VIKOR Method for MAGDM Based on Q-Rung Interval-Valued Orthopair Fuzzy Information and Its Application to Supplier Selection of Medical Consumption Products

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Abstract: The VIKOR model has been considered a viable tool for many decision-making applications in the past few years, given the advantages of considering the compromise between maximizing the utility of group and minimizing personal regrets. The q-rung interval-valued orthopair fuzzy set (q-RIVOFS) is a generalization of intuitionistic fuzzy set (IFS) and Pythagorean fuzzy set (PFS) and has emerged to solve more complex and uncertain decision making problems which IFS and PFS cannot handle. In this manuscript, the key innovation is to combine the traditional VIKOR model with q-RIVOFS to develop the q-rung interval-valued orthopair fuzzy VIKOR model. In the new developed model, to express more information, the attribute’s values in MAGDM problems are depicted by q-RIVOFNs. First of all, some basic theories and aggregation operators of q-RIVOFNs are simply introduced. Then we develop the origin VIKOR model to q-RIVOFS environment and briefly express the computing steps of this new established model. Thereafter, the effectiveness of the model is verified by an example of supplier selection of medical consumer products and through comparative analysis, the superiority of the new method is further illustrated.

Keywords: multiple attribute group decision making (MAGDM); q-rung interval-valued orthopair fuzzy sets (q-RIVOFSs); VIKOR method; q-RIVOF-VIKOR model; supplier selection; medical consumption products

1. Introduction

In view of the merits of the VIKOR model in considering the compromise between group utility maximization and individual regret minimization, in recent years, it has been recognized as a meaningful tool that can be applied to many decision areas. In previous literature, some traditional decision models have been applied to MADM problems, such as the ELECTRE model [1–4], the MABAC model [5–7], the COPRAS model [8,9], the TOPSIS model [10–12], The TODIM model [13–15], and the GRA model [16–18]. Compared with the above methods, the VIKOR model not only considers the objectivity of the decision maker and the complexity of the decision-making environment, but also considers the conflict criteria, so as to obtain more effective and accurate evaluation results. Du and Liu [19] developed the traditional VIKOR model into intuitionistic trapezoidal fuzzy environment. Park, et al. [20] established the IVIF-VIKOR model for MADM problems. Qin, et al. [21] came up with an extension of VIKOR model on the basis of interval type-2 fuzzy information. Ghadikolaei, et al. [22]
extended the VIKOR model from the real number environment to the hesitating fuzzy linguistic environment, so it can better reflect the fuzziness of decision makers in making decisions in MADM problems. Wang, et al. [23] tried to expand the VIKOR model to the neutrosophic environment of triangular fuzzy, and applied it to evaluate the potential commercialization of emerging technologies. In order to select industrial robots more effectively, Narayamadranorthy, et al. [24] used an expanding VIKOR model on the foundation of interval intuitionistic hesitating fuzzy entropy. Later, some scholars Yang, et al. [25] determined the VIKOR model of language hesitation intuition to deal with the problem of MADM. Wang, et al. [26] established a VIKOR model based on projection in the context of picture fuzzy environment and used it in the risk assessment of construction projects. Wu, et al. [27] created the HFLTS-VIKOR model with possibility distributions.

Because of the uncertainty and decision problem of decision support system (DSS), in the practical DSS problem, we often cannot give the accurate evaluation value of the alternative to choose the best one. To overcome this problem, in 1965, the fuzzy set theory defined by Zadeh [28], initially applied membership functions instead of precise real numbers to describe the estimation results. Atanassov [29,30] added another metric that complements non-membership functions. In recent years, the proposed Pythagorean fuzzy set (PFS) [31,32] further expanded the scope of IFS, making the sum of squares of its membership degree and non-membership degree less than or equal to 1. Obviously, PFS is more extensive than IFS and can express more decision-making information, and the decision problems of IFS are special cases of PFS decision problems. In the previous literature, a great deal of research has been done on PFS. For example, Zhang and Xu [33] presented a combination of PFS and TOPSIS models to deal with MADM problems. In order to better understand the new fuzzy set of PFS, Peng and Yang [34] primarily put forward the division and subtraction operations of PFS. Reformat and Yager [35] applied Pythagorean fuzzy information to collaborative recommendation systems. Gou, et al. [36] studied some precious properties of continuous PFS. Garg [37] defined some new aggregation operators of PFS on the foundation of Einstein operations. Wu and Wei [38] came out some Hamacher aggregation operators of PFS to merge fuzzy information. Zeng, et al. [39] utilized the PFOWAWAD operator to study MADM issues under the context of PFS. Ren, et al. [40] established the PF-TODIM model. Combining with Pythagorean fuzzy environment, Wei and Lu [41] proposed a new MADM [42] operator. Wei [43] innovated some fuzzy interactive aggregation operators for arithmetic and geometric operations based on PFS. Wei and Lu [44] proposed some fuzzy power aggregation operators in the Pythagorean theorem. Wei and Wei [45] created ten cosine similarity measures in the fuzzy context of the Pythagorean theorem. Liang, et al. [46] studied some Bonferroni mean operators using Pythagorean fuzzy information. Liang, et al. [47] presented the PFGA operation based on Bonferroni mean aggregation operator. Combining the PFSs [31,32] and DHFSs [48,49], Wei and Lu [50] brought in the definition of the DHPFSs and proposed some DHPF-Hamacher aggregation operators. Peng, et al. [51] created some new PF information measures of MADM problems.

