\left(\pi_{\theta_1}^-(\omega),\ \pi_{\theta_2}^-(\omega)\right) >:\ \omega \in \Omega\},\ \forall \omega \in \Omega\}.$$

Definition 2.5. Intersection (Deli et al., 2015)

Assume that
$\theta_1 = \{< \omega,\ \tau_{\theta_1}^+(\omega),\ \iota_{\theta_1}^+(\omega),\ \pi_{\theta_1}^+(\omega),\ \tau_{\theta_1}^-(\omega),\ \iota_{\theta_1}^-(\omega),\ \pi_{\theta_1}^-(\omega) >:\ \omega \in \Omega\}$
and
$\theta_2 = \{< \omega,\ \tau_{\theta_2}^+(\omega),\ \iota_{\theta_2}^+(\omega),\ \pi_{\theta_2}^+(\omega),\ \tau_{\theta_2}^-(\omega),\ \iota_{\theta_2}^-(\omega),\ \pi_{\theta_2}^-(\omega) >:\ \omega \in \Omega\}$
are any two BNSs in Ω. Then,

$$\theta_1(\omega) \cap \theta_2(\omega) = \{< \omega, \min\left(\tau_{\theta_1}^+(\omega),\ \tau_{\theta_2}^+(\omega)\right),$$

$$\max\left(\iota_{\theta_1}^+(\omega),\ \iota_{\theta_2}^+(\omega)\right), \max\left(\pi_{\theta_1}^+(\omega),\ \pi_{\theta_2}^+(\omega)\right),$$
$$\max\left(\tau_{\theta_1}^-(\omega),\ \tau_{\theta_2}^-(\omega)\right), \min\left(\iota_{\theta_1}^-(\omega), \iota_{\theta_2}^-(\omega)\right),$$
$$\min\left(\pi_{\theta_1}^-(\omega),\ \pi_{\theta_2}^-(\omega)\right) >:\ \omega \in \Omega\}.$$

Definition 2.6. Compliment (Deli et al., 2015)
Assume that
$\theta_1 = \{< \omega,\ \tau_{\theta_1}^+(\omega),\ \iota_{\theta_1}^+(\omega),\ \pi_{\theta_1}^+(\omega),\ \tau_{\theta_1}^-(\omega),\ \iota_{\theta_1}^-(\omega),\ \pi_{\theta_1}^-(\omega) >:\ \omega \in \Omega\}$ is a BNS. Then the compliment of θ_1 is denoted as:

$$\theta_1^{'} = \{< \omega,\ 1 - \tau_{\theta_1}^+(\omega),\ 1 - \iota_{\theta_1}^+(\omega),\ 1 - \pi_{\theta_1}^+(\omega),$$

$$\{-1\} - \tau_{\theta_1}^-(\omega),\ \{-1\} - \iota_{\theta_1}^-(\omega),$$
$$\{-1\} - \pi_{\pi_1}^-(\omega) >:\ \omega \in \Omega\}$$

Definition 2.7. Hamming Distance (HD) (Pramanik et al., 2018)
Assume that $\theta_1 =< \tau_{\theta_1}^+,\ \iota_{\theta_1}^+,\ \pi_{\theta_1}^+,\ \tau_{\theta_1}^-,\ \iota_{\theta_1}^-,\ \pi_{\theta_1}^- >$ and $\theta_2 =< \tau_{\theta_2}^+,\ \iota_{\theta_2}^+,\ \pi_{\theta_2}^+,\ \tau_{\theta_2}^-,\ \iota_{\theta_2}^-,\ \pi_{\theta_2}^- >$ are any two BNNs. HD between θ_1 and θ_2 is defined as:

$$\aleph(\theta_1, \theta_2) = \frac{1}{6}[\left|\tau_{\theta_1}^+ - \tau_{\theta_2}^+ + \left|\iota_{\theta_1}^+ - \iota_{\theta_2}^+ + \left|\pi_{\theta_1}^+ - \pi_{\theta_2}^+\right| + \left|\tau_{\theta_1}^- - \tau_{\theta_2}^-\right| + \left|\iota_{\theta_1}^- - \iota_{\theta_2}^- + \left|\pi_{\theta_1}^- - \pi_{\theta_2}^-\right| \quad (1)$$

