A Revisit to NC-VIKOR Based MAGDM Strategy in Neutrosophic Cubic Set Environment

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Abstract. Multi attribute group decision making with VIKOR (VlseKriterijuska Optimizacija I Komoromisno Resenje) strategy has been widely applied to solving real-world problems. Recently, Pramianik et al. [S. Pramanik, S. Dalapati, S. Alam, and T. K. Roy. NC-VIKOR based MAGDM strategy under neutrosophic cubic set environment, Neutrosophic Sets and Systems, 20 (2018), 95-108] proposed VIKOR strategy for solving MAGDM, where compromise solutions are not identified in neutrosophic cubic environment. To overcome the shortcomings of the paper, we further modify the VIKOR strategy by incorporating compromise solution in neutrosophic cubic set environment. Finally, we solve an MAGDM problem using the modified NC-VIKOR strategy to show the feasibility, applicability and effectiveness of the proposed strategy. Further, we present sensitivity analysis to show the impact of different values of the decision making mechanism coefficient on ranking order of the alternatives.

Keywords: MAGDM, NCS, NC-VIKOR strategy.

1. Introduction

Neutrosophic set [1] is derived from Neutrosophy [1], a new branch of philosophy. It is characterized by the three independent functions, namely, truth membership function, indeterminacy function and falsity membership function as independent components. Each of three independent components of NS belongs to $[^{-}0, 1^{+}]$. Wang et al. [4] introduced single valued neutrosophic set (SVNS) where each of truth, indeterminacy and falsity membership function belongs to [0, 1]. Applications of NSs and SVNSs are found in various areas of research such as conflict resolution [5], clustering analysis [6-9], decision making [10-39], educational problem [40, 41], image processing [42-45], medical diagnosis [46, 47], social problem [48, 49], etc. Wang et al. [50] proposed interval neutrosophic set (INS). Mondal et al. [51] defined tangent function of interval neutrosophic set and develop a strategy for multi attribute decision making (MADM) problems. Dalapati et al. [52] defined a new cross entropy measure for interval neutrosophic set and developed a multi attribute group decision making (MAGDM) strategy.

By combining SVNS and INS, Ali et al. [53] proposed neutrosophic cubic set (NCS). Zhan et al. [54] presented two weighted average operators on NCSs and employed the operators for MADM problems. Banerjee et al. [55] introduced the grey relational analysis based MADM strategy in NCS environment. Lu and Ye [56] proposed three cosine measures between NCSs and presented MADM strategy in NCS environment. Pramanik et al. [57] defined similarity measure for NCSs and proved its basic properties. In the same study, Pramanik et al. [57] presented a new MAGDM strategy with linguistic variables in NCS environment. Pramanik et al. [58] proposed the score and accuracy functions for NCSs and prove their basic properties. In the same study, Pramanik et al. [58] developed a strategy for ranking of neutrosophic cubic numbers (NCNs) based on the score and accuracy functions. In the same study, Pramanik et al. [58] first developed a TODIM (Tomada de decisao interativa e multicritévio), called the NC-TODIM and presented new NC-TODIM [58] strategy for solving MAGDM in NCS environment. Shi and Ye [59] introduced Dombi aggregation operators of NCSs and applied them for MADM problem. Pramanik et al. [60] proposed an extended technique for order preference by similarity to ideal solution (TOPSIS) strategy in NCS environment for solving MADM problem. Ye [61] present operations and aggregation method of neutrosophic cubic numbers for MADM. Pramanik et al. [62] presented some operations and properties of neutrosophic cubic soft set.

Opricovic [63] proposed the VIKOR strategy for a multi criteria decision making (MCDM) problem with conflicting criteria [64-65]. In 2015, Bausys and Zavadskas [66] extended the VIKOR strategy to INS environment and applied it to solve MCDM problem. Further, Hung et al. [67] proposed VIKOR strategy for interval neutrosophic MAGDM. Pouresmaeil et al. [68] proposed an MAGDM strategy based on TOPSIS and VIKOR in SVNS environment. Liu and Zhang [69] extended VIKOR startyegy in neutrosophic hesitant fuzzy set environment. Hu et al. [70] proposed interval neutrosophic projection based VIKOR strategy and employed it for doctor selection. Selvakumari et al. [71] proposed VIKOR strategy for decision making problem using octagonal neutrosophic soft matrix. Pramanik et al. [72] proposed VIKOR based MAGDM strategy under bipolar neutrosophic set environment.