Nevertheless, to describe more decision information, Yager [52] later defined q-rung orthopair fuzzy sets (q-ROFSs), and based on PFS, the condition that the square sum of its membership and non-membership is less than or equal to 1 becomes that the sum of the \( q \)th power of the two is less than or equal to 1. Obviously, compared to IFS, q-ROFSs is more general, and PFS is a special case. Liu and Wang [53] put forward the q-ROFWA operator and the q-ROFWG operator. Wei, et al. [54] defined some q-rung orthopair fuzzy MSM operators including q-ROFMSM operator, q-ROFWMSM operator, q-ROFDMMSM operator, q-ROFWDMSM operator. Wei, et al. [55] gave some q-ROF Heronian mean operators. Yang and Pang [56] provided some new definition of partitioned Bonferroni mean operators under q-ROFS. Wang, et al. [57] came up with some q-rung interval-valued fuzzy Hamy mean operators including q-RIVOFHM operator, q-RIVOFWHM operator, q-RIVOFDHM operator and q-RIVOFWDHM operator. Liu and Liu [58] offered some power Bonferroni mean operators with linguistic q-rung orthopair fuzzy information. Xu, et al. [59] gave the definition of q-RDHOFS and presented some q-RDHOF Heronian mean operators.
However, to date, it is clear that the VIKOR model with q-RIVOFNs information has not been studied. Therefore, it’s essential to take q-RIVOF-VIKOR model into consideration. The aim of our manuscript is to create an enlarged VIKOR model with the original VIKOR method and q-RIVOF information to settle MADM problems more effectively. Our manuscript is structured as: the definition, score function, accuracy function, operation rules, and some aggregation operators of q-RIVOFNs are briefly given in Section 2. The calculation process of traditional VIKOR model is briefly depicted in Section 3. Integrating the original VIKOR model with q-RIVOFNs information, the q-RIVOF-VIKOR technique is built and the calculation processes are simply shown in Section 4. An example of a vendor selection of healthcare consumer products has been illustrated by this new model and some comparisons between the q-RIVOF-VIKOR model and two q-RIVOFNs aggregation operators—including q-RIFOWA and q-RIFOWG operators—are also carried out to further explain merit of the new method in Section 5. Some conclusions of our manuscript are made in Section 6.

2. Preliminaries

Based on the theorems of q-ROFSs and the interval values, the essential definition and theorems of q-RIVOFNs are retrospected in brief below.

2.1. The q-RIVOFNs

Definition 1 [57]. Let $X$ be a fix set. A q-RIVOFNs has the following definition:

$$\overline{P} = \{x, (\overline{\mu}_P(x), \overline{\nu}_P(x)) \mid x \in X\}$$  \hspace{1cm} (1)

where the function $\mu_P(x) = \left[\mu^L_P(x), \mu^U_P(x)\right] : X \rightarrow [0, 1]$ defines the membership degree and the function $\nu_P(x) = \left[\nu^L_P(x), \nu^U_P(x)\right] : X \rightarrow [0, 1]$ defines the non-membership degree of the element $x \in X$ to $\overline{P}$ respectively, and, for every $x \in X$, it meets that

$$\left(\mu^U_P(x)\right)^q + \left(\nu^U_P(x)\right)^q \leq 1, q \geq 1.$$ \hspace{1cm} (2)

$$\pi_P(x) = \left[\pi^L_P(x), \pi^U_P(x)\right] = \left[\sqrt[4]{1 - \left(\mu^L_P(x)\right)^q + \left(\nu^L_P(x)\right)^q}, \sqrt[4]{1 - \left(\mu^U_P(x)\right)^q + \left(\nu^U_P(x)\right)^q}\right]$$

is the degree of indeterminacy membership. For convenience, we called $\overline{p} = \left(\left[\mu^L_P, \mu^U_P\right], \left[\nu^L_P, \nu^U_P\right]\right)$ a q-RIVOFN.