3. Modified VIKOR Strategy for MAGDM under BNS Environment

Assume that
i. $\xi'_r, (r = 1, 2, \ldots, R)$ is the r-th alternative of R alternatives,
ii. λ'_s ($s = 1, 2, \ldots, S$) is the s-th attribute of S attributes,
iii. $\rho_m (\ge 0)(m = 1, 2, \ldots, S)$ is the weight of the k-th attribute and $\sum_{m=1}^{S} \rho_m = 1$,
iv. $\omega_t (\ge 0)$ is the weight of t-th decision-maker (DM) and $\omega_t (t = 1, 2, \ldots T)$ and $\sum_{t=1}^{T} \omega_t = 1$,

Modified VIKOR strategy is developed as follows:

Step: 1. **Formulate the decision matrices.**

Assume that $X^t = (\theta'^t_{rs})_{R \times S}$ $(t = 1, 2, 3, \ldots, T)$ is the decision matrix of t-th DM, where rating of the alternative ξ_r is provided by the t-th DM over the attribute $\lambda'_s (s = 1, 2, 3, \ldots, S)$. Assume that BNN $\theta'_{rs} =< \tau'^+_{rs},\ \iota'^+_{rs}, \pi'^+_{rs},\ \tau'^-_{rs},\ \iota'^-_{rs},\ \pi'^-_{rs} >$ reflects the rating value of thr r-th alternative over the s-th attribute. Then, X^t is constructed as follows:

$$X^t = [\theta'^t_{rs}]_{R \times S} \begin{bmatrix} & \lambda'_1 & \lambda'_2 & \ldots & \lambda'_S \\ \xi'_1 & \theta'^t_{11} & \theta'^t_{12} & \ldots & \theta'^t_{1S} \\ \xi'_2 & \theta'^t_{21} & \theta'^t_{22} & \ldots & \theta'^t_{2S} \\ . & . & . & \ldots & . \\ \xi'_R & \theta'^t_{R1} & \theta'^t_{R2} & \ldots & \theta'^t_{RS} \end{bmatrix} \quad (2)$$

Here, $\theta'^t_{rs} =< \tau'^{t+}_{rs},\ \iota'^{t+}_{rs}, \pi'^{t+}_{rs},\ \tau'^{t-}_{rs},\ \iota'^{t-}_{rs},\ \pi'^{t-}_{rs} >$

Step: 2. Normalize the decision matrices.

For cost-type attribute, the normalization technique (Pramanik et al., 2018b) is employed as follows:

$$\widetilde{\theta}'^{t^*}_{rs} = < \{1\} - \tau'_{rs}t+, \{1\} - \iota'_{rs}t+, \{1\} - \pi'_{rs}t+, \{-1\} -\tau'_{rs}t+, \{-1\} - \iota'_{rs}t, \{-1\} - \pi'_{rs}t- > \quad (3)$$

Using the formula (3), the normalized decision matrix (4) is formulated as:

$$X^t = \begin{pmatrix} & \lambda'_1 & \lambda'_2 & \dots & \lambda'_S \\ \xi'_1 & \widetilde{\theta}'^t_{11} & \widetilde{\theta}'^t_{12} & \dots & \widetilde{\theta}'^t_{1S} \\ \xi'_2 & \widetilde{\theta}'^t_{21} & \widetilde{\theta}'^t_{22} & \dots & \widetilde{\theta}'^t_{2S} \\ . & . & . & \dots & . \\ \xi'_R & \widetilde{\theta}'^t_{R1} & \widetilde{\theta}'^t_{R2} & \dots & \widetilde{\theta}'^t_{RS} \end{pmatrix} \quad (4)$$

Here, $\widetilde{\theta}'_{rs}t = \begin{cases} \theta'_{rs}t \text{, when } \lambda_s \text{ is a benefit type attribute.} \\ \widetilde{\theta}'^{t^*}_{rs} \text{, when } \lambda_s \text{ is a cost type attribute.} \end{cases}$

Step: 3. Aggregate the decision matrices.

BNN weighted averaging (BNWA) operator (Pramanik et al., 2018b) is employed to aggregate the decision matrices (X^t) to formulate the aggregated decision matrix (AGM) X as:

$$\begin{aligned} \theta'_{rs} &= BNWA(\widetilde{\theta}'^1_{rs}, \widetilde{\theta}'^2_{rs}, \dots, \widetilde{\theta}'^T_{rs}) \\ &= (\omega_1 \widetilde{\theta}'^1_{rs} \oplus \omega'_2 \widetilde{\theta}'^2_{rs} \oplus \omega'_3 \widetilde{\theta}'^3_{rs} \oplus \dots \oplus \omega'_t \widetilde{\theta}'^T_{rs}) \\ &= < \tfrac{1}{T}\left(\sum_{t=1}^T \omega_t \tilde{\tau}'^{+(t)}_{rs}, \sum_{t=1}^T \omega_t \tilde{\iota}'^{+(t)}_{rs}, \sum_{t=1}^T \sum_{t=1}^T \omega_t \tilde{\pi}'^{+(t)}_{ij}, \sum_{t=1}^T \omega_t \tilde{\tau}'^{-(t)}_{rs}, \sum_{t=1}^T \omega_t \tilde{\iota}'^{-(t)}_{rs}, \sum_{t=1}^T \omega_t \tilde{\pi}'^{-(t)}_{rs}\right) > \end{aligned} \quad (5)$$

r = 1, 2, 3, …, R; s = 1, 2, 3, …, S.