The remainder of the paper is organized as follows: In the section 2, we review some basic concepts and operations related to NS, SVNS, NCS. In Section 3, we present a modified NC-VIKOR strategy to solve the MAGDM problems in NCS environment. In Section 4, we solve an illustrative example using the modified NC-VIKOR in NCS environment. Then, in Section 5, we present the sensitivity analysis. In Section 6, we present conlcusion and future scope research.

2. Preliminaries

Definition 1. Single valued neutrosophic set

Let X be a space of points (objects) with a generic element in X denoted by x. A single valued neutrosophic set [4] B in X is expressed as:

B = {< x: ($T_B(x), I_B(x), F_B(x)$)>: $x \in X$}, where $T_B(x), I_B(x), F_B(x) \in [0, 1]$.

For each $x \in X$, $T_B(x), I_B(x), F_B(x) \in [0, 1]$ and $0 \le T_B(x) + I_B(x) + F_B(x) \le 3$.

Definition 2. Interval neutrosophic set

An interval neutrosophic set [50] $\tilde{A}(x)$ of a nonempty set X is expressed by truth-membership function $T_{\tilde{A}}(x)$, the indeterminacy membership function $I_{\tilde{A}}(x)$ and falsity membership function $F_{\tilde{A}}(x)$. For each $x \in X$, $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$, $F_{\tilde{A}}(x) \subseteq [0, 1]$ and $\tilde{A}$ defined as follows:

$\tilde{A}(x)$ = {< x, $[T^-_{\tilde{A}}(x), T^+_{\tilde{A}}(x)]$, $[I^-_{\tilde{A}}(x), I^+_{\tilde{A}}(x)]$, $[F^-_{\tilde{A}}(x), F^+_{\tilde{A}}(x)]$ | $\forall\ x \in X$}. Here, $T^-_{\tilde{A}}(x)$, $T^+_{\tilde{A}}(x)$, $I^-_{\tilde{A}}(x), I^+_{\tilde{A}}(x)$, $F^-_{\tilde{A}}(x), F^+_{\tilde{A}}(x): X \rightarrow\ ]^-0, 1^+[$ and $^-0 \le \sup T^+_{\tilde{A}}(x) + \sup I^+_{\tilde{A}}(x) + \sup F^+_{\tilde{A}}(x) \le 3^+$.

Here, we consider $T^-_{\tilde{A}}(x), T^+_{\tilde{A}}(x)$, $I^-_{\tilde{A}}(x), I^+_{\tilde{A}}(x)$, $F^-_{\tilde{A}}(x), F^+_{\tilde{A}}(x)$: $X \rightarrow [0, 1]$ for real applications.

Definition 3. Neutrosophic cubic set

A neutrosophic cubic set [53] in a non-empty set X is defined as N = {< x, $\tilde{A}(x)$, A(x) >: $\forall\ x \in X$}, where $\tilde{A}$ and A are the interval neutrosophic set and neutrosophic set in X respectively. For convenience, we can simply use N = < $\tilde{A}$, A > to represent an element N in neutrosophic cubic set and the element N can be called a neutrosophic cubic number (NCN).

Some operations of neutrosophic cubic sets: [53]

i. Union of any two neutrosophic cubic sets

Let $N_1 = < \tilde{A}_1(x), A_1(x) >$ and $N_2 = < \tilde{A}_2(x), A_2(x) >$ be any two neutrosophic cubic sets in a non-empty set H. Then the union of N_1 and N_2 denoted by $N_1 \cup N_2$ is defined as follows:

$N_1 \cup N_2 = \left\langle \tilde{A}_1(x) \cup \tilde{A}_2(x), A_1(x) \cup A_2(x), \forall x \in X \right\rangle$, where,

$\tilde{A}_1(x)\cup\tilde{A}_2(x)$ = {< x , [max{ $T^-_{\tilde{A}_1}(x)$, $T^-_{\tilde{A}_2}(x)$ },max { $T^+_{\tilde{A}1}(x)$, $T^+_{\tilde{A}_2}(x)$ }], [min { $I^-_{\tilde{A}_1}(x)$, $I^-_{\tilde{A}_2}(x)$ }, min { $I^+_{\tilde{A}_1}(x)$, $I^+_{\tilde{A}_2}(x)$ }], [min { $F^-_{\tilde{A}_1}(x)$, $F^-_{\tilde{A}_2}(x)$ }, min { $F^+_{\tilde{A}_1}(x)$, $F^+_{\tilde{A}_2}(x)$ }]>: $x\in X$} and $A_1(x)\cup A_2(x)$ = {< x, max { $T_{A_1}(x)$, $T_{A_2}(x)$ }, min { $I_{A_1}(x)$, $I_{A_2}(x)$ }, min { $F_{A_1}(x)$, $F_{A_2}(x)$ }>: $\forall$ $x\in X$}.

