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VIKOR Method for Decision-Making Problems Based on Q-Single-Valued Neutrosophic Sets: Law Application

Vakkas Uluçay[1,*], Necmiye Merve Şahin[2], Nisa İrem Toz[3], Enver Bozkurt[2]

[1] Department of Mathematics, Kilis 7 Aralık University, Kilis 79000-Turkey; vulucay27@gmail.com.

[2] Department of Law, Hasan Kalyoncu University, Gaziantep 27410, Turkey; necmiyemerve.sahin@gmail.com; enver.bozkurt@hku.edu.tr.

[3] Department of Mathematics, Gaziantep University, Gaziantep 27310-Turkey; nsatz89@gmail.com.

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Abstract

Different frameworks can be chosen to solve Multi-Criteria Decision-Making (MCDM) problems emerging in business, cyber environment, economy, health care, engineering and other areas. Uncertainty, vagueness and non-rigid boundaries of the initial information are frequently noticed when dealing with the practicalities of the MCDM tasks. Single-valued neutrosophic sets are considered as the effective tool to express uncertainty of the information, however in some cases it lacks the desirable generality and flexibility. The Q-single-valued neutrosophic sets were recently proposed to deal with this situation. Then, we develop a VIKOR method based on the Q-single-valued neutrosophic sets for novel MCDM method. In the decision-making framework, the proposed method is not only a way to solve the problem of MCDM, but also contains an important mathematical idea as a different solution approach. By applying this method to the real-life problem of cyber warfare, demonstrated the flexibility, effectiveness and feasibility of the proposed VIKOR method and compare the obtained results with the results of other existing methods.

Keywords: Cyber war, Cyber law, Neutrosophic set, Q-neutrosophic set, VIKOR method, Decision-making.

1 | Introduction

With the revolutionary developments in the last quarter century in the field of technology, mankind has reached a standard of living and style that he could not even imagine. The enlargement of the possibilities in the information environment of the newly developing technology is the biggest problem for the lawyers in defining the terms. Computers have shrunk, mobile phones have become almost computers, and the living space where these two devices cannot be taken or used has almost disappeared. These developments have also caused some important problems in the field of law, new concepts have emerged, the definitions of these concepts have begun to be discussed and to have legal consequences. However, following the developments in this field and putting forth appropriate definitions, reconciliation in the international arena and regulation in the national field is the difficulties faced by the lawyers. So, solving uncertain and imprecise data sets in real life is necessary as science and technology advance. Zadeh [1] first explicitly and systematically proposed fuzzy sets to solve these problems effectively. Atanassov [2] described the meanings of non-membership degree

Corresponding Author: vulucay27@gmail.com

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and hesitation degree and the relationship with membership degree, leading to the development of intuitionistic fuzzy sets. Neutrosophic sets, one of the fundamental models that deal with uncertainty, first appeared in mathematics in 1998 by Smarandache [3], [4] as an extension of the concepts of the classical sets, fuzzy sets [1] and intuitionistic fuzzy sets [2]. This structure makes the neutrosophic an effective common framework and empowers it to deal with indeterminate information which were not considered by fuzzy and intuitionistic fuzzy sets. Although fuzzy sets and their various extensions are very useful mathematical approaches to overcome uncertainty, it is not practical and useful to use these theories on the uncertainty problem. Molodtsov [5] raised the notion of soft sets, based on the theory of adequate parametrization, as another approach to handle uncertain data. Thanks to this important feature, which is not found in any of the other mathematical approaches developed for uncertainty, interest in soft sets continues to increase day by day.