The ADM is obtained as follows:

$$X = \begin{pmatrix} & \lambda'_1 & \lambda'_2 & \dots & \lambda'_S \\ \xi'_1 & \theta'_{11} & \theta'_{12} & \dots & \theta'_{1S} \\ \xi'_2 & \theta'_{21} & \theta'_{22} & \dots & \theta'_{2S} \\ . & . & . & \dots & . \\ \xi'_R & \theta'_{R1} & \theta'_{R2} & \dots & \theta'_{RS} \end{pmatrix} \quad (6)$$

Step: 4. Calculate **the "Positive Ideal Solution (PIS)" and "Negative Ideal Solution (NIS)."**

The "PIS" and "NIS" are calculated, respectively, as:

$$\theta'^{+}_{rs} = < \max_r \tau'^{+}_{rs}, \min_r \iota'^{+}_{rs}, \min_r \pi'^{+}_{rs}, \min_r \tau'^{-}_{rs}, \max_r \iota'^{-}_{rs}, \max_r \pi'^{-}_{rs} > \quad (7)$$

$$\theta'^{-}_{rs} = < \min_r \tau'^{+}_{rs}, \max_r \iota'^{+}_{rs}, \max_r \pi'^{+}_{rs}, \max_r \tau'^{-}_{rs}, \min_r \iota'^{-}_{rs}, \min_r \pi'^{-}_{rs} > \quad (8)$$

Step: 5. Compute the values of χ'_i and ζ'_i.

"Maximum group utility" χ'_i and the "minimum individual regret of the opponent" ζ'_i are calculated as follows:

$$\chi'_r = \sum_{s=1}^S \frac{\rho_s \times \aleph(\theta'^{+}_{rs}, \widetilde{\theta}'_{rs})}{\aleph(\theta'^{+}_{rs}, \theta'^{-}_{rs})} \quad (9)$$

$$\zeta'_r = \max_s \left\{ \frac{\rho_s \times \aleph(\theta'^{+}_{rs}, \widetilde{\theta}'_{rs})}{\aleph(\theta'^{+}_{rs}, \theta'^{-}_{rs})} \right\} \quad (10)$$

Here, ρ_s presents the weight for λ'_s.

Step: 6. Calculate the values of $\mho'_r$.

$$\mho'_r = \wp' \frac{(\chi'_r - \chi'^-)}{(\chi'^+ - \chi'^-)} + (1 - \wp') \frac{(\zeta'_r - \zeta'^-)}{(\zeta'^+ - \zeta'^-)} \quad (11)$$

Here, $\chi'- = \min_r \chi'_r, \chi'^+ = \max_r \chi'_r$,

$$\zeta'- = \min_r \zeta'_r, \zeta'^+ = \max_r \zeta'_r, (r = 1, 2, 3, \dots, R) \quad (12)$$

and $\wp'$ is the "Decision-Making Mechanism Coefficient" (DMMC).

Step: 7. Prepare the ranking.

Ranking of the alternatives is done using χ', ζ', and $\mho'$ in decreasing order.

Step 8. Fix the CS.

The alternative $\xi'1$ is a CS if it attains the best rank based on the measure (minimum) subject to the two conditions:

C_1."Acceptable advantage"

$$\mho'(\xi'^2) - \mho'(\xi'^2) \geq \mho D' \quad (13)$$

where $D\mho' = \frac{1}{(R-1)}$, $\xi'1$,$\xi'2$ are in the 1st and the 2nd rank by $\mho$.

C_2: "Acceptable stability in decision making":

Alternative $\xi'1$ must also be the best ranked by χ' or/and ζ'.