ii. Intersection of any two neutrosophic cubic sets

Intersection of N_1 and N_2 denoted by $N_1\cap N_2$ is defined as follows:

$N_1\cap N_2$ = $\left\langle \tilde{A}_1(x)\cap\tilde{A}_2(x), A_1(x)\cap A_2(x)\,\forall x\in X\right\rangle$, where $\tilde{A}_1(x)\cap\tilde{A}_2(x)$ = {< x, [min { $T^-_{\tilde{A}_1}(x)$, $T^-_{\tilde{A}_2}(x)$ }, min { $T^+_{\tilde{A}1}(x)$, $T^+_{\tilde{A}_2}(x)$ }], [max { $I^-_{\tilde{A}_1}(x)$, $I^-_{\tilde{A}_2}(x)$ }, max { $I^+_{\tilde{A}_1}(x)$, $I^+_{\tilde{A}_2}(x)$ }], [max { $F^-_{\tilde{A}_1}(x)$, $F^-_{\tilde{A}_2}(x)$ }, max { $F^+_{\tilde{A}_1}(x)$, $F^+_{\tilde{A}_2}(x)$ }]>: $x\in X$} and $A_1(x)\cap A_2(x)$ = {< x, min { $T_{A_1}(x)$, $T_{A_2}(x)$ }, max { $I_{A_1}(x)$, $I_{A_2}(x)$ }, max { $F_{A_1}(x)$, $F_{A_2}(x)$ }>: $\forall$ $x\in X$}.

iii. Complement of a neutrosophic cubic set

Let N_1=< $\tilde{A}_1(x), A_1(x)$ > be an NCS in X. Then compliment of N_1=< $\tilde{A}_1(x), A_1(x)$ > is denoted by N_1^c = {< x, $\tilde{A}_1^c(x)$, $A_1^c(x)$>: $\forall$ $x\in X$}.

Here, $\tilde{A}_1{}^c$ = {< x, [$T^+_{\tilde{A}_1{}^c}(x)$, $T^-_{\tilde{A}_1{}^c}(x)$], [$I^+_{\tilde{A}_1{}^c}(x)$, $I^-_{\tilde{A}_1{}^c}(x)$], [$F^+_{\tilde{A}_1{}^c}(x)$, $F^-_{\tilde{A}_1{}^c}(x)$]>: $\forall$ x ∈ X},

where, $T^-_{\tilde{A}_1{}^c}(x)$ = {1} - $T^-_{\tilde{A}_1}(x)$, $T^+_{\tilde{A}_1{}^c}(x)$ = {1} - $T^+_{\tilde{A}_1}(x)$, $I^-_{\tilde{A}_1{}^c}(x)$ = {1} - $I^-_{\tilde{A}_1}(x)$, $I^+_{A_1{}^c}(x)$ = {1} - $I^+_{\tilde{A}_1}(x)$, $F^-_{\tilde{A}_1{}^c}(x)$ = {1} - $F^-_{\tilde{A}_1}(x)$, $F^+_{\tilde{A}_1{}^c}(x)$ = {1} - $F^+_{\tilde{A}_1}(x)$, and $T_{A_1^c}(x)$ = {1} - $T_{A_1}(x)$, $I_{A_1^c}(x)$ = {1} - $I_{A_1}(x)$, $F_{A_1^c}(x)$ = {1} - $F_{A_1}(x)$.

iv. Containment

Let N_1=< $\tilde{A}_1, A_1$ > = {< x, [$T^-_{\tilde{A}_1}(x)$, $T^+_{\tilde{A}_1}(x)$], $[I^-_{\tilde{A}_1}(x), I^+_{\tilde{A}_1}(x)]$, $\left(T_{A_1}(x), I_{A_1}(x), F_{A_1}(x)\right)$ >: $x\in X$} and N_2=< $\tilde{A}_2, A_2$ > = {< x, [$T^-_{\tilde{A}_2}(x)$, $T^+_{\tilde{A}_2}(x)$], $[I^-_{\tilde{A}_2}(x), I^+_{\tilde{A}_2}(x)]$, $\left(T_{A_2}(x), I_{A_2}(x), F_{A_2}(x)\right)$ >: $x\in X$} be any two neutrosophic cubic sets in a non-empty set X,

