Extended GRA Strategy for Multi-Attribute Decision Making with Trapezoidal Neutrosophic Numbers

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Abstract. Multi-attribute decision making(MADM) strategy has been proposed to handle uncertain decision making problem .The most extensively used models of Grey system theory is grey relational analysis (GRA). This strategy was flourished by Chinese Professor J.Deng. This strategy also known as Deng's Grey Incidence Analysis model. GRA uses a generic concept of intelligence. It describes any circumstance as, no information as black, and perfect information as white. Nevertheless, these idealized situations ever appear in real world problem. In this paper, we extend GRA strategy for multi attribute decision making in trapezoidal neutrosophic number (TrNN) environment. Here, we describe score and accuracy function for TrNNs. Then Hamming distance for twoTrNNs are also described. Lastly, a numerical problem is solved to explain thepertinence of the proposed strategy.

Keywords: Neutrosophic set, Trapezoidal neutrosophic fuzzy number, Multi-attribute decision making, VIKOR strategy.

1 Introduction

In 1998, Smarandache [1] consecrated the notion of neutrosophic set by incorporating philosophy of neutrosophy [1] in mathematical arena. Thereafter, Wang et al. [2] defined single valued neutrosophic set.Neutrosophic set and its various extensions and hybrid sets have been widely employed in decision making problems [3-58], conflict resolution [59], image processing [60], medical diagnosis [61], social science [62], etc.

Ye [63] introduced trapezoidal neutrosophic number (TrNN) in 2017. The TrNN and the single valued neutrosophic set (SVNS) [2] are very effective mathematical tools to deal with indeterminacy, incomplete, and inconsistent information. Single valued trapezoidal neutrosophic number (SVTrNN) [63, 64] is an extension of SVNS. Each element of SVTrNN is distinguished by trapezoidal number with truth membership degree, indeterminacy membership degree and falsity membership degree. Biswas et al. [65] documented value and ambiguity based ranking strategy for SVTrNN and employed the strategy to handle multi-attribute decision making (MADM) problem. Biswas et al. [66] developed a technique for order of preference by similarity to ideal solution (TOPSIS) strategy for MADM with TrNNs. Biswas et al. [67] presented distance measure based MADM strategy with interval trapezoidal neutrosophic numbers (ITrNNs).

In 1982, Deng [68, 69] introduced a grey relation analysis (GRA) to deal with uncertainty. Rao and Singh [70] introduced modified GRA strategy for decision making in manufacturing situation. In 2011, Pramanik and Mukhopadhayaya [71] studied a GRA based multi criteria group decision making (MCGDM) strategy for teacher selection in intuitionistic fuzzy set environment. In 2011, Wei [72] introduced a GRA strategy for intuitionistic fuzzy MCDM. Biswas et al. [73] discussed an entropy related GRA for MADM strategy in SVNS environment. Dey et al. [74] developed a GRA based MCGDM strategy for weaver selection in Khadi institutions in intuitionistic fuzzy environment in 2015. In 2015, Pramanik and Mondal [75] proposed a GRA for MADM strategy in an interval neutrosophic set environment. Dey et al. [76] studied an extended GRA for neutrosophic MADM strategy in interval uncertain linguistic setting. Banerjee et al. [77] constructed an MADM model via GRA for neutrosophic cubic set envinment.

GRA based MADM strategy is not proposed in the literature. To fill the research gap, we propose an extended GRA based MADM strategy to deal decision making problems in TrNN environment.

This paper is organized as follows: In section 2, we introduce some definitions relating to neutrosophic set and trapezoidal neutrosophic number. In section 3, we develop an extended GRA strategy for MADM. In section 5, an illustrative example is discussed to demonstrate the applicability of the proposed strategy. Lastly, section 6 represents the concluding remarks.

2 Preliminaries

In this section, we recall some basic definitions related to neutrosophic sets , trapezoidal neutrosophic set and GRAstrategy.