The CS is stable within whole decision-making process that could be:
1. "voting by majority rule" (when $\wp' > 0.5$).
2. "by consensus" (when $\wp' = 0.5$),

iii. "with veto'' (If $\wp' < 0.5$)

If one of the conditions is not met, then CSs are identified as follows:

- Here, $\xi'1$ and $\xi'2$ are CSs if only C_2 is not satisfied, or
- $\xi'1$,$\xi'2$, $\xi'3, \dots$,$\xi'P$ are CSs if C_1 is not satisfied; and
- $\xi'P$ is determined by $\mho'(\xi'^P) - \mho'(\xi'^1) \leq D\mho'$ for maximum P.

4. Illustrative Example

The MAGDM problem (Pramanik et al., 2018b) which is adapted from Ye (2014) is considered here. The MAGDM is described as follows:

An investment company forms an expert committee consisting of three DMs in order to invest a sum of money in the best option. The four alternatives are Car company (ξ_1), Food company (ξ_2), Computer company (ξ_3), and Arms company (ξ_4). Three criteria are risk factor (λ_1), growth factor (λ_2), and environment impact (λ_3).

Weight vector of the attributes $\rho = (0.37,\ 0.33,\ 0.3)^T$ and weight vector of DMs $\omega = (0.38,\ 0.32,\ 0.3)^T$.

Following Zhang et al. (2016a), the criteria are considered as benefit type.

The problem is to find the best option for investment.

Step: 1.
Using the ratings provided by the DMs, the decision matrices are constructed in terms of BNNs as:

Decision matrix for 1st DM:

$$M^1 = \begin{pmatrix} & \lambda_1 & \lambda_2 & \lambda_3 \\ \xi_1 & (.5,.6,.7,-.3,-.6,-.3) & (.8,.5,.6,-.4,-.6,-.3) & (.9,.4,.6,-.1,-.6,-.5) \\ \xi_2 & (.6,.2,.2,-.4,-.5,-.3) & (.6,.3,.7,-.4,-.3,-.5) & (.7,\ .5,\ .3,\ -.4,\ -.3,\ -.3) \\ \xi_3 & (.8,.3,.5,-.6,-.4,-.5) & (.5,.2,.4,-.1,-.5,-.3) & (.4,.2,.8,\ -\ .5,\ -\ .3,-.2) \\ \xi_4 & (.7,.5,.3,-.6,-.3,-.3) & (.8,.7,.2,-.8,-.6,-.1) & (.6,\ .3,\ .4,\ -.3,\ -.4,\ -.7) \end{pmatrix}$$

Decision matrix for 2nd DM:

$$M^2 = \begin{pmatrix} & \lambda_1 & \lambda_2 & \lambda_3 \\ \xi_1 & (.6,.3,.4,-.5,-.3,-.7) & (.5,.3,.4,-.3,-.3,-.4) & (.1,.5,.7,-.5,-.2,-.6) \\ \xi_2 & (.7,.4,.5,-.3,-.2,-.1) & (.8,.4,.5,-.7,-.3,-.2) & (.6,\ .2,\ .7,\ -.5,\ -.2,\ -.9) \\ \xi_3 & (.8,.3,.2,-.5,-.2,-.6) & (.3,.2,.1,-.6,-.3,-.4) & (.7,.5,.4,\ -\ .4,\ -\ .3,-.2) \\ \xi_4 & (.3,.5,.2,-.5,-.5,-.2) & (.5,.6,.4,-.3,-.6,-.7) & (.4,\ .3,\ .8,\ -.5,\ -.6,\ -.5) \end{pmatrix}$$

Decision matrix for 3rd DM:

$$M^3 = \begin{pmatrix} & \lambda_1 & \lambda_2 & \lambda_3 \\ \xi_1 & (.9,.6,.4,-.7,-.3,-.2) & (.7,.5,.3,-.6,-.2,-.5) & (.4,.2,.3,-.2,-.5,-.7) \\ \xi_2 & (.5,.3,.2,-.6,-.4,-.1) & (.5,.2,.7,-.3,-.2,-.5) & (.6,\ .3,\ .2,\ -.7,\ -.6,\ -.3) \\ \xi_3 & (.2,.5,.6,-.4,-.5,-.7) & (.3,.2,.7,-.2,-.3,-.5) & (.8,.2,.4,\ -\ .2,\ -\ .3,-.6) \\ \xi_4 & (.8,.5,.5,-.4,-.6,-.3) & (.9,.3,.4,-.5,-.6,-.7) & (.7,\ .4,\ .3,\ -.2,\ -.5,\ -.7) \end{pmatrix}$$

Step: 2. In this problem, Step 2 is not required as the criteria are benefit type.