then, (i) $N_1 \subseteq N_2$ if and only if $T^-_{\tilde{A}_1}(x) \le T^-_{\tilde{A}_2}(x)$, $T^+_{\tilde{A}_1}(x) \le T^+_{\tilde{A}_2}(x)$, $I^-_{\tilde{A}_1}(x) \ge I^-_{\tilde{A}_2}(x)$, $I^+_{\tilde{A}_1}(x) \ge I^+_{\tilde{A}_2}(x)$, $F^-_{\tilde{A}_1}(x) \ge F^-_{\tilde{A}_2}(x)$, $F^+_{\tilde{A}_1}(x) \ge F^+_{\tilde{A}_2}(x)$, and $T_{A_1}(x) \le T_{A_2}(x)$, $I_{A_1}(x) \ge I_{A_2}(x)$, $F_{A_1}(x) \ge F_{A_2}(x)$ for all $x\in X$.

Definition 4. Distance between two NCNs

Let N_1= < [a_1, a_2], [b_1, b_2], [c_1, c_2], (a, b, c) > and N_2 = < [d_1, d_2], [e_1, e_2], [f_1, f_2], (d, e, f) > be any two NC-numbers, then distance [58] between them is defined by

$$H(N_1, N_2) = \frac{1}{9}[|a_1-d_1|+|a_2-d_2|+|b_1-e_1|+|b_2-e_2|+|c_1-f_1|+|c_2-f_2|+|a-d|+|b-e|+|c-f|] \quad (1)$$

Definition 5. Procedure of normalization

In general, benefit type attributes and cost type attributes can exist simultaneously in MAGDM problem. Therefore the decision matrix must be normalized. Let a_{ij} be an NC-number to express the rating value of i-th alternative with respect to j-th attribute (Ψ_j). When attribute $\Psi_j\in$ C or $\Psi_j \in$ G (where C and G be the set of cost type attributes and set of benefit type attributes respectively), the normalized values for cost type attribute and benefit type attribute are calculated by using the following expression (2).

$$a_{ij}^{*}=\begin{cases}a_{ij} & \text{if } \Psi_j \in G\\ 1-a_{ij} & \text{if } \Psi_j \in C\end{cases} \quad (2)$$

where a_{ij} is the performance rating of i th alternative for attribute Ψ_j.

3. VIKOR strategy for solving MAGDM problem in NCS environment

In this section, we propose modified NC-VIKOR strategy fro an MAGDM strategy in NCS environment. Assume that $\Phi=\{\Phi_1,\Phi_2,\Phi_3,...,\Phi_r\}$ be a set of r alternatives and $\Psi=\{\Psi_1,\Psi_2,\Psi_3,...,\Psi_s\}$ be a set of s attributes. Assume that $W=\{w_1,w_2,w_3,...,w_s\}$ be the weight vector of the attributes, where $w_k \geq 0$ and $\sum_{k=1}^{s} w_k = 1$. Assume that $E=\{E_1,E_2,E_3,...,E_M\}$ be the set of M decision makers and $\zeta=\{\zeta_1,\zeta_2,\zeta_3,...,\zeta_M\}$ be the set of weight vector of decision makers, where $\zeta_p \geq 0$ and $\sum_{p=1}^{M} \zeta_p = 1$.

The proposed MAGDM strategy consists of the following steps:

Step: 1. Construction of the decision matrix

Let $DM^p = (a_{ij}^p)_{r\times s}$ (p = 1, 2, 3, …, t) be the p-th decision matrix, where information about the alternative Φ_i provided by the decision maker or expert E_p with respect to attribute Ψ_j (j = 1, 2, 3, …, s). The p-th decision matrix denoted by DM^p (See Equation (3)) is constructed as follows:

$$DM^p=\begin{pmatrix} & \Psi_1 & \Psi_2 \ldots & \Psi_s\\ \Phi_1 & a_{11}^p & a_{12}^p \ldots & a_{1s}^p\\ \Phi_2 & a_{21}^p & a_{22}^p & a_{2s}^p\\ . & . & . \; . & .\\ \Phi_r & a_{r1}^p & a_{r2}^p \ldots & .a_{rs}^p\end{pmatrix} \quad (3)$$

Here p = 1, 2, 3,…, M; i = 1, 2, 3,…, r; j = 1, 2, 3,…, s.