Definition 2. 1. Let Z be a universal set. A single-valued neutrosophic set [2] Y in Z is given by

$$Y = \{z, < T_Y(z), I_Y(z), F_Y(z) > \mid z \in Z\} \tag{2}$$

where $T_Y(z): Z \to [0,1], I_Y(z): Z \to [0,1]$ and $F_Y(z): Z \to [0,1]$ with the condition $0 \le T_Y(z) + I_Y(z) + F_Y(z) \le 3$ for all $z \in Z$.The functions $T_Y(z), I_Y(z)$ and $F_Y(z)$ are respectively, the truth membership function, the indeterminacy membership function and the falsity membership function of the element *z* to the set Y.

Definition 2. 2. Let X be a single valued trapezoidal neutrosophic number [63, 64]. Then, its truth membership function is

$$T_X(z) = \begin{cases} \dfrac{(z-e)t_X}{(f-e)}, e \le z < f \\ t_X, f \le z \le g \\ \dfrac{(h-z)t_X}{(h-g)}, g < z \le h \\ 0, otherwise \end{cases} \tag{3}$$

Its indeterminacy membership function is

$$I_X(z) = \begin{cases} \dfrac{(f-z)+(z-e)i_X}{(f-e)}, e \le z < f \\ i_X, f \le z \le g \\ \dfrac{z-g+(h-z)i_X}{h-g}, g < z \le h \\ 0, otherwise \end{cases} \tag{4}$$

And its falsity membership function is

$$F_X(z) = \begin{cases} \dfrac{f-z+(z-e)f_X}{f-e}, e \le z < f \\ f_X, f \le z \le g \\ \dfrac{z-g+(h-z)f_X}{h-g}, g < z \le h \\ 0, otherwise \end{cases} \tag{5}$$

Where $0 \le T_X(z) \le 1, 0 \le I_X(z) \le 1$ and $0 \le F_X(z) \le 1$ and $0 \le T_X(z) + I_X(z) + F_X(z) \le 3; e, f, g, h \in R$ .Then $X = ([e, f, g, h]; t_X, i_X, f_X)$ is called a neutrosophic trapezoidal number.

If $0 \le e \le f \le g \le h$,then m is called a positive TrNN. If $e \le f \le g \le h \le 0$,then X is called a negative TrNN. If $0 \le e \le f \le g \le h \le 1$ and $T_X, I_X, F_X \in [0,1]$, then X is called a normalized TrNN ,which is used in this paper.

Definition 2. 3. Let $K =< (e, f, g, h); T_K, I_K, F_K >$ be TNN. Then the score function [63] $S(K)$ of TrNN is defined by

$$S(K) = \frac{1}{12}(e + f + g + h)(2 + T_K - I_K - F_K), S(K) \in [0,1] \tag{6}$$

Definition 2. 4. The accuracy function [78] $Ac(K)$ of TrNN $K =< (e, f, g, h); T_K, I_K, F_K >$ is defined by

$$Ac(K) = \frac{1}{6}(g + h - e - f)(2 + T_K - F_K), Ac(K) \in [0,1] \tag{7}$$

Definition 2. 5. Comparison of two TrNNs:

Let $K_1 =< (e_1, f_1, g_1, h_1); T_{K_1}, I_{K_1}, F_{K_1} >$ and $K_2 =< (e_2, f_2, g_2, h_2); T_{K_2}, I_{K_2}, F_{K_2} >$ be two TrNN.

The comparison between thetwo TrNNs [78] is stated as follows:

1.If Sc (K_1) > Sc(K_2),then $K_1 > K_2$.

2. If Sc(K_1) = Sc(K_2) and Ac(K_1)>Ac(K_2), then $K_1 > K_2$.

3.If Sc(K_1) = Sc(K_2) and Ac(K_1)=Ac(K_2), then K_1 = K_2.