1.1 | Neutrosophic Sets and Extensions

Recently, neutrosophic sets and Neutrosophic Soft Sets (NSS) were studied deeply by different researchers, for example, soft multi set theory [6], soft expert sets [7], fuzzy soft sets [8] and NSS neutrosophic soft set [9], the complex neutrosophic soft expert set and its application in decision making [10], neutrosophic soft expert sets [11], generalized neutrosophic soft expert set for multiple-criteria decision-making [12], Q-neutrosophic soft and extensions [13]-[19] and applied the concepts of the neutrosophic set to various field a new similarity measure on falsity value between single valued neutrosophic sets based on the centroid points of transformed single valued neutrosophic numbers with applications to pattern recognition [20], in determining the level of teachers' commitment to the teaching profession using classical and fuzzy logic [21], comparing the social justice leadership behaviors of school administrators according to teacher perceptions using classical and fuzzy logic [22], decision-making applications for adequacy of online education [23], interval-valued fermatean neutrosophic score function [24], Neutrosophic Triplet m-Banach Spaces [25], neutrosophic triplet field and neutrosophic triplet vector space [26], neutrosophic structures [27], [32] neutrosophic algebra structures [33]-[34], new similarity measure between single-valued neutrosophic sets and decision-making applications in professional proficiencies [35], neutrosophic modeling of Talcott Parsons's action and decision-making applications for it [36]. Ihsan et al. [37] optimizing hard disk selection via a fuzzy parameterized single-valued neutrosophic soft set, Bhat [38] an enhanced AHP group decision-making model employing neutrosophic trapezoidal numbers, Saberhoseini et al. [39] choosing the best private-sector partner according to the risk factors in neutrosophic environment, Mohanta and Sharanappa [40] neutrosophic data envelopment analysis: a comprehensive review and current trends, Hosseinzadeh and Tayyebi [41] a compromise solution for the neutrosophic multi-objective linear programming problem and its application in transportation problem, Edalatpanah [42] a nonlinear approach for neutrosophic linear programming, Bui et al. [43] the sequence of NSS and a decision-making problem in medical diagnosis, Al-Sharqi and Al-Quran [44] similarity measures on interval-complex NSS with applications to decision making and medical diagnosis under uncertainty, Ali et al. [45] hausdorff distance and similarity measures for single-valued neutrosophic sets with application in multi-criteria decision making, Talouki et al. [46] image completion based on segmentation using neutrosophic sets, Veeramani et al. [47] Neutrosophic DEMATEL approach for financial ratio performance evaluation of the NASDAQ exchange.

1.2 | Literature on the VIKOR Method

Decision making is the act of identifying and choosing alternatives to find out the best solution from a pool of options based on different factors and considering the decision maker's expectations. Every decision is made within an environment, which is defined as the collection of information, alternatives, values and preferences available at the time when the decision must be made. Till date, several Multi-Criteria Decision-Making (MCDM) methods have been proposed and successfully deployed to solve complex decision-making problems arising from different corners of engineering and management. Amongst those techniques, VIKOR (the serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' which means multi-criteria optimization and compromise solution) method has gained much popularity among the decision-making community due to its simple and easily comprehensible computational steps [48]. Opricovic used the VIKOR model to investigate some MCGDM problems with conflicting criteria [49], [50]. Some recent studies on the VIKOR method; Toptancı [52] Occupational Health And Safety (OHS) indicators in the Turkish metal industry, Ariafar et al. [53] concept of grey preference degree as the Grey Hungarian Algorithm (GHA) to solve LAM under uncertainty, Fakhrehosseini [54] TOPSIS, VIKOR and COPRAS in condition of risk and uncertainty, Hamta et al. [55] a hybrid multiple criteria decision-making technique, Movahedi et al. [56] developing a hybrid model, Nezhad et al. [57] selection of the best contractor by AHP and VIKOR method, Bera et al. [58] Susceptibility of deforestation hotspots in Terai-Dooars belt of Himalayan Foothills: A comparative analysis of VIKOR and TOPSIS models, Mishra et al. [59] Fermatean hesitant fuzzy sets and modified VIKOR method, Li, et al. [60] a CRITIC-VIKOR based robust approach to support risk management of subsea pipelines, Khan et al. [61] VIKOR method for Pythagorean fuzzy sets, neutrosophic environments with on [62]-[65] and VIKOR method in neutrosophic environments [67]-[70].