Step: 2. Normalization of the decision matrix

We use Equation (2) for normalizing the cost type attributes and benefit type attributes. After normalization, the normalized decision matrix (Equation (3)) is represented as follows (see Equation 4):

$$DM^p=\begin{pmatrix} & \Psi_1 & \Psi_2 \ldots & \Psi_s\\ \Phi_1 & a_{11}^{*p} & a_{12}^{*p} \ldots & a_{1s}^{*p}\\ \Phi_2 & a_{21}^{*p} & a_{22}^{*p} & a_{2s}^{*p}\\ . & . & \ldots & .\\ \Phi_r & a_{r1}^{*p} & a_{r2}^{*p} \ldots & .a_{rs}^{*p}\end{pmatrix} \quad (4)$$

Here, p = 1, 2, 3,…, M; i = 1, 2, 3,…, r; j = 1, 2, 3,…, s.

Step: 3. Aggregated decision matrix

For group decision, we aggregate all the individual decision matrices (DM^p, $p=1,2,...,M$) to an aggregated decision matrix (DM) using the neutrosophic cubic numbers weighted aggregation (NCNWA) [73] operator as follows:

$$a_{ij} = NCNWA_{\zeta}(a_{ij}^1, a_{ij}^2, ..., a_{ij}^M) = (\zeta_1 a_{ij}^1 \oplus \zeta_2 a_{ij}^2 \oplus \zeta_3 a_{ij}^3 \oplus ... \oplus \zeta_M a_{ij}^M) =$$
$$< \Bigg([\sum_{p=1}^{M} \zeta_p T_{ij}^{-(p)}, \sum_{p=1}^{M} \zeta_p T_{ij}^{+(p)}], [\sum_{p=1}^{M} \zeta_p I_{ij}^{-(p)}, \sum_{p=1}^{M} \zeta_p I_{ij}^{+(p)}],$$
$$[\sum_{p=1}^{M} \zeta_p F_{ij}^{-(p)}, \sum_{p=1}^{M} \zeta_p F_{ij}^{+(p)}], (\sum_{p=1}^{M} \zeta_p T_{ij}^{(p)}, \sum_{p=1}^{M} \zeta_p I_{ij}^{(p)}, \sum_{p=1}^{M} \zeta_p F_{ij}^{(p)}] \Bigg) > \quad (5)$$

Therefore, the aggregated decision matrix is defined as follows:

$$DM = \begin{pmatrix} & \Psi_1 & \Psi_2 & ... ..\Psi_s \\ \Phi_1 & a_{11} & a_{12}... & a_{1s} \\ \Phi_2 & a_{21} & a_{22} & a_{2s} \\ . & . & & \\ \Phi_r & a_{r1} & a_{r2}... & a_{rs} \end{pmatrix} \quad (6)$$

Here, i = 1, 2, 3, …, r; j = 1, 2, 3, …, s; p =1, 2, …., M.

Step: 4. Define the positive ideal solution and negative ideal solution

$$a_{ij}^{+} = <[\max_i t_{ij}^{-}, \max_i t_{ij}^{+}], [\min_i i_{ij}^{-}, \min_i i_{ij}^{+}], [\min_i f_{ij}^{-}, \min_i i_{ij}^{+}], (\max_i t_{ij}, \min_i f_{ij}, \min_i f_{ij}) > \quad (7)$$
$$a_{ij}^{-} = <[\min_i t_{ij}^{-}, \min_i t_{ij}^{+}], [\max_i i_{ij}^{-}, \max_i i_{ij}^{+}], [\max_i f_{ij}^{-}, \max_i i_{ij}^{+}], (\min_i t_{ij}, \max_i f_{ij}, \max_i f_{ij}) > \quad (8)$$

Step: 5. Compute Γ_i and Z_i

Γ_i and Z_i represent the average and worst group scores for the alternative A_i respectively with the relations

$$\Gamma_i = \sum_{j=1}^{s} \frac{w_j \times D(a_{ij}^{+}, a_{ij}^{*})}{D(a_{ij}^{+}, a_{ij}^{-})} \quad (9)$$
$$Z_i = \max_j \left\{ \frac{w_j \times D(a_{ij}^{+}, a_{ij}^{*})}{D(a_{ij}^{+}, a_{ij}^{-})} \right\} \quad (10)$$

Here, w_j is the weight of Ψ_j.

The smaller values of Γ_i and Z_i correspond to the better average and worse group scores for alternative A_i, respectively.