Step: 3.
Utilizing *BNWA* (see the formula (5), the AGM is constructed as follows:

$$M = \begin{pmatrix} & \lambda_1 & \lambda_2 & \lambda_3 \\ \xi_1 & (.22,.17,.17,-.16,-.14,-.13) & (.22,.14,.15,-.14,-.13,-.13) & (.16,.12,.18,-.10,-.10,-.20) \\ \xi_2 & (.20,.10,.10,-.14,-.12,-.10) & (.21,.10,.21,-.15,-.10,-.13) & (.21,\ .11,\ .13,\ -.17,\ -.12,\ -.16) \\ \xi_3 & (.21,.12,.16,-.17,-.12,-.20) & (.13,.10,.13,-.10,-.12,-.13) & (.21,.10,.18,\ -\ .13,\ -\ .10,-.11) \\ \xi_4 & (.20,.17,.11,-.17,-.15,-.10) & (.24,.18,.11,-.19,-.20,-.16) & (.19,\ .11,\ .17,\ -.11,\ -.16,\ -.21) \end{pmatrix}$$

Step: 4.
The PIS =

$$\left(\overset{\lambda_1}{(.22,.10,.10,-.14,-.12,-.10)}\ \overset{\lambda_2}{(.24,.10,.11,-.19,-.10,-.13)}\ \overset{\lambda_3}{(.21,.10,.13,-.17,-.10,-.11)} \right)$$

and the NIS =

$$\left(\overset{\lambda_1}{(.20,.17,.17,-.14,-.15,-.20)}\ \overset{\lambda_2}{(.13,.18,.21,-.10,-.20,-.16)}\ \overset{\lambda_3}{(.16,.12,.18,-.10,-.16,-.11)} \right)$$

Step: 5.

Table 2
Ranking and CS

	ξ_1	ξ_2	ξ_3	ξ_4	Ranking order	CS
χ	0.75	0.38	0.60	0.75	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$	ξ_2
ζ	0.34	0.16	0.33	0.34	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$	ξ_2
$(\wp\prime = 0.5)$	1	0	0.77	1	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$	ξ_2

Utilizing eq. (9), and eq. (10), we obtain

$\chi_1 = 0.75$, $\chi_2 = 0.38$, $\chi_3 = 0.60$, $\chi_4 = 0.75$ and $\zeta_1 = 0.34$, $\zeta_2 = 0.16$, $\zeta_3 = 0.33$, $\zeta_4 = 0.34$.

Step: 6.
For, $\wp' = 0.5$, using eq. (11), the obtained results are as follows:

$$\mho'_1 = 1,\ \mho'_2 = 0,\ \mho'_3 = .77,\ \mho'_4 = 1.$$

Step: 7.
The ranking order (see Table 2) is obtained as:

$$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$$

.
Step 8. Determine the CS
We have $\mho'(\xi_2) = 0$, and $\mho'(\xi_3) = 0.77$.

Therefore, $\mho'(\xi_3) - \mho'(\xi_2) = 0.77 > 0.333$ that satisfies the condition 1

$$\mho'(\xi_2) - \mho'(\xi_1) \geq \frac{1}{(r-1)}$$

According to χ, ζ, we see that ξ_2 is the best alternative that satisfies the condition 2.

So ξ_2 is the CS. Since ξ_2 satisfies the both conditions, no need to calculate the CS.

5. Sensitivity Analysis

Table 3 reflects impact of ranking orders for different DMMC $(\wp')$

Table 3
Values of, $\wp\prime$ and ranking of alternatives

$\wp\prime$	$\mho'_r$	Ranking
0.1	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.915$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.2	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.88$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.3	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.845$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.4	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.81$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.5	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.77$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.6	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.74$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.7	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.7$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$.
0.8	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.670$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$
0.9	$\mho'_1 = 1$, $\mho'_2 = 0$, $\mho'_3 = 0.64$, $\mho'_4 = 1$	$\xi_2 \succ \xi_3 \succ \xi_4 = \xi_1$

Note 1: The ranking order remains the same for different values of DMMC.