Based on the results of the above literature research VIKOR strategy in Q-single valued neutrosophic set environment doesn't study in the literature. To fill up this research gap, we propose a new VIKOR method to deal with MCDM problems in Q-single valued neutrosophic set environment. Since Q-single valued neutrosophic sets are developing and novel sets, there is a scarcity in the number of studies in the literature, which is a contribution of this study. We developed QSVNS as a new approach to the operator in [66]. Also, we solve an MCDM problem with cyber wars related example based on VIKOR strategy in Q-single valued neutrosophic sets.

2 | Preliminaries

Definition 1 ([3]). A neutrosophic set F on universe $\aleph$ is defined as:

$$F = \left\{\langle x, \mu_F\ x), \eta_F\ x), \vartheta_F\ x) : x \in \aleph\rangle\right\}.$$

Here $\mu_F\ x)$ is the truth value, $\eta_F\ x)$ is the indeterminacy value, and $\vartheta_F\ x)$ is the falsity value. The $\mu_F\ x), \eta_F\ x), \vartheta_F\ x)$ functions are true standard or nonstandard subsets.

$$\mu_F\ x), \eta_F\ x), \vartheta_F\ x) : \aleph \rightarrow]\ {}^-0, 1^+[\text{and } {}^-0 \le \mu_F\ x) + \eta_F\ x) + \vartheta_F\ x) \le 3^+.$$

Abu Qamar and Hassan [15] presented the idea of a Q-Neutrosophic Sets (Q-NS) to handle two-dimensional, imprecise, uncertain data and extended this concept to multiple Q-NS and Q-NSS.

Definition 2 ([51]). Assume that $\aleph$ is the universe. Then, a single-valued neutrosophic set F in $\aleph$ defined as:

$$F = \left\{\langle x, \mu_F\ x), \eta_F\ x), \vartheta_F\ x) : x \in \aleph\rangle\right\},$$

where $\mu_F\ x), \eta_F\ x), \vartheta_F\ x) \in [0,1]$ for each point x in such that $0 \le \mu_F\ x) + \eta_F\ x) + \vartheta_F\ x) \le 3$.

Definition 3 ([15]). Let X be a universal set and Q a nonempty set. A Q-neutrosophic set F_Q in X and Q is an object of the form:

$$F_Q = \left\{\langle\ x, q), \mu_{F_Q}\ x, q), \eta_{F_Q}\ x, q), \vartheta_{F_Q}\ x, q)\ \rangle :\ x \in X, q \in Q\right\},$$
$${}^-0 \le \mu_{F_Q}\ x) + \eta_{F_Q}\ x) + \vartheta_{F_Q}\ x) \le 3^+.$$

Definition 4 ([15]). Let X be a universal set, Q be any non-empty set, I be any positive integer and I be a unit interval [0, 1]. A multi Q-neutrosophic set $\mathscr{F}_Q$ in X and Q is a set ordered sequences.

$$\mathscr{F}_Q = \left\{\langle\ x, q), \mu_{\mathscr{F}_{Q_i}}\ x, q), \eta_{\mathscr{F}_{Q_i}}\ x, q), \vartheta_{\mathscr{F}_{Q_i}}\ x, q)\rangle : x \in X, q \in Q, \quad i = 1, 2, \ldots, 1\right\},$$

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where $\mu_{\mathcal{F}_{Q_i}}, \quad \eta_{\mathcal{F}_{Q_i}}, \vartheta_{\mathcal{F}_{Q_i}}: X \times Q \rightarrow I^l;\ i = 1,2, \dots, l$ are respectively, truth membership function, indeterminacy membership function and falsity membership function for each $x \in X$ and $q \in Q$ and satisfy the condition,

$$^-0 \le \mu_{\mathcal{F}_{Q_i}} x) + \eta_{\mathcal{F}_{Q_i}} x) + \vartheta_{\mathcal{F}_{Q_i}} x) \le 3^+,$$

where l is called the dimension of $\mathcal{F}_Q$.