Step: 6. Calculate the values of ϕ_i (i = 1, 2, 3, …, r)

$$\varphi_i = \gamma \frac{(\Gamma_i - \Gamma^{-})}{(\Gamma^{+} - \Gamma^{-})} + (1-\gamma) \frac{(Z_i - Z^{-})}{(Z^{+} - Z^{-})} \quad (11)$$

Here, $\Gamma_i^{-} = \min_i \Gamma_i$, $\Gamma_i^{+} = \max_i \Gamma_i$, $Z_i^{-} = \min_i Z_i$, $Z_i^{+} = \max_i Z_i$ (12)

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

Step: 7. Rank the priority of alternatives

Rank the alternatives by φ_i, Γ_i and Z_i according to the rule of traditional VIKOR strategy. The smaller value reflects the better alternative.

Step: 8. Determine the compromise solution

Obtain alternative Φ^1 as a compromise solution, which is ranked as the best by the measure φ (Minimum) if the following two conditions are satisfied:

Condition 1. Acceptable stability: $\varphi(\Phi^2)-\varphi(\Phi^1)\geq\frac{1}{(r-1)}$, where Φ^1, Φ^2 are the alternatives with first and second position in the ranking list by φ; r is the number of alternatives.

Condition 2. Acceptable stability in decision making: Alternative Φ^1 must also be the best ranked by Γ or/and Z. This compromise solution is stable within whole decision making process.
If one of the conditions is not satisfied, then a set of compromise solutions is proposed as follows:

◊ Alternatives Φ^1 and Φ^2 are compromise solutions if only condition 2 is not satisfied, or

◊ Φ^1, Φ^2, Φ^3,…, Φ^r are compromise solutions if condition 1 is not satisfied and Φ^r is decided by constraint $\varphi(\Phi^r)-\varphi(\Phi^1)\leq\frac{1}{(r-1)}$ for maximum r.

4. Illustrative example

To demonstrate the feasibility, applicability and effectiveness of the proposed strategy, we solve an MAGDM problem adapted from [74]. We assume that an investment company wants to invest a sum of money in the best option. The investment company forms a decision making board comprising of three members (E_1, E_2, E_3) who evaluate the four alternatives to invest money. The alternatives are Car company (Φ_1), Food company (Φ_2), Computer company (Φ_3) and Arms company (Φ_4). Decision makers take decision to evaluate alternatives based on the attributes namely, risk factor (Ψ_1), growth factor (Ψ_2), environment impact (Ψ_3). We consider three criteria as benefit type based on Pramanik et al. [58]. Assume that the weight vector of attributes is $W=(0.36, 0.37, 0.27)^T$ and weight vector of decision makers or experts is $\zeta=(0.26, 0.40, 0.34)^T$. Now, we apply the modified NC-VIKOR strategy using the following steps.

Step: 1. Construction of the decision matrix

We construct the decision matrices as follows:

Decision matrix for DM^1 in NCN form

$$\begin{pmatrix} & \Psi_1 & \Psi_2 & \Psi_3 \\ \Phi_1 & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> \\ \Phi_2 & <[.6,.8],[.2,.3],[.2,.4],(.8,.3,.4)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \\ \Phi_3 & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.6,.8],[.2,.3],[.2,.4],(.8,.3,.4)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> \\ \Phi_4 & <[.3,.4],[.5,.6],[.5,.7],(.4,.6,.7)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \end{pmatrix} \quad (13)$$

Decision matrix for DM^2 in NCN form

$$\begin{pmatrix} & \Psi_1 & \Psi_2 & \Psi_3 \\ \Phi_1 & <[.3,.4],[.5,.6],[.5,.7],(.4,.6,.7)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \\ \Phi_2 & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \\ \Phi_3 & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> \\ \Phi_4 & <[.6,.8],[.2,.3],[.2,.4],(.8,.3,.4)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \end{pmatrix} \quad (14)$$

Decision matrix for DM^3 in NC-number form

$$\begin{pmatrix} & \Psi_1 & \Psi_2 & \Psi_3 \\ \Phi_1 & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> \\ \Phi_2 & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> \\ \Phi_3 & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.6,.8],[.2,.3],[.2,.4],(.8,.3,.4)> & <[.6,.8],[.2,.3],[.2,.4],(.8,.3,.4)> \\ \Phi_4 & <[.7,.9],[.1,.2],[.1,.2],(.9,.2,.2)> & <[.4,.5],[.4,.5],[.4,.5],(.5,.5,.5)> & <[.3,.4],[.5,.6],[.5,.7],(.4,.6,.7)> \end{pmatrix} \quad (15)$$

Step: 2. Normalization of the decision matrix

Since all the criteria are considered as benefit type, we do not need to normalize the decision matrices (DM^1, DM^2, DM^3).