Definition 2 [57]. Let $\overline{p} = \left(\left[\mu^L_P, \mu^U_P\right], \left[\nu^L_P, \nu^U_P\right]\right)$ be a q-RIVOFN, a score function $S$ can be written as follows:

$$S(\overline{p}) = \frac{1}{4}\left[1 + \left(\mu^L_P\right)^q - \left(v^L_P\right)^q\right] + \frac{1}{4}\left(1 + \left(\mu^U_P\right)^q - \left(v^U_P\right)^q\right), S(\overline{p}) \in [0, 1].$$  \hspace{1cm} (3)

Definition 3 [57]. Let $\overline{p} = \left(\left[\mu^L_P, \mu^U_P\right], \left[\nu^L_P, \nu^U_P\right]\right)$ be a q-RIVOFN, an accuracy function $H$ can be written as follows:

$$H(\overline{p}) = \frac{\left(\mu^L_P\right)^q + \left(v^L_P\right)^q + \left(\mu^U_P\right)^q + \left(v^U_P\right)^q}{2}, H(\overline{p}) \in [0, 1].$$  \hspace{1cm} (4)

According to $S$ and $H$, the order relation between two q-RIVOFNs will be obtained as below:

Definition 4 [57]. Let $\overline{p}_1 = \left(\left[\mu^L_1, \mu^U_1\right], \left[\nu^L_1, \nu^U_1\right]\right)$ and $\overline{p}_2 = \left(\left[\mu^L_2, \mu^U_2\right], \left[\nu^L_2, \nu^U_2\right]\right)$ be two q-RIVO FNs, assume that $S(\overline{p}_1) = \frac{1}{4}\left[1 + \left(\mu^L_1\right)^q - \left(v^L_1\right)^q\right] + \frac{1}{4}\left(1 + \left(\mu^U_1\right)^q - \left(v^U_1\right)^q\right)$ and $S(\overline{p}_2) = \frac{1}{4}\left[1 + \left(\mu^L_2\right)^q - \left(v^L_2\right)^q\right] + \frac{1}{4}\left(1 + \left(\mu^U_2\right)^q - \left(v^U_2\right)^q\right)$ be the scores of $\overline{p}_1$ and $\overline{p}_2$, and let $H(\overline{p}_1) = \frac{\left(\mu^L_1\right)^q + \left(v^L_1\right)^q + \left(\mu^U_1\right)^q + \left(v^U_1\right)^q}{2}$ and $H(\overline{p}_2) = \frac{\left(\mu^L_2\right)^q + \left(v^L_2\right)^q + \left(\mu^U_2\right)^q + \left(v^U_2\right)^q}{2}$.
\[(\mu_1^2 + \nu_1^2 + (\mu_2^2 + \nu_2^2)^2 + (\mu_3^2 + \nu_3^2)^2) \text{ and } H(\overline{p}_2) = \frac{1}{2} H(\overline{p}_1) H(\overline{p}_2)\] be the accuracy degrees of \(\overline{p}_1\) and \(\overline{p}_2\), respectively, then when \(S(\overline{p}_1) < S(\overline{p}_2), \overline{p}_1 < \overline{p}_2\) when \(S(\overline{p}_1) = S(\overline{p}_2), \) (1) if \(H(\overline{p}_1) = H(\overline{p}_2), \) then \(\overline{p}_1 = \overline{p}_2; (2)\) if \(H(\overline{p}_1) < H(\overline{p}_2), \overline{p}_1 < \overline{p}_2.\)

**Definition 5** [57]. Let \(\overline{p}_1 = \left(\left[\mu_1^2, \mu_1^U\right], \left[\nu_1^2, \nu_1^U\right]\right), \overline{p}_2 = \left(\left[\mu_2^2, \mu_2^U\right], \left[\nu_2^2, \nu_2^U\right]\right)\) and \(\overline{p} = \left(\left[\mu^2, \mu^U\right], \left[\nu^2, \nu^U\right]\right)\) be three q-RIVOFNs, and some basic rules about them are defined as follows:

1. \(\overline{p}_1 \oplus \overline{p}_2 = \left(\left[\frac{1}{\sqrt{2}}(\mu_1^2 + \mu_2^2)^{\lambda}, \frac{1}{\sqrt{2}}(\mu_1^2 + \mu_2^2)^{\lambda}\right], \left[\frac{1}{\sqrt{2}}(\nu_1^2 + \nu_2^2)^{\lambda}, \frac{1}{\sqrt{2}}(\nu_1^2 + \nu_2^2)^{\lambda}\right]\right);\)
2. \(\overline{p}_1 \odot \overline{p}_2 = \left[\left[\frac{1}{\sqrt{2}}(\mu_1^2 + \mu_2^2)^{\lambda}, \frac{1}{\sqrt{2}}(\nu_1^2 + \nu_2^2)^{\lambda}\right], \left[\frac{1}{\sqrt{2}}(\mu_1^2 + \mu_2^2)^{\lambda}, \frac{1}{\sqrt{2}}(\nu_1^2 + \nu_2^2)^{\lambda}\right]\right];\)
3. \(\lambda \overline{p} = \left(\left[\frac{1}{\sqrt{2}}(1-(\mu_1^2)^{\lambda}), \frac{1}{\sqrt{2}}(1-\mu_1^2)^{\lambda}\right], \left[\frac{1}{\sqrt{2}}(1-(\nu_1^2)^{\lambda}), \frac{1}{\sqrt{2}}(1-\nu_1^2)^{\lambda}\right]\right), \lambda > 0;\)
4. \((\overline{p})^\lambda = \left(\left[\frac{1}{\sqrt{2}}(1-(\mu^2)^{\lambda}), \frac{1}{\sqrt{2}}(1-\mu^2)^{\lambda}\right], \left[\frac{1}{\sqrt{2}}(1-(\nu^2)^{\lambda}), \frac{1}{\sqrt{2}}(1-\nu^2)^{\lambda}\right]\right), \lambda > 0;\)
5. \(\overline{p} = \left(\left[\mu^2, \mu^U\right], \left[\nu^2, \nu^U\right]\right).\)