Definition 5 ([15]). Let X be a universal set, E be a set of parameters, and Q be a nonempty set. Let $\partial^l QNS(X)$ denote the set of all multi Q-NS on X with dimension $l = 1$. Let $A \in E$. A pair (F_Q, A) is called a Q-NSS over X, where F_Q is mapping given by:

$$F_Q : A \rightarrow \partial^1 QNS\ X).$$

Such that $F_Q\ e) = \varnothing\ if\ e \notin A$. A Q-NSS can be represented by the set of ordered pairs

$$(F_Q, A) = \{e, F_Q\ e) : e \in A,\ \ F_Q \in \partial^1 QNSS(X)\}.$$

The set of all Q-NSS in X and Q is denoted by $QNSS\ X)$.

3 | VIKOR Method for Q-Single-Valued Neutrosophic Sets

MCDM assessment is a complex, imprecise and time-consuming process. It is also an important process to choose the best alternative. We use the VIKOR method to deal with the uncertain and irreconcilable problems we encounter in real life. In this section, VIKOR method is defined on Q-single-valued neutrosophic sets in order to solve MCDM problems where all preference information provided by decision makers is more practical and flexible. The VIKOR method was developed to provide a rational, systematic decision-making process in which a person discovers the best solution and a compromise solution that can be used to solve a MCDM problem in a neutrosophic setting. In *Fig. 1*, the steps of the VIKOR method in MCDM problems in Q-single-valued neutrosophic sets are explained.

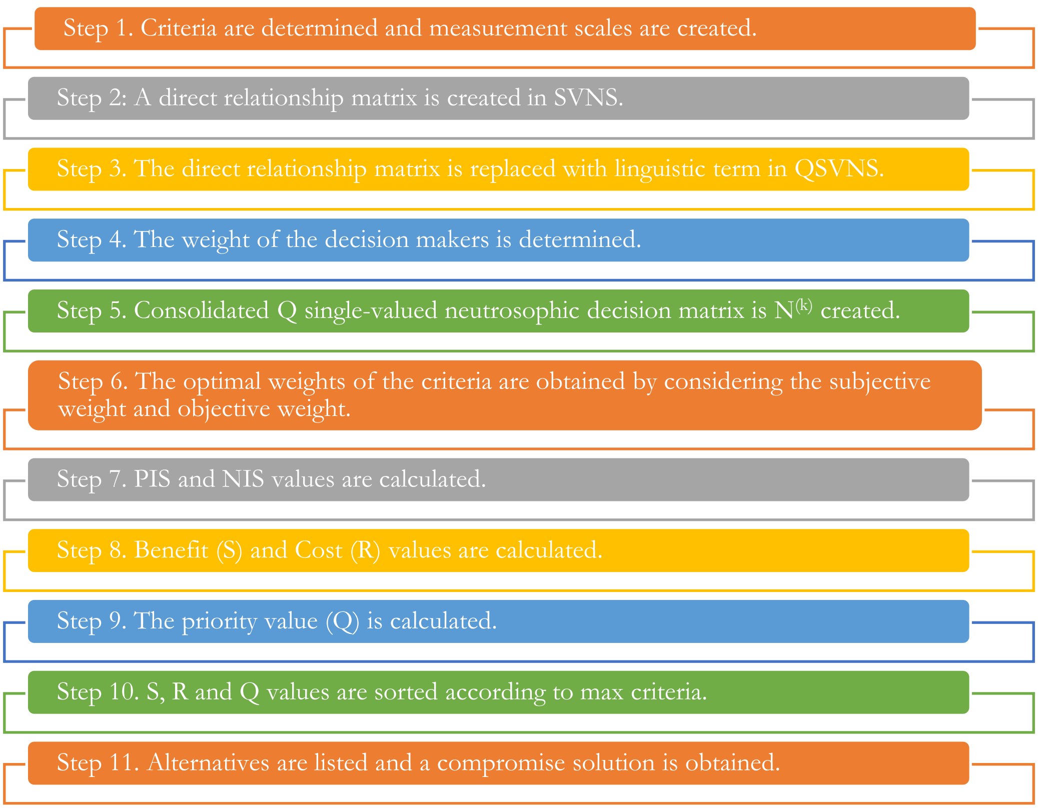

Fig. 1. VIKOR method for Q-single-valued neutrosophic sets.