Definition 2. 6. Let $K_1 = ([e_1, f_1, g_1, g_1]; t_{K_1}, i_{K_1}, f_{K_1})$ and $K_2 = ([e_2, f_2, g_2, h_2]; t_{K_2}, i_{K_2} f_{K_2})$ be two neutrosophic trapezoidal fuzzy numbers, its Hamming distance [66] between K_1 and K_2 is defined as follows:

$$d(K_1, K_2) = \frac{1}{12}\begin{pmatrix} |e_1(2 + t_{K_1} - i_{K_1} - f_{K_1}) - e_2(2 + t_{K_2} - i_{K_2} - f_{K_2})| + |f_1(2 + t_{K_1} - i_{K_1} - f_{K_1}) - f_2(2 + t_{K_2} - i_{K_2} - f_{K_2})| \\ + |g_1(2 + t_{K_1} - i_{K_1} - f_{K_1}) - g_2(2 + t_{K_2} - i_{K_2} - f_{K_2})| + |h_1(2 + t_{K_1} - i_{K_1} - f_{K_1}) - h_2(2 + t_{K_2} - i_{K_2} - f_{K_2})| \end{pmatrix} \quad (9)$$

3. Standardize the decision matrix

Let $D = (c_{ij})_{p\times q}$ be a neutrosophic decision matrix, where the SVTrNN $\tilde{c}_{ij} = ([c_{ij}^1, c_{ij}^2, c_{ij}^3, c_{ij}^4]; t_{\tilde{c}_{ij}}, i_{\tilde{c}_{ij}}, f_{\tilde{c}_{ij}})$ is the rating value of alternative Y_i w.r.t.attribute Z_j. Now to eliminate the effect from different physical dimension into decision making process, we should standardize the decision matrix $(c_{ij})_{p\times q}$ based on two common types of attribute such as benefit and cost type attribute.We consider the following technique to obtain the standardized decision matrix $Z^* = (\tilde{z}_{ij})_{p\times q}$, in which the component z_{ij}^k of the entry $\tilde{z}_{ij} = ([z_{ij}^1, z_{ij}^2, z_{ij}^3, z_{ij}^4]; t_{\tilde{z}_{ij}}, i_{\tilde{z}_{ij}}, f_{\tilde{z}_{ij}})$ in the matrix Z are considered as:

i. For benefit types attribute:

$$\tilde{z}_{ij} = ([\frac{c_{ij}^1}{q_j^+}, \frac{c_{ij}^2}{q_j^+}, \frac{c_{ij}^3}{q_j^+}, \frac{c_{ij}^4}{q_j^+}]; t_{\tilde{z}_{ij}}, i_{\tilde{z}_{ij}}, f_{\tilde{z}_{ij}})\} \quad (10)$$

ii. For cost type attribute:

$$\tilde{z}_{ij} = ([\frac{q_j^-}{c_{ij}^4}, \frac{q_j^-}{c_{ij}^3}, \frac{q_j^-}{c_{ij}^2}, \frac{q_j^-}{c_{ij}^1}]; t_{\tilde{z}_{ij}}, i_{\tilde{z}_{ij}}, f_{\tilde{z}_{ij}}) \quad (11)$$

Where $q_j^+ = \max\{c_{ij}^4 \,|\, i = 1, 2, ..., p\}$ and $q_j^- = \min\{c_{ij}^1 \,|\, i = 1, 2, ..., p\}$ for j=1,2,….,q.

Then we obtain the following standardized decision matrix:

$$Z = (\tilde{z}_{ij})_{m\times n} = \begin{pmatrix} z_{11} & z_{12} & z_{1n} \\ z_{21} & z_{22}\cdots & z_{2n} \\ \vdots & \ddots & \vdots \\ z_{m1} & z_{m2}\cdots & z_{mn} \end{pmatrix} \quad (12)$$

4. GRA strategy for solving MCDM problem under trapezoidal neutrosophic number environment:

Assume that $\tilde{B} = \{\tilde{B}_1, \tilde{B}_2, ..., \tilde{B}_p\}$ be the p alternatives and $R' = \{R_1', R_2', ..., R_q'\}$ be the set of q attributes. Also assume that the rating values each of the alternative corresponding to each of the attribute are expressed in the form of $m_{ij} = ([b_1, b_2, b_3, b_4]; t_{m_{ij}}, i_{m_{ij}}, f_{m_{ij}})$. Using the following steps (see figure1), we describe GRA strategy for TrNN by considering the weight vector $\tilde{w} = \{\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_q\}^T$ of attributes where $\tilde{w}_b \in [0,1]$ and . $\sum_{b=1}^{q} \tilde{w}_b = 1$.