6. Conclusion

In this paper, VIKOR strategy is revisited under the BNS environment to overcome the shortcoming in obtaining CS in the paper (Pramanik et al., 2018b). CS strategy is incorporated in VIKOR strategy (Pramanik et al., 2018b). An illustrative MAGDM problem is solved to reflect the applicability of the modified VIKOR strategy. The impact of the DMMC on ranking of alternatives is shown by performing sensitivity analysis. The modified VIKOR strategy can be easily extended under the IBNS setting. The modified VIKOR strategy is applicable in solving MADM and MAGDM such as fault diagnosis (Zhang et al., 2016a), supplier selection (Chai et al., 2013), supply chain management (Fan & Stevenson, 2018), fault diagnosis (Zhang et al., 2016b), project selection (Yazdi et al., 2020), air surveillance (Fan et al., 2018), watershed hydrological system (Garg & Kaur, 2022), etc.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

References

Abdel-Basset, M., Mohamed, M., Elhoseny, M., Son, L. H., Chiclana, F., & Zaied, A. (2019). Cosine similarity measures of bipolar neutrosophic set for diagnosis of bipolar disorder diseases. *Artificial Intelligence in Medicine*, *101*, 101735. https://doi.org/10.1016/j.artmed.2019.101735

Ali, M., Son, L. H., Deli, I., & Tien, N. D. (2017). Bipolar neutrosophic soft sets and applications in decision making. *Journal of Intelligent & Fuzzy Systems*, *33*(6), 4077–4087.

Akram, M., & Sarwar, M. (2017). Novel multiple criteria decision making methods based on bipolar neutrosophic sets and bipolar neutrosophic graphs. *Italian Journal of Pure and Applied Mathematics*, *38*, 368–389.

Akram, M., & Shum, K. P. (2017). Bipolar neutrosophic planar graphs. *Journal of Mathematical Research with Applications*, *37*(6), 631–648. https://doi.org/10.3770/j.issn:2095-2651.2017.06.001

Atanassov, K. T. (1983). *Intuitionistic fuzzy sets*. Bulgaria: Technology Library of Bulgaria Academy of Science.

Atanassov, K. T., & Stoeva, S. (1983). Intuitionistic fuzzy sets. In *Polish Symposium on fuzzy and Interval and Fuzzy Mathematics*, 23–26.

Bausys, R., & Zavadskas, E. K. (2015). Multicriteria decision making approach by VIKOR under interval neutrosophic set environment. *Economic Computation and Economic Cybernetics Studies and Research*, *49*, 33–48. https://doi.org/10.5281/zenodo.3056284

Broumi, S., Dhar, M., Bakhouyi, A., Bakali, A., & Talea, M. (2022). Medical diagnosis problems based on neutrosophic sets and their hybrid structures: A survey. *Neutrosophic Sets and Systems*, *49*(1), 1–18. https://doi.org/10.5281/zenodo.6426357

Chai, J., Liu, J. N., & Ngai, E. W. (2013). Application of decision-making techniques in supplier selection: A systematic review of literature. *Expert Systems with Applications*, *40*(10), 3872–3885. https://doi.org/10.1016/j.eswa.2012.12.040

Chakraborty, A., Mondal, S. P., Alam, S., Ahmadian, A., Senu, N., De, D., & Salahshour, S. (2019). Disjunctive representation of triangular bipolar neutrosophic numbers, de-bipolarization technique and application in multi-criteria decision-making problems, *Symmetry*, *11*(7), 932. https://doi.org/10.3390/sym11070932

Chang, C. L. (2010). A modified VIKOR method for multiple criteria analysis. *Environmental Monitoring and Assessment*, *168*, 339–344. https://doi.org/10.1007/s10661-009-1117-0

Chen, L. Y., & Wang, T. C. (2009). Optimizing partners' choice in IS/IT outsourcing projects: The strategic decision of fuzzy VIKOR. *International Journal of Production Economics*, *120*(1), 233–242. https://doi.org/10.1016/j.ijpe.2008.07.022

Deli, I., Ali, M., & Smarandache, F. (2015). Bipolar neutrosophic sets and their application based on multi-criteria decision making problems. In *2015 International Conference on Advanced Mechatronic Systems, 2015*, 249–254.

Devi, K. (2011). Extension of VIKOR method in intuitionistic fuzzy environment for robot selection. *Expert Systems with Applications*, *38*(11), 14163–14168. https://doi.org/10.1016/j.eswa.2011.04.227

El-Hefenawy, N., Metwally, M. A., Ahmed, Z. M., & El-Henawy, I. M. (2016). A review on the applications of neutrosophic sets. *Journal of Computational and Theoretical Nanoscience*, *13*(1), 936–944. https://doi.org/10.1166/jctn.2016.4896

Fan, E., Xie, W., Pei, J., Hu, K., & Li, X. (2018). Neutrosophic Hough transform-based track initiation method for multiple target tracking. *IEEE Access*, *6*, 16068–16080. https://doi.org/10.1109/ACCESS.2018.2814827

Fan, Y., & Stevenson, M. (2018). A review of supply chain risk management: Definition, theory, and research agenda. *International Journal of Physical Distribution & Logistics Management*, *48*(3), 205–230. https://doi.org/10.1108/IJPDLM-01-2017-0043