According to *Fig. 1*, VIKOR consists of 11 steps. There are two types of optimal criteria weights, which distinguish VIKOR from other methods, these are subjective and objective weights.

Let $D^{k)}$ be a set of decision makers where k = 1,2,…,p. A_i represents alternatives where i = 1,2,…,m and C_j represent criteria j = 1,2,…,n. The criteria are classified as cost criteria and benefit criteria.

Step 1. Criteria are defined and measurement scales are created.

Step 2. A direct relationship matrix is established with Q-SVNS. We will obtain the Q-single-valued neutrosophic decision matrix $[R_{ij}]_{mxn}$, $(i = 1,2, \dots, k \text{ and } j = 1,2, \dots, p)$ as follows:

$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \dots & C_n, \end{array} \\ [R_{ij}]_{mxn} = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} R_{11} & R_{12} & \dots & R_{1n} \\ R_{21} & R_{22} & \dots & R_{2n} \\ \vdots & \vdots & & \vdots \\ R_{m1} & R_{m2} & \dots & R_{mn} \end{bmatrix}, \end{array}$$

where $R_{ij} = \langle (x_{ij} q_{ij}) : (\mu_{ij}, \eta_{ij}, \vartheta_{ij}) \rangle$.

Step 3. The direct relationship matrix is replaced with linguistic terms.

Step 4. The weights of the decision makers are determined. The weights of the decision makers can be obtained with the following formula:

$$\varpi_k = \frac{\mu_k + \eta_k \left(\frac{\mu_k}{\mu_k + \vartheta_k} \right)}{\sum_{k=1}^{p} (\mu_k + \eta_k (\frac{\mu_k}{\mu_k + \vartheta_k}))}, \qquad \varpi_k \geq 0, \quad \sum_{k=1}^{p} \varpi_k = 1. \tag{1}$$

μ: Accuracy-represents the membership function.

η: Uncertainty-represents the membership function.

ϑ: Falsity-represents the membership function.

Step 5. Consolidated Q-single-valued neutrosophic decision matrix is created $\mathscr{N}^{(k)} = (\mathscr{N}_{ij}^{k})_{mxn}$. Let the decision maker have a Q-single-valued decision matrix Q-single-valued neutrosophic weight operator is used to sum all the individual decision matrices $\mathscr{N}$.

$$\mathscr{N}^{(k)} = (\mathscr{N}_{ij}^{k})_{mxn}, k = 1,2, \dots, p, i = 1,2, \dots, m \text{ and } j = 1,2, \dots, n.$$

$$d_{ij} = QSVNA\left(d_{ij}^{1)}, d_{ij}^{2)}, \dots, d_{ij}^{p)}\right) = \left(1 - \prod_{k=1}^{p}\left(1 - \mu_{ij}^{k)}\right)^{\frac{1}{p}}, \prod_{k=1}^{p}\left(1 - \eta_{ij}^{k)}\right)^{\frac{1}{p}}, \prod_{k=1}^{p}\left(1 - \vartheta_{ij}^{k)}\right)^{\frac{1}{p}}\right). \tag{2}$$

The aggregate decision matrix $\mathscr{N}$ is defined as follows:

$$\mathscr{N} = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix}, \quad d_{ij} = \langle (x_{ij} q_{ij}) : (\mu_{ij}, \eta_{ij}, \vartheta_{ij}) \rangle.$$

Step 6. The optimal weights of the criteria are obtained.

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There are two types of weights in this section that are subjective and need to be considered. These:

3.1 | Subjective Weight

The rating of the alternatives according to each criterion is collected by the decision makers. The importance weights of the criteria corresponding to the alternatives are determined using the linguistic rating scale as follows:

Table 1. The linguistic terms in Q-SVNS.