Step-1: First we defined decision matrix as follows:

$$Q = \begin{pmatrix} & R_1' & R_2' & .... & R_q' \\ \tilde{B}_1 & m_{11} & m_{12} & .... & m_{1q} \\ \tilde{B}_2 & m_{21} & m_{22} & .... & m_{2q} \\ .... & .... & .... & .... & ..... \\ \tilde{B}_P & m_{p1} & m_{p2} & .... & m_{pq} \end{pmatrix} \quad (13)$$

Step-2: Generally decision making problem consists of cost and benefit attributes. So we need to standardize the decision matrix. To standardize in benefit criteria we use the equation (10) and for cost criteria we use (11). After standardizing, the decision matrix reduces to

$$Q' = \begin{pmatrix} & R'_1 & R'_2 & .... & R'_q \\ \tilde{B}_1 & m'_{11} & m'_{12} & .... & m'_{1q} \\ \tilde{B}_2 & m'_{21} & m'_{22} & .... & m'_{2q} \\ .... & .... & .... & .... & ..... \\ \tilde{B}_P & m'_{p1} & m'_{p2} & .... & m'_{pq} \end{pmatrix} \quad (14)$$

Step-3: In this step we calculate score value and accuracy value using equation (8) and (9).
Step-4: Here, we describe the positive ideal solution (PIS) and negative ideal solution (NIS) for TrNN.

$$T^+ = ([b_1^+, b_2^+, b_3^+, b_4^+]; \max t_{m_{ij}}, \min i_{m_{ij}}, \min f_{m_{ij}}) \quad (15)$$

$$T^- = ([b_1^-, b_2^-, b_3^-, b_4^-]; \min t_{m_{ij}}, \max i_{m_{ij}}, \max f_{m_{ij}}) \quad (16)$$

Step-5: Determine the grey relation coefficient of each alternative from T^+ and T^- by the following equations:

$$\chi_{bc}^+ = \frac{\min\limits_{1\le b\le p}\min\limits_{1\le b\le p} D(x_{bc}, T_c^+) + \rho \max\limits_{1\le b\le p}\max\limits_{1\le b\le p} D(x_{bc}, T_c^+)}{D(x_{bc}, T_c^-) + \rho \max\limits_{1\le b\le p}\max\limits_{1\le b\le p} D(x_{bc}, T_c^+)} \quad (17)$$

$$\chi_{bc}^- = \frac{\min\limits_{1\le b\le p}\min\limits_{1\le b\le p} D(x_{bc}, T_c^-) + \rho \max\limits_{1\le b\le p}\max\limits_{1\le b\le p} D(x_{bc}, T_c^-)}{D(x_{bc}, T_c^-) + \rho \max\limits_{1\le b\le p}\max\limits_{1\le b\le p} D(x_{bc}, T_c^-)} \quad (18)$$

where the identification coefficient is considered as $\rho = 0.5$.

Step-6: In this step, we empoly the pre-determined weight vector of attributes as $w = \{w_1, w_2, ..., w_q\}$ and $\sum\limits_{c=1}^{q} w_c = 1$

Step-7: In this step, we determine the degree of grey relation coefficient of each alternative $\tilde{B}_b$ (b=1,2,…, p) from χ_{bc}^+ and χ_{bc}^- by the following equations:

$$\vartheta_b^+ = \sum_{c=1}^{q} w_c \chi_{bc}^+ \quad (19)$$

$$\vartheta_b^- = \sum_{c=1}^{q} w_c \chi_{bc}^- \quad (20)$$

Step-8:Evaluating the relative closeness co-efficient ϑ_b for each alternative $\tilde{B}_b$ (b=1,2,…, p) w.r.t. the positive ideal solution T^+ as

$$\vartheta_b = \frac{\vartheta_b^+}{\vartheta_b^+ + \vartheta_b^-} \quad (21)$$

forb=1,2, …., p.