Step: 3. Aggregated decision matrix

Using equation eq. (5), the aggregated decision matrix of (13, 14, 15) is presented below:

	Ψ_1	Ψ_2	Ψ_3
Φ_1	<[.44, .56], [.36, .46], [.36, .51], (.56, .46,.50)>	<[.48, .60], [.32, .42], [.32, .42], (.60, .42,.42)>	<[.62, .80], [.18, .28], [.18, .28], (.80, .28, .28)>
Φ_2	<[.45, .58], [.35, .45], [.35, .47], (.58, .45, .47)>	<[.50, .64], [.30, .40], [.30, .40], (.64, .40, .40)>	<[.60, .76], [.20, .30], [.20, .30], (.76, .30,.30)>
Φ_3	<[.62, .80], [.18, .28], [.18, .28], (.80, .28, .28)>	<[.64, .84], [.16, .26], [.16, .32], (.84, .26, .32)>	<[.47, .60], [.33, .43], [.33, .47], (.60, .43, .47)>
Φ_4	<[.56, .73], [.24, .34], [.24, .41], (.73, .34, .41)>	<[.40, .50], [.40, .50], [.40, .50], (.50, .50, .50)>	<[.56, .73], [.24, .34], [.24, .37], (.73, .34,.37)>

(16)

Step: 4. Define the positive ideal solution and negative ideal solution

The positive ideal solution a_{ij}^{+} =

Ψ_1	Ψ_2	Ψ_3
<[.62, .80], [.18, .28], [.18, .28], (.80, .28,.28)>	<[.64, .84], [.16, .26], [.16, .32], (.84, .26,.32)>	<[.62, .80], [.18, .28], [.18, .28], (.80, .28, .28)>

and the negative ideal solution

a_{ij}^{-} =

Ψ_1	Ψ_2	Ψ_3
<[.44, .56], [.36, .46], [.36, .51], (.56, .46,.50)>	<[.40, .50], [.40, .50], [.40, .50], (.50, .50,.50)>	<[.47, .60], [.33, .43], [.33, .43], (.60, .43, .47)>

Step: 5. Compute Γ_i and Z_i

Using Equation (9) and Equation (10), we obtain

$$\Gamma_1=\left(\frac{0.36\times 0.2}{0.37}\right)+\left(\frac{0.37\times 0.16}{0.25}\right)+\left(\frac{0.27\times 0}{0.16}\right)=0.43,\ \Gamma_2=\left(\frac{0.36\times 0.18}{0.37}\right)+\left(\frac{0.37\times 0.14}{0.25}\right)+\left(\frac{0.27\times 0.02}{0.16}\right)=0.42,$$

$$\Gamma_3=\left(\frac{0.36\times 0}{0.37}\right)+\left(\frac{0.37\times 0}{0.25}\right)+\left(\frac{0.27\times 0.19}{0.16}\right)=0.32,\ \Gamma_4=\left(\frac{0.36\times 0.08}{0.37}\right)+\left(\frac{0.37\times 0.25}{0.25}\right)+\left(\frac{0.27\times 0.07}{0.16}\right)=0.57.$$

And $Z_1=\max\left\{\left(\frac{0.36\times 0.2}{0.37}\right),\left(\frac{0.37\times 0.16}{0.25}\right),\left(\frac{0.27\times 0}{0.16}\right)\right\}=0.24,\ Z_2=\max\left\{\left(\frac{0.36\times 0.18}{0.37}\right),\left(\frac{0.37\times 0.14}{0.25}\right),\left(\frac{0.27\times 0.02}{0.16}\right)\right\}=0.21,$

$$Z_3=\max\left\{\left(\frac{0.36\times 0}{0.37}\right),\left(\frac{0.37\times 0}{0.25}\right),\left(\frac{0.27\times 0.19}{0.16}\right)\right\}=0.32,\ Z_4=\max\left\{\left(\frac{0.36\times 0.08}{0.37}\right),\left(\frac{0.37\times 0.25}{0.25}\right),\left(\frac{0.27\times 0.07}{0.16}\right)\right\}=0.37.$$

Step: 6. Calculate the values of ϕ_i

Using Equations (11), (12) and $\gamma=0.5$, we obtain

$$\varphi_1=0.5\times\frac{(0.43-0.32)}{0.25}+0.5\times\frac{(0.24-0.21)}{0.16}=0.31,\ \phi_2=0.5\times\frac{(0.42-0.32)}{0.25}+0.5\times\frac{(0.21-0.21)}{0.16}=0.2,$$

$$\phi_3=0.5\times\frac{(0.32-0.32)}{0.25}+0.5\times\frac{(0.32-0.21)}{0.16}=0.34,\ \phi_4=0.5\times\frac{(0.57-0.32)}{0.25}+0.5\times\frac{(0.37-0.21)}{0.16}=1\ .$$