2.2. Some q-RIVOF Aggregation Operators

**Definition 6** [57]. Let \(\overline{p}_j = \left(\left[\mu_j^2, \mu_j^U\right], \left[\nu_j^2, \nu_j^U\right]\right)\) \((j = 1, 2, \ldots, n)\) be a list of q-RIVOFNs with weighting vector \(w_j = (w_{j1}, w_{j2}, \ldots, w_{jn})^T\), thereby satisfying \(w_j \in [0, 1]\) and \(\sum_{j=1}^n w_j = 1\), then the q-RIVOFWA operator can be written as:

\[
\text{q-RIVOFWA}(\overline{p}_1, \overline{p}_2, \ldots, \overline{p}_n) = \sum_{j=1}^n w_j \overline{p}_j = \left(\left[\sqrt{1 - \prod_{j=1}^n \left(1 - (\mu_j^2)^{w_j}\right)^{\lambda}}, \sqrt{1 - \prod_{j=1}^n \left(1 - (\mu_j^2)^{w_j}\right)^{\lambda}}\right], \left[\sqrt{1 - \prod_{j=1}^n \left(1 - (\nu_j^2)^{w_j}\right)^{\lambda}}, \sqrt{1 - \prod_{j=1}^n \left(1 - (\nu_j^2)^{w_j}\right)^{\lambda}}\right]\right)
\]

**Definition 7** [57]. Let \(\overline{p}_j = \left(\left[\mu_j^2, \mu_j^U\right], \left[\nu_j^2, \nu_j^U\right]\right)\) \((j = 1, 2, \ldots, n)\) be a list of q-RIVOFNs with weighting vector \(w_j = (w_{j1}, w_{j2}, \ldots, w_{jn})^T\), thereby satisfying \(w_j \in [0, 1]\) and \(\sum_{j=1}^n w_j = 1\), then the q-RIVOFWG operator can be written as:

\[
\text{q-RIVOFWG}(\overline{p}_1, \overline{p}_2, \ldots, \overline{p}_n) = \prod_{j=1}^n \overline{p}_j^{w_j} = \left(\left[\prod_{j=1}^n (\mu_j^2)^{w_j}, \prod_{j=1}^n (\mu_j^2)^{w_j}\right], \left[\prod_{j=1}^n (\nu_j^2)^{w_j}, \prod_{j=1}^n (\nu_j^2)^{w_j}\right]\right)
\]

3. Traditional VIKOR Model

The VIKOR model, which firstly define by Opricovic and Tzeng [60], is a meaningful tool to investigate MADM problems and has been broadly applied to in the fields of industry, business economy and management in recent years. Assume that there are \(m\) alternatives \(\{A_1, A_2, \ldots, A_m\}\), \(n\) attributes \(\{G_1, G_2, \ldots, G_n\}\) with weighting vector \(\{w_1, w_2, \ldots w_n\}\) which meets the condition of \(0 \leq w_i \leq 1, \sum_{i=1}^n w_i = 1\) and \(\lambda\) experts with weighting vector \(\{v_1, v_2, \ldots, v_\lambda\}\), respectively, satisfies \(0 \leq v_i \leq 1, \sum_{i=1}^\lambda v_i = 1\).
Set up the matrix \( R^\lambda = \left[a^\lambda_{ij}\right]_{m \times n} \), \( i = 1, 2, \ldots, m \), \( j = 1, 2, \ldots, n \) which is used to evaluate each alternative on each indicator, then the traditional VIKOR model can be presented as below.

**Step 1.** Establish the decision matrices \( R^\lambda = \left[a^\lambda_{ij}\right]_{m \times n} \), \( i = 1, 2, \ldots, m \), \( j = 1, 2, \ldots, n \) based on expert’s decision making results, and fuse all the evaluation information by using some aggregation operators such as WA operator and WG operator to get fused results matrix \( R = \left[a_{ij}\right]_{m \times n} \), \( i = 1, 2, \ldots, m \), \( j = 1, 2, \ldots, n \);

**Step 2.** Calculate PIS \( a^+_j \) and NIS \( a^-_j \)

\[
a^+_j = \left\{ \max_i (a_{ij}) \right\}, \quad a^-_j = \left\{ \min_i (a_{ij}) \right\}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n
\]  

(7)

**Step 3.** According to the Formula (7) and the attribute weighting vector \( w_i (j = 1, 2, \ldots, n) \), the results of \( \Psi_i \) and \( Y_i \) which represents the mean and worst group scores of the alternatives \( A_i \) can be obtained as follows.

\[
\Psi_i = \sum_{j=1}^{n} w_j \frac{d(a^+_j, a^-_j)}{d(a^+_j, a^-_j)}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n
\]  

(8)

\[
Y_i = \max_j \left\{ \frac{d(a^+_j, a^-_j)}{w_j d(a^+_j, a^-_j)} \right\}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n
\]  

(9)

where \( 0 \leq w_i \leq 1 \) indicates the weighting vector of attributes which satisfies \( \sum_{i=1}^{n} w_i = 1 \) and \( d \) denotes the q-rung orthopair fuzzy distance measures.