Garg, H., & Kaur, G. (2022). Algorithm for solving the decision-making problems based on correlation coefficients under cubic intuitionistic fuzzy information: A case study in watershed hydrological system. *Complex and Intelligent Systems*, *8*, 179–198. https://doi.org/10.1007/s40747-021-00339-4

Hashim, R. M., Gulistan, M., Rehman, I, Hassan, N., & Nasruddin, A. M. (2020). Neutrosophic bipolar fuzzy set and its application in medicines preparations. *Neutrosophic Sets and Systems*, *31*, 86–100. https://doi.org/10.5281/zenodo.3639217

Hu, J., Pan, L., & Chen, X. (2017). An interval neutrosophic projection-based VIKOR method for selecting doctors. *Cognitive Computation*, *9*, 801–816. https://doi.org/10.1007/s12559-017-9499-8

Huang, Y., Wei, G., & Wei, C. (2017). VIKOR method for interval neutrosophic multiple attribute group decision-making. *Information*, *8*(4), 144. https://doi.org/10.3390/info8040144

Mardani, A., Zavadskas, E. K., Govindan, K., Amat Senin, A., & Jusoh, A. (2016). VIKOR technique: A systematic review of the state of the art literature on methodologies and applications. *Sustainability*, *8*(1), 37. https://doi.org/10.3390/su8010037

Molodtsov, D. (1999). Soft set theory—first results. *Computers & Mathematics with Applications*, *37*(4-5), 19–31. https://doi.org/10.1016/S0898-1221(99)00056-5

Muzaffar, A., Nafis, N. T., & Sohail, S. S. (2020). Neutrosophy logic and its classification: An overview. *Neutrosophic Sets and Systems*, *35*, 239–251. http://fs.unm.edu/NSS2/index.php/111/article/view/26

Nguyen, G.N., Son, L.H., Ashour, A.S., & Dey, N. (2019). A survey of the state-of-the-arts on neutrosophic sets in biomedical diagnoses. *International Journal of Machine Learning and Cybernetics*, *10*, 1–13. https://doi.org/10.1007/s13042-017-0691-7

Opricovic, S. (1998). *Multicriteria optimization in civil engineering*. PhD thesis. Serbia: Faculty of Civil Engineering.

Opricovic, S., & Tzeng, G. H. (2003). Fuzzy multicriteria model for postearthquake land-use planning. *Natural Hazards Review*, *4*(2), 59–64. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:2(59)

Otay, İ, & Kahraman, C. (2019). A state-of-the-art review of neutrosophic sets and theory. *Fuzzy Multi-Criteria Decision-Making Using Neutrosophic Sets*, 3–24. https://doi.org/10.1007/978-3-030-00045-5_1

Park, J. H., Cho, H. J., & Kwun, Y. C. (2011). Extension of the VIKOR method for group decision making with interval-valued intuitionistic fuzzy information. *Fuzzy Optimization and Decision Making*, *10*, 233–253. https://doi.org/10.1007/s10700-011-9102-9

Peng, X., & Dai, J. (2018). A bibliometric analysis of neutrosophic set: Two decades review from 1998 to 2017. *Artificial Intelligence Review*, *53*(1), 199–255. https://doi.org/10.1007/s10462-018-9652-0.

Pouresmaeil, H., Shivanian, E., Khorram, E., & Fathabadi, H.S. (2017). An extended method using TOPSIS and VIKOR for multiple attribute decision making with multiple decision makers and single valued neutrosophic numbers. *Advances and Applications in Statistics*, *50*(4), 261–292. https://doi.org/10.17654/AS050040261

Pramanik, S., Dey, P. P., Giri, B. C., & Smarandache, F. (2017). Bipolar neutrosophic projection based models for solving multi-attribute decision making problems. *Neutrosophic Sets and Systems, 15,* 70–79. https://doi.org/10.5281/zenodo.570936

Pramanik, S., Dalapati, S., Alam, S., & Roy, T. K. (2018a). TODIM method for group decision making under bipolar neutrosophic set environment. In F. Smarandache, & S. Pramanik (Eds.), *New trends in neutrosophic theory and applications* (pp. 140–155). Pons Editions. https://doi.org/10.3390/math6050067

Pramanik, S., Dalapati, S., Alam, S., & Roy, T. K. (2018b). VIKOR based MAGDM strategy under bipolar neutrosophic set environment. *Neutrosophic Sets and Systems*, *19*(1), 57–69. https://doi.org/10.5281/zenodo.1235341