Step 7. Rank the priority of alternatives

The preference ranking order of the alternatives is presented in Table 1

	Φ_1	Φ_2	Φ_3	Φ_4	Ranking order	Best alternative
Γ	0.43	0.42	0.32	0.57	$\Phi_3 \succ \Phi_2 \succ \Phi_1 \succ \Phi_4$	Φ_3
Z	0.24	0.21	0.32	0.37	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$	Φ_2
$\varphi(\gamma=0.5)$	0.31	0.20	0.34	1	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$	Φ_2

Table 1 Preference ranking order and compromise solution based on Γ, Z and φ

Step 8. Determine the compromise solution

The preference ranking order based on φ in decreasing order and alternative with best position is Φ_2 with $\varphi(\Phi_2) = 0.20$, and second best position Φ_1 with $\varphi(\Phi_1) = 0.31$. Therefore, $\varphi(\Phi_1) - \varphi(\Phi_2) = 0.11 < 0.333$ (since, r = 4; 1/(r-1) = 0.333), which does not satisfy the condition 1

($\varphi(\Phi^2) - \varphi(\Phi^1) \geq \frac{1}{(r-1)}$ **),** but alternative Φ_2 is the best ranked by Γ, Z, which satisfies the condition 2.

Therefore, we obtain the compromise solution as follows:

$\varphi(\Phi_1) - \varphi(\Phi_2) = 0.11 < 0.333$, $\varphi(\Phi_3) - \varphi(\Phi_2) = 0.14 < 0.333$, $\varphi(\Phi_4) - \varphi(\Phi_2) = 0.80 > 0.333$.

So Φ_1, Φ_2, Φ_3 are compromise solutions.

5. The influence of parameter γ

Table 2 shows how the ranking order of alternatives (Φ_i) changes with the change of the value of γ

Table 2. Values of ϕ_i (i = 1, 2, 3, 4) and ranking of alternatives for different values of γ .

Values of γ	Values of ϕ_i	Preference order of alternatives
$\gamma = 0.1$	$\phi_1 = 0.22$, $\phi_2 = \mathbf{0.04}$, $\phi_3 = 0.62$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$
$\gamma = 0.2$	$\phi_1 = 0.24$, $\phi_2 = \mathbf{0.08}$, $\phi_3 = 0.55$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$
$\gamma = 0.3$	$\phi_1 = 0.26$, $\phi_2 = \mathbf{0.12}$, $\phi_3 = 0.48$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$
$\gamma = 0.4$	$\phi_1 = 0.29$, $\phi_2 = \mathbf{0.16}$, $\phi_3 = 0.41$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$
$\gamma = 0.5$	$\phi_1 = 0.31$, $\phi_2 = \mathbf{0.2}$, $\phi_3 = 0.34$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_1 \succ \Phi_3 \succ \Phi_4$
$\gamma = 0.6$	$\phi_1 = 0.34$, $\phi_2 = \mathbf{0.24}$, $\phi_3 = 0.28$, $\phi_4 = 1$	$\Phi_2 \succ \Phi_3 \succ \Phi_1 \succ \Phi_4$
$\gamma = 0.7$	$\phi_1 = 0.36$, $\phi_2 = 0.28$, $\phi_3 = \mathbf{0.21}$, $\phi_4 = 1$	$\Phi_3 \succ \Phi_2 \succ \Phi_1 \succ \Phi_4$
$\gamma = 0.8$	$\phi_1 = 0.39$, $\phi_2 = 0.32$, $\phi_3 = \mathbf{0.14}$, $\phi_4 = 1$	$\Phi_3 \succ \Phi_2 \succ \Phi_1 \succ \Phi_4$
$\gamma = 0.9$	$\phi_1 = 0.42$, $\phi_2 = 0.36$, $\phi_3 = \mathbf{0.07}$, $\phi_4 = 1$	$\Phi_3 \succ \Phi_2 \succ \Phi_1 \succ \Phi_4$

6. Conclusion

In this article, we have presented a modified NC-VIKOR strategy to overcome the shortcomings of obtaining compromise solution [73]. In the modified NC-VIKOR stratgey, we have incorporated the technique of determining compromise solution. Finally, we solve an MAGDM problem to show the feasibility, applicability and efficiency. We present a sensitivity analysis to show the impact of different values of the decision making mechanism coefficient on ranking order of the alternatives.

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