**Step 4.** Calculate the results of \( \Theta_i \) by following the Equation:

\[
\Theta_i = \alpha \times \frac{(\Psi_i - \Psi^+)}{(\Psi^- - \Psi^+)} + (1 - \alpha) \times \frac{(Y_i - Y^+)}{(Y^- - Y^+)}
\]  

(10)

where

\[
\Psi^+ = \min_i (\Psi_i), \quad \Psi^- = \max_i (\Psi_i)
\]  

(11)

\[
Y^+ = \min_i (Y_i), \quad Y^- = \max_i (Y_i)
\]  

(12)

where \( \alpha \) denotes the coefficient of decision making strategic. \( \alpha > 0.5 \) means “the maximum group utility”, \( \alpha = 0.5 \) means equality degree and \( \alpha < 0.5 \) means the minimum regret degree.

**Step 5.** Then according to \( \Theta_i \) to select the best alternative, obviously, the smaller the \( \Theta_i \), the best alternative \( A_i \) is.

4. The VIKOR Model for q-RIVOFs MAGDM Problems

Assume that there are \( m \) alternatives \( \{A_1, A_2, \ldots, A_m\} \), \( n \) projects \( \{G_1, G_2, \ldots, G_n\} \) with weighting vector \( \{w_1, w_2, \ldots, w_n\} \) which meets the condition of \( 0 \leq w_i \leq 1, \sum_{i=1}^{n} w_i = 1 \) and \( \lambda \) experts with weighting vector \( \{\omega_1, \omega_2, \ldots, \omega_\lambda\} \), respectively, the conditions are satisfied \( 0 \leq \omega_i \leq 1, \sum_{i=1}^{\lambda} \omega_i = 1 \).

Construct the q-RIVOF evaluation matrix \( R^\lambda = \left[\tilde{a}^\lambda_{ij}\right]_{m \times n} = \left[\left(\tilde{\mu}^L_{ij}, \tilde{\mu}^U_{ij}\right)\right]_{m \times n} = \left[\left(\tilde{\nu}^L_{ij}, \tilde{\nu}^U_{ij}\right)\right]_{m \times n} \), \( i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \), where \( \tilde{a}^\lambda_{ij} = \left[\left(\tilde{\mu}^L_{ij}, \tilde{\mu}^U_{ij}\right), \left(\tilde{\nu}^L_{ij}, \tilde{\nu}^U_{ij}\right)\right] \) indicates the q-RIVOF information of the alternative \( A_i (i = 1, 2, \ldots, m) \) on account of the indicators \( G_j (j = 1, 2, \ldots, n) \) by expert \( D^\lambda \). \( \left[\left(\tilde{\mu}^L_{ij}, \tilde{\mu}^U_{ij}\right), \left(\tilde{\nu}^L_{ij}, \tilde{\nu}^U_{ij}\right)\right] \in [0, 1] \) denotes the membership degree of alternatives \( A_i \) satisfies the attribute
which represents the mean and worst group scores of the alternatives \( A_i \) and it indicates that the attribute \( G_j \) given by the decision maker is not satisfied, respectively, \( 0 \leq \left( \left[ \left( \mu_{ij}^L \right)^{\frac{1}{n}} \right] + \left( \left[ \lambda_{ij}^R \right]^q \right) \right) \leq 1 (i = 1, 2, \ldots, m, j = 1, 2, \ldots, n) \). then, based on q-RIVOFs and traditional VIKOR model, the q-RIVOF-VIDKOR model is established to settle MADM problems more reasonably and effectively, the computing steps are simply depicted as follows.

\begin{itemize}
  \item **Step 1.** Give the q-RIVOFNs decision making matrixes \( R^\lambda = \left[ \tilde{r}_{ij} \right]_{mxn} = \left[ \left[ \left( \mu_{ij}^L \right)^{\frac{1}{n}}, \left( \lambda_{ij}^R \right)^q \right]_{mxn} \right] \), \( i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \) based on expert’s evaluation results, and fuse all the evaluation information by utilizing q-RIVOFS or q-RIVOFWG operators to obtain the fused matrix \( R = \left[ \tilde{r}_{ij} \right]_{mxn} = \left[ \left[ \left( \mu_{ij}^L \right)^{\frac{1}{n}}, \mu_{ij}^U \right], \left[ \left( \lambda_{ij}^R \right)^q, \lambda_{ij}^U \right] \right]_{mxn} \), \( i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \).
  