Rani, P., Mishra, A. R., Pardasani, K. R., Mardani, A., Liao, H., & Streimikiene, D. (2019). A novel VIKOR approach based on entropy and divergence measures of Pythagorean fuzzy sets to evaluate renewable energy technologies in India. *Journal of Cleaner Production*, *238*, 117936. https://doi.org/10.1016/j.jclepro.2019.117936

Shumaiza, Akram, M., Al-Kenani, A. N., & Alcantud, J. C. R. (2019). Group decision-making based on the VIKOR method with trapezoidal bipolar fuzzy information. *Symmetry*, *11*(10), 1313. https://doi.org/10.3390/sym11101313

Smarandache, F. (1998). *A unifying field in logics, neutrosophy: Neutrosophic probability, set and logic*. USA: American Research Press.

Uluçay, V., Kılıç, A., Yildiz, I., & Sahin, M. (2018). A new approach for multi-attribute decision-making problems in bipolar neutrosophic sets. *Neutrosophic Sets and Systems*, *23*, 142–159. https://doi.org/10.5281/zenodo.2154873

Ünver, M., Türkarslan, E., Elik, N., & Ye, J. (2022). Intuitionistic fuzzy-valued neutrosophic multi-sets and numerical applications to classification. *Complex & Intelligent Systems, 8*(2), 1703–1721. https://doi.org/10.1007/s40747-021-00621-5

Vahdani, B., Hadipour, H., Sadaghiani, J. S., & Amiri, M. (2010). Extension of VIKOR method based on interval-valued fuzzy sets. *The International Journal of Advanced Manufacturing Technology*, *47*, 1231–1239. https://doi.org/10.1007/s00170-009-2241-2

Wang, H., Madiraju, P., Zhang, Y. Q., & Sunderraman, R. (2005). Interval neutrosophic sets. *International Journal of Applied Mathematics & Statistics*, *3*, 1–18. https://doi.org/10.48550/arXiv.math/0409113

Wang, L., Zhang, H. Y., & Wang, J. Q. (2018). Frank Choquet Bonferroni mean operators of bipolar neutrosophic sets and their application to multi-criteria decision-making problems. *International Journal of Fuzzy Systems*, *20*, 13–28. https://doi.org/10.1007/s40815-017-0373-3

Yazdi, A. K., Komijan, A. R., Wanke, P. F., & Sardar, S. (2020). Oil project selection in Iran: A hybrid MADM approach in an uncertain environment. *Applied Soft Computing*, *88*, 106066. https://doi.org/10.1016/j.asoc.2020.106066

Ye, J. (2014). Similarity measures between interval neutrosophic sets and their applications in multi criteria decision-making. *Journal of Intelligent and Fuzzy Systems*, *26*(1), 165–172. https://doi.org/10.3233/IFS-120724

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Zhang, C., Li, D., Kang, X., Song, D., Sangaiah, A. K., & Broumi, S. (2020). Neutrosophic fusion of rough set theory: An overview. *Computers in Industry*, *115*, 103117. https://doi.org/10.1016/j.compind.2019.07.007

Zhang, M., Liu, P., & Shi, L. (2016a). An extended multiple attribute group decision making TODIM method based on the neutrosophic numbers. *Journal of Intelligent & Fuzzy Systems*, *30*(3), 1773–1781. https://doi.org/10.3233/IFS-151889

Zhang, W. R. (1994). Bipolar fuzzy sets and relations: A computational framework for cognitive modeling and multi agent decision analysis. *In Proceedings of the IEEE Industrial Fuzzy Control and Intelligent Systems Conference, and the NASA Joint Technology Workshop on Neural Networks and Fuzzy Logic, Fuzzy Information Processing Society Biannual Conference*, 1994, 305–309.

Zhang, W. R. (1998). (Yin)(Yang) bipolar fuzzy sets. In *1998 IEEE International Conference on Fuzzy Systems Proceedings,* 1, 835–840.

Zhang, N., & Wei, G. (2013). Extension of VIKOR method for decision making problem based on hesitant fuzzy set. *Applied Mathematical Modelling*, *37*(7), 4938–4947. https://doi.org/10.1016/j.apm.2012.10.002

Zhang, C., Zhai, Y., Li, D., & Mu, Y. (2016b). Steam turbine fault diagnosis based on single-valued neutrosophic multigranulation rough sets over two universes. *Journal of Intelligent & Fuzzy Systems*, *31*(6), 2829–2837. https://doi.org/10.3233/jifs-169165

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