Step-9: Rankingthe alternative according to the relative closeness coefficient ϑ_b (b=1,2,..., p)

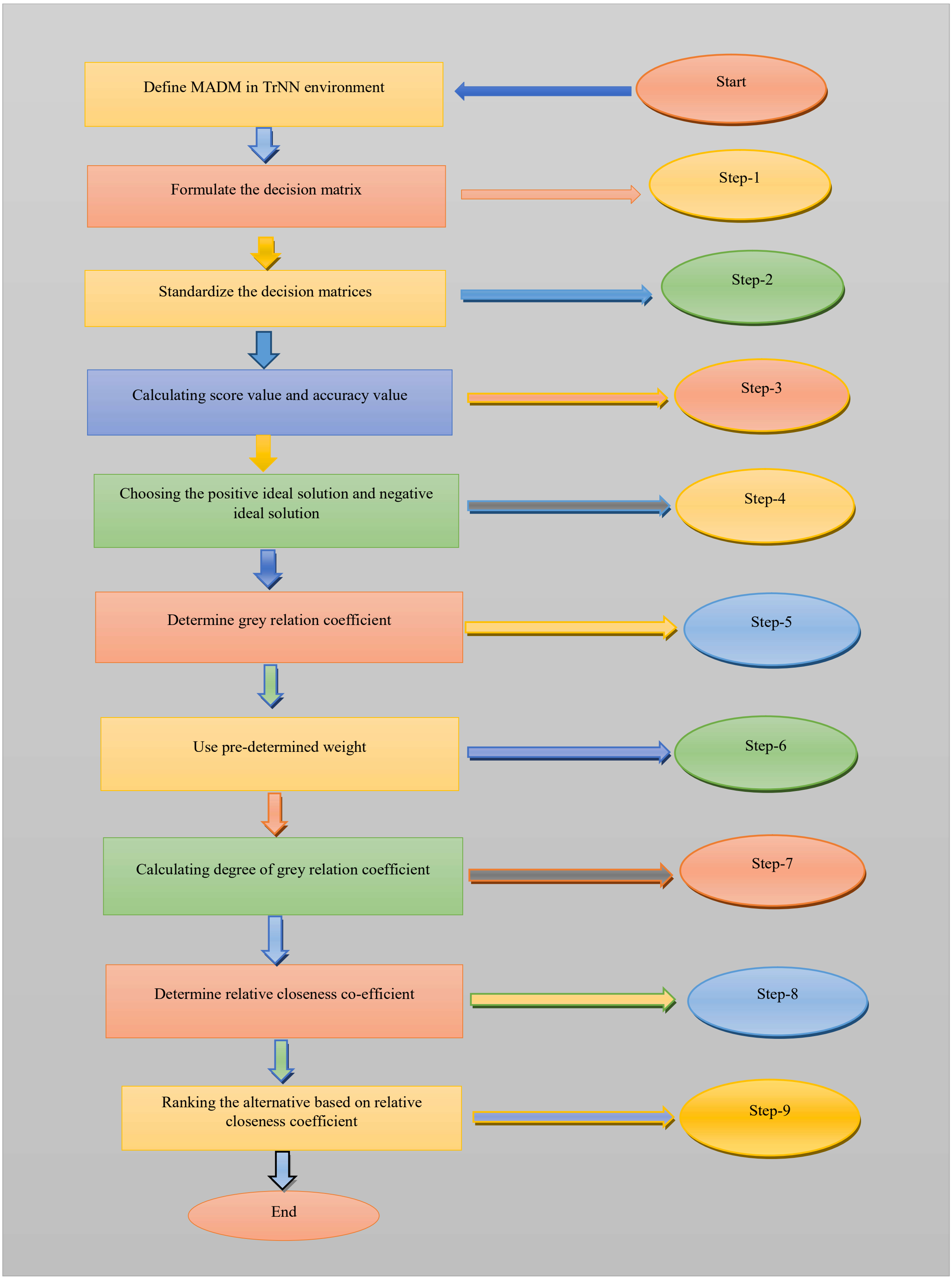

Fig 1: GRA strategy based on MADM in trapezoidal neutrosophic number.