  \item **Step 2.** Calculate PIS \( \tilde{r}_j^+ \) and NIS \( \tilde{r}_j^- \) by following the Equation:

\[
\begin{align*}
\tilde{r}_j^+ &= \left[ \left( \mu_{ij}^L - \mu_{ij}^U \right)^+, \left( \mu_{ij}^U \right)^+ \right], \left[ \left( \lambda_{ij}^R \right)^q - \lambda_{ij}^U \right], \left( \lambda_{ij}^U \right)^+, \left( \lambda_{ij}^U \right)^+ \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (13)
\end{align*}
\]

\[
\begin{align*}
\tilde{r}_j^- &= \left[ \left( \mu_{ij}^L - \mu_{ij}^U \right)^-, \left( \mu_{ij}^U \right)^- \right], \left[ \left( \lambda_{ij}^R \right)^q - \lambda_{ij}^U \right], \left( \lambda_{ij}^U \right)^-, \left( \lambda_{ij}^U \right)^- \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (14)
\end{align*}
\]

For benefit attribute:

\[
\begin{align*}
\tilde{r}_j^+ &= \left[ \max \left( \mu_{ij}^L \right), \max \left( \mu_{ij}^U \right) \right], \left[ \min \left( \lambda_{ij}^R \right), \min \left( \lambda_{ij}^U \right) \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (15)
\end{align*}
\]

\[
\begin{align*}
\tilde{r}_j^- &= \left[ \min \left( \mu_{ij}^L \right), \min \left( \mu_{ij}^U \right) \right], \left[ \max \left( \lambda_{ij}^R \right), \max \left( \lambda_{ij}^U \right) \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (16)
\end{align*}
\]

For cost attribute:

\[
\begin{align*}
\tilde{r}_j^+ &= \left[ \min \left( \mu_{ij}^L \right), \min \left( \mu_{ij}^U \right) \right], \left[ \max \left( \lambda_{ij}^R \right), \max \left( \lambda_{ij}^U \right) \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (17)
\end{align*}
\]

\[
\begin{align*}
\tilde{r}_j^- &= \left[ \max \left( \mu_{ij}^L \right), \max \left( \mu_{ij}^U \right) \right], \left[ \min \left( \lambda_{ij}^R \right), \min \left( \lambda_{ij}^U \right) \right], i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (18)
\end{align*}
\]

**Step 3.** On the basis of the Equations (17) and (18) and \( w_j (j = 1, 2, \ldots, n) \), the results of \( \Psi_i \) and \( \chi_i \) which represents the mean and worst group scores of the alternatives \( A_i \) can be obtained as follows.

\[
\Psi_i = \sum_{j=1}^{n} w_j \frac{d \left( \tilde{r}_j^+, \tilde{r}_j^- \right)}{d \left( \tilde{r}_j^+ \right)}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (19)
\]

\[
\chi_i = \max_j \left\{ \frac{d \left( \tilde{r}_j^+, \tilde{r}_j^- \right)}{d \left( \tilde{r}_j^+ \right)} \right\}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (20)
\]

where \( 0 \leq w_j \leq 1 \) indicates the weighting vector of attributes which satisfies \( \sum_{i=1}^{n} \omega_i = 1 \) and \( d \) denotes the q-rung orthopair fuzzy distance measures. For the traditional normalized Hamming distance (HD) measures or Euclidean distance measures (ED) are limited to deal with some special situations, thus, we shall use the combination form of three distance measures mentioned as follows.

\[
d \left( \tilde{r}_{ij}, \tilde{r}_{ij} \right) = \sum_{k=1}^{3} \chi_k d \left( \tilde{r}_{ij}, \tilde{r}_{ij} \right), i \in [0, 1], \sum_{k=1}^{3} \chi_k = 1.
\]
where \(0 \leq \chi_k \leq 1\) indicates the weighting vector of distance measures \(d^k\) and

\[
d^1(\tilde{r}_{ij}, \tilde{r}_{ij}) = \left( \frac{\left| (\mu_{ij}^1)^q - (\mu_{ij}^1)^q \right| + \left| (\mu_{ij}^1)^q - (\mu_{ij}^q)^q \right| + \left| (\mu_{ij}^1)^q - (\mu_{ij}^q)^q \right| + \left| (\mu_{ij}^1)^q - (\mu_{ij}^q)^q \right|}{4} \right)
\]

\[
d^2(\tilde{r}_{ij}, \tilde{r}_{ij}) = \left( \frac{\left| (\mu_{ij}^1)^q - (\mu_{ij}^1)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q \right| - \left| (\mu_{ij}^1)^q + (\mu_{ij}^q)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q \right|}{4} \right)
\]

\[
d^3(\tilde{r}_{ij}, \tilde{r}_{ij}) = \left\{ \begin{array}{l}
\max \left( \frac{2 - (\mu_{ij}^1)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q}{4}, \right) \\
\min \left( \frac{2 - (\mu_{ij}^1)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q - (\mu_{ij}^q)^q}{4} \right)
\end{array} \right\}
\]

**Step 4.** Calculate the results of \(\Theta_i\) by following the Equation:

\[
\Theta_i = \alpha \times \frac{(\Psi_i - \Psi^+)}{(\Psi^- - \Psi^+)} + (1 - \alpha) \times \frac{(Y_i - Y^+)}{(Y^- - Y^+)}
\]

where

\[
\Psi^+ = \min_i (\Psi_i), \Psi^- = \max_i (\Psi_i)
\]

\[
Y^+ = \min_i (Y_i), Y^- = \max_i (Y_i)
\]

Step 5. According to \(\Theta_i\) to select the best alternative, obviously, the smaller the \(\Theta_i\), the best alternative \(A_i\) is.

5. The Numerical Example

5.1. Numerical for q-RIVOFNs MAGDM Problems

The supplier terms of an enterprise is undoubtedly very important, and in the future will be an even more important influence on the quality of a vendor’s business, as it will affect the business of purchasing, production, inventory, and sales, and so on. The relationship between suppliers and future enterprise is not a simple relationship between management and managed, suppliers will become a strategic partner companies, it is a win-win relationship. So supplier preliminary evaluation and selection is quite important. Medical supplies products have their own characteristics to distinguish it from other types of products, which can be distinguished from their production, transportation, marketing, and other aspects. It can be seen that supplier selection of medical consumption products is the classical MADM or MAGDM issue [61–72]. In this subsection, an example for supplier selection of medical consumption products with q-RIVOF information shall be presented in order to demonstrate the method proposed in this paper. There is a panel with five possible medical consumption products suppliers. \(\eta_i (i = 1, 2, 3, 4, 5)\) to sort. Experts select four attributes to appraise the five feasible construction projects: ① G1 is the environmental improvement quality; ② G2 is the transportation convenience of suppliers; ③ G3 is the green image; ④ G4 is the environmental competencies. The five feasible medical consumption products suppliers \(\eta_i (i = 1, 2, 3, 4, 5)\) are to
be evaluated using the q q-RIVOF information under the above four attributes by three experts $D^\lambda$ (Assume the weighting vector of experts is $(0.35, 0.25, 0.40)$ and attribute index’s weighting vector is $(0.27, 0.37, 0.16, 0.20)$).

Next, we make use of the VIKOR technique with q-RIVOFNs developed for medical consumption products supplier selection.

**Step 1.** Give the q-RIVOFNs decision making matrixes $R^\lambda = \left[ \tilde{r}_{ij}^\lambda \right]_{m \times n}$ by Equations (13) and (14), for all attributes are benefit we can easily gain the results of (PIS) $\eta^+$ and (NIS) $\eta^-$ as follows;

$$\eta^+ = \left\{ \left( [0.6051, 0.7445], [0.1275, 0.2305] \right), \left( [0.3411, 0.4487], [0.4278, 0.5975] \right), \left( [0.6243, 0.7462], [0.4800, 0.6448] \right), \left( [0.6312, 0.7766], [0.4630, 0.5576] \right) \right\}$$

$$\eta^- = \left\{ \left( [0.3975, 0.5017], [0.6051, 0.7445] \right), \left( [0.3108, 0.5282], [0.4278, 0.5975] \right), \left( [0.3411, 0.4487], [0.3903, 0.5537] \right), \left( [0.4278, 0.5975], [0.5017, 0.6051] \right) \right\}$$

**Step 2.** Calculate PIS $\tilde{r}^+_{ij}$ and NIS $\tilde{r}^-_{ij}$ by Equations (13) and (14), for all attributes are benefit we can easily gain the results of (PIS) $\eta^+$ and (NIS) $\eta^-$ as follows;

**Step 3.** According to the Formulas (19) and (20) and $w_i (j = 1, 2, \ldots, n)$, the results of $\Psi_j$ and $Y_j$ which denote the mean and the worst group scores of alternative $\eta_j$ can be obtained. Suppose the weights of distance measures $d^k$ are $(0.3, 0.4, 0.3)$, then the results of combination distance can be calculated in Table 4.
Table 4. The results of combination distance.

|     | G₁  | G₂  | G₃  | G₄  |
|-----|-----|-----|-----|-----|
| G₁  | 0.0585 | 0.0750 | 0.0829 | 0.0860 |
| G₂  | 0.0062 | 0.0004 | 0.0012 | 0.0086 |
| G₃  | 0.1797 | 0.1019 | 0.0435 | 0.1031 |
| G₄  | 0.1142 | 0.0600 | 0.0235 | 0.0281 |

Then the results of Ψᵢ and Υᵢ are calculated as:

Ψ₁ = 0.6112, Ψ₂ = 0.0292, Ψ₃ = 0.8467, Ψ₄ = 0.4445, Ψ₅ = 0.5890,
Υ₁ = 0.5890, Υ₂ = 0.0166, Υ₃ = 0.3088, Υ₄ = 0.1818, Υ₅ = 0.2919.

Step 4. On the basis of Ψᵢ and Υᵢ obtained by above steps, we can calculate the results of Θᵢ, the results are recorded as below. (Let α = 0.4)

Θ₁ = 0.7172, Θ₂ = 0.0000, Θ₃ = 1.0000, Θ₄ = 0.5424, Θ₅ = 0.8392.