5. Numerical problem

Here, we describe trapezoidal neutrosophic number MADM to illustrate the applicability and effectiveness of the proposed strategy. We solve a decision making problem adapted from [65] which is stated as follows. A customer intends to buy a tablet from the set of elementarily chosen four tablets $\tilde{B}_i$ (i=1, 2, 3, 4). The customer considers four attributes which include: features (R'_1), hardware specification (R'_2), affordable price (R'_3) and customer care(R'_4).

Step-1: Here we defined decision matrix

$$Q = \begin{array}{cc} & \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{array}{c} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \\ \tilde{B}_4 \end{array} & \begin{pmatrix} ([0.5,0.6,0.7,0.8];0.65,0.25,0.20) & ([0.7,0.8,0.8,0.9];0.60,0.35,0.30) & ([0.4,0.5,0.5,0.6];0.48,0.26,0.20) & ([0.4,0.5,0.6,0.7];0.55,0.42,0.20) \\ ([0.7,0.8,0.8,0.9];0.80,0.20,0.15) & ([0.6,0.7,0.8,0.9];0.50,0.40,0.35) & ([0.3,0.4,0.5,0.6];0.50,0.45,0.35) & ([0.6,0.6,0.7,0.8];0.70,0.40,0.15) \\ ([0.4,0.5,0.6,0.7];0.50,0.40,0.30) & ([0.7,0.8,0.9,0.9];0.85,0.30,0.25) & ([0.6,0.6,0.7,0.7];0.65,0.22,0.18) & ([0.6,0.6,0.7,0.7];0.85,0.25,0.15) \\ ([0.6,0.7,0.7,0.8];0.70,0.35,0.25) & ([0.5,0.6,0.6,0.7];0.65,0.35,0.30) & ([0.5,0.6,0.6,0.7];0.60,0.40,0.30) & ([0.5,0.6,0.7,0.7];0.70,0.30,0.20) \end{pmatrix} \end{array}$$

Step-2:The selected four attribute are benefit type attribute .Thus we can standardized the decision matrix $\left(Q_{ij}\right)_{4X4}$ to $\left(Q'_{ij}\right)_{4X4}$ by using equation (11). The standardized decision matrix represented as follow.

$$Q' = \begin{array}{cc} & \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{array}{c} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \\ \tilde{B}_4 \end{array} & \begin{pmatrix} ([0.62,0.75,0.88,1];0.65,0.25,0.20) & ([0.78,0.89,0.89,1];0.60,0.35,0.30) & ([0.67,0.83,0.83,1];0.48,0.26,0.20) & ([0.57,0.71,0.85,1];0.55,0.42,0.20) \\ ([0.78,0.89,0.89,1];0.80,0.20,0.15) & ([0.67,0.78,0.89,1];0.50,0.40,0.35) & ([0.50,0.67,0.83,1];0.50,0.45,0.35) & ([0.75,0.75,0.86,1];0.70,0.40,0.15) \\ ([0.57,0.71,0.86,1];0.50,0.40,0.30) & ([0.78,0.89,1,1];0.85,0.30,0.25) & ([0.86,0.86,1,1];0.65,0.22,0.18) & ([0.86,0.86,1,1];0.85,0.25,0.15) \\ ([0.75,0.88,0.88,1];0.70,0.35,0.25) & ([0.71,0.86,0.86,1];0.65,0.35,0.30) & ([0.71,0.86,0.86,1];0.60,0.40,0.30) & ([0.71,0.85,1,1];0.70,0.30,0.20) \end{pmatrix} \end{array}$$