Step 5. According to Θᵢ to select the best alternative, obviously, the smaller value the Θᵢ is, the best alternative ηᵢ is. Apparently, the ordering of ηᵢ is Θ₂ > Θ₄ > Θ₁ > Θ₅ > Θ₃, and the best choice is η₂.

5.2. Comparative Analyses for q-RIVOFNs MAGDM Problems

In this subsection, we shall compare our presented VIKOR model for q-RIVOFNs with other existing q-RIVOF decision making tools including q-RIVOFWA operator and q-RIVOFWG operator proposed by Wang, Gao, Wei and Wei [57] to explain the model we developed is scientifically valid. Using the fused q-RIVOFNs results of Table 5 and the weights of attributes, the fused results depicted by q-RIVOFNs of each alternative are listed in Table 6.

Table 5. The fused q-RIVOFNs matrix.

|     | G₁                            | G₂                            |
|-----|-------------------------------|-------------------------------|
| η₁  | ([0.6171,0.7179],[0.2998,0.4025]) | ([0.4834,0.5860],[0.2750,0.4595]) |
| η₂  | ([0.6709,0.7975],[0.1275,0.2305]) | ([0.6243,0.7462],[0.2604,0.3798]) |
| η₃  | ([0.3975,0.5017],[0.6051,0.7445]) | ([0.3411,0.4487],[0.2430,0.3770]) |
| η₄  | ([0.4932,0.5993],[0.2899,0.4101]) | ([0.5763,0.6855],[0.4434,0.6448]) |
| η₅  | ([0.4224,0.8095],[0.3042,0.5041]) | ([0.4316,0.5634],[0.4800,0.5864]) |

Table 6. The fused results of each alternative ηᵢ

|                  | q-RIVOFWA Operator | q-RIVOFWG Operator |
|------------------|---------------------|---------------------|
| η₁ = (0.5246,0.6383,0.3078,0.4693) | η₁ = (0.5013,0.6258,0.3162,0.4829) |
| η₂ = (0.6395,0.7642,0.2314,0.3456) | η₂ = (0.6380,0.7619,0.2799,0.3813) |
| η₃ = (0.4254,0.5631,0.3741,0.5267) | η₃ = (0.4041,0.5218,0.4706,0.6092) |
| η₄ = (0.5361,0.6984,0.3237,0.5143) | η₄ = (0.5307,0.6839,0.3726,0.5533) |
| η₅ = (0.4411,0.6986,0.3337,0.5106) | η₅ = (0.4227,0.6482,0.3985,0.5258) |
According to the score function of q-RIVOFNs, the score results \( s(\eta_i) \) of each alternative can be determined as follows.

For q-RIVOFWA operator:
\[
s(\eta_1) = 0.5461, s(\eta_2) = 0.6228, s(\eta_3) = 0.5092, s(\eta_4) = 0.5599, s(\eta_5) = 0.5489.
\]

For q-RIVOFWG operator:
\[
s(\eta_1) = 0.5380, s(\eta_2) = 0.6188, s(\eta_3) = 0.4785, s(\eta_4) = 0.5462, s(\eta_5) = 0.5267.
\]

Then the ordering of alternatives by q-RIVOFWA and q-RIVOFWG operators is listed in Table 7.

| Order       |
|-------------|
| q-RIVOFWA   | \( \eta_2 > \eta_4 > \eta_5 > \eta_1 > \eta_3 \) |
| q-RIVOFWG   | \( \eta_2 > \eta_4 > \eta_1 > \eta_5 > \eta_3 \) |
| q-RIVOF-VIKOR| \( \eta_2 > \eta_4 > \eta_1 > \eta_5 > \eta_3 \) |

Compare the results of the q-RIVOF-VIKOR model with q-RIVOFWA and q-ROIVFWG operators, the aggregation results are a little bit different in ranking of alternatives but the optimal scheme is the same. However, q-RIVOF-VIKOR model has the remarkable characteristics of considering the compromise between group utility maximization and individual regret minimization and can be more accurate and valid in MAGDM problems.

6. Conclusions

In this manuscript, the q-RIVOF-VIKOR model based on the traditional VIKOR model is presented. Firstly, we started with a review of the concept of q-RIVOFs and introduced the score function, accuracy function, operation rules, and some aggregation operators of q-RIVOFNs. Furthermore, we combined the traditional VIKOR technique with q-RIVOFNs information, the q-RIVOF-VIKOR model is built and the calculational steps are detailedly given. The proposed model considers the compromise between group utility maximization and individual regret minimization, which is proved to be more accurate and effective. Finally, the new model is illustrated by taking the supplier selection of medical consumer products as an example, and the advantages of the new method are further illustrated by comparing q-RIVOF-VIKOR model with two q-RIVOFNs aggregation operators. In the future, the q-RIVOF-VIKOR model can be used in many other uncertain and fuzzy environments, such as risk analysis [73–84].

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