Step-3: Calculating score value and accuracy value by using equation (7) and (8)

$$Sc(Q') = \begin{array}{cc} & \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{array}{c} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \\ \tilde{B}_4 \end{array} & \begin{pmatrix} 0.60 & 0.58 & 0.56 & 0.50 \\ 0.73 & 0.49 & 0.42 & 0.60 \\ 0.47 & 0.70 & 0.69 & 0.75 \\ 0.61 & 0.53 & 0.53 & 0.65 \end{pmatrix} \end{array}$$

$$Ac(Q') = \begin{array}{cc} & \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{array}{c} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \\ \bar{B}_4 \end{array} & \begin{pmatrix} .21 & 0.08 & 0.12 & 0.22 \\ .097 & 0.158 & 0.23 & 0.15 \\ 0.12 & 0.14 & 0.11 & 0.13 \\ 0.10 & 0.11 & 0.11 & 0.18 \end{pmatrix} \end{array}$$

Step-4: Identifying positive ideal solution (PIS) T^+ and negative ideal solution (NIS) T^- using equation (15) and (16)

$$T^+ = \begin{array}{c} \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{pmatrix} ([0.78,0.89,0.89,1];0.80,0.20,0.15) & ([0.78,0.89,1,1];0.85,0.30,0.25) & ([0.86,0.86,1,1];0.65,0.22,0.18) & ([0.86,0.86,1,1];0.85,0.25,0.15) \end{pmatrix} \end{array}$$

$$T^- = \begin{array}{c} \begin{array}{cccc} R'_1 & R'_2 & R'_3 & R'_4 \end{array} \\ \begin{pmatrix} ([0.57,0.71,0.86,1];0.50,0.40,0.30) & ([0.67,0.78,0.89,1];0.50,0.40,0.35) & ([0.50,0.67,0.83,1];0.50,0.45,0.35) & ([0.57,0.71,0.85,1];0.55,0.42,0.20) \end{pmatrix} \end{array}$$

Step-5: Using (17) and (18) we calculate grey relation coefficient:

$$\chi^+ = \begin{pmatrix} 0.33 & 0.56 & 0.52 & 0.37 \\ 1 & 0.41 & 0.36 & 0.52 \\ 0.58 & 1 & 1 & 1 \\ 0.58 & 0.54 & 0.54 & 0.58 \end{pmatrix}$$

$$\chi^- = \begin{pmatrix} 0.49 & 0.6 & 0.49 & 1 \\ 0.35 & 1 & 1 & 0.55 \\ 1 & 0.38 & 0.33 & 0.34 \\ 0.49 & 0.55 & 0.52 & 0.47 \end{pmatrix}$$

Step-6:In this step, we assume the weights are

$w_1 = 0.22,\ w_2 = 0.22,\ w_3 = 0.33,\ w_4 = 0.22$

Step-7: Calculate the degree of grey relation coefficient by equation (19) and (20)

$\vartheta_1^+ = 0.4488, \vartheta_2^+ = 0.5434,\ \vartheta_3^+ = 0.8976,\ \vartheta_1^+ = 0.536$

$\vartheta_1^- = 0.6215,\ \vartheta_2^- = 0.748,\ \vartheta_3^- = 0.4873, \vartheta_4^- = 0.5038$

Step-8: Using equation (21) we evaluate the relative closeness co-efficient

$\vartheta_1 = 0.6215,\ \vartheta_2 = 0.4208,\ \vartheta_3 = 0.6481,\ \vartheta_4 = 0.5155$

Step-9:The ranking of the alternative based on relative closeness co-efficient is

$\tilde{B}_3 > \tilde{B}_4 > \tilde{B}_2 > \tilde{B}_1$

We see that $\tilde{B}_3$ has highest value. Therefore, $\tilde{B}_3$ is the best solution.

6.Conclusion

In this paper we have investigated MADM strategy in single valued trapezoidal neutrosophic number environment. We have developed an extended GRA based MADM strategy for MADM problem. A numerical example has been provided to show the applicability and effectiveness of the proposed strategy. In future, the developed strategy can be applied to real-world problems such as teacher selection [71], brick selection [79], pattern recognition [80], clustering analysis [81], etc.

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