Linguistic Terms	Impact Score	Q-Svns
Too low	1	(0, 0, 0.1)
Low	2	(0, 0.1, 0.3)
Medium low	3	(0.1, 0.3, 0.5)
Medium	4	(0.3, 0.5, 0.7)
Medium high	5	(0.5, 0.7, 0.9)
High	6	(0.7, 0.9, 1)
Too high	7	(0.9, 1, 1)

Considering that the criterion weight is obtained using the equation:

$$w_j = Q-SVNSA\left(w_j^1, w_j^2, \dots, w_j^l\right) = \left(1 - \prod_{k=1}^{l}\left(1 - \mu_{ij}^{k)}\right)^{\psi_k}, \prod_{k=1}^{p}\left(\eta_{ij}^{k)}\right)^{\psi_k}, \prod_{k=1}^{p}\left(\vartheta_{ij}^{k)}\right)^{\psi_k}\right). \quad (3)$$

$$j = 1,2, \dots, n \text{ and } w_j = \left(\mu_j, \eta_j, \vartheta_j\right).$$

The subjective weight of each criterion is obtained using the formula below:

$$w_j^s = \mu_k + \eta_k\left(\frac{\mu_k}{\mu_k+\vartheta_k}\right)\left[-\left(\frac{1}{\ln m}\right)\sum_{i=1}^{m}\mu_k + \eta_k\left(\frac{\mu_k}{\mu_k+\vartheta_k}\right)\right]^{-1}. \quad (4)$$

$$j = 1,2, \dots, n \text{ and } \sum_{j=1}^{n} w_j^s = 1.$$

3.2 | Objective Weight

The evaluation criteria are normalized using the following equation:

$$P_{ij} = \frac{d_{ij}}{\sum_{i=1}^{m} d_{ij}}. \quad (5)$$

Here P_{ij} is the predicted result of criterion j.

Next, the predicted results of the j criterion entropy set E_j are calculated.

$$E_j = -\left(\frac{1}{\ln m}\right)\sum_{i=1}^{m} P_{ij}\ln P_{ij}. \quad (6)$$

Here m is the number of criteria and $0 \leq E_j \leq 1$.

After that, in order to obtain the objective weights of the criteria, the divergence div_j, which is the degree of dev iation of the information of the j criterion, must be defined.

$$div_j = 1 - E_j. \quad (7)$$

The greater the degree of deviation of this criterion, the more important the criterion is in the decision-making process. Finally, objective weights can be obtained using the following equation:

$$w_j^o = \frac{div_j}{\sum_{j=1}^{n} div_j}. \tag{8}$$

Step 7. Q-single-valued neutrosophic values of Positive Ideal Solution (PIS) are calculated $f_j^+ = \langle (x_j q_j) : (\mu_j^+, \eta_j^+, \vartheta_j^+) \rangle$ and Q-single-valued neutrosophic values of Negative Ideal Solution (NIS) are calculated $f_j^- = \langle (x_j q_j) : (\mu_j^-, \eta_j^-, \vartheta_j^-) \rangle, <, j = 1,2, \dots, n$.

$$f_j^- = \begin{Bmatrix} \min d_{ij}, \text{benefit criterion} \\ \max d_{ij}, \quad \text{cost criterion} \end{Bmatrix},$$

$$f_j^+ = \begin{Bmatrix} \max d_{ij}, \text{benefit criterion} \\ \min d_{ij}, \quad \text{cost criterion} \end{Bmatrix},$$

$$j = 1,2, \dots, n.$$

Step 8. Calculate the utility measure (S_i) and regret measure (R_i) for the alternative as follows:

$$S_i = \sum_{j=1}^{n} \frac{w_j \|f_j^+ - f_{1j}\|}{\|f_j^+ - f_j^-\|}, \qquad i = 1,2, \dots, m. \tag{9}$$

$$R_i = \max \left\{ \frac{w_j \|f_j^+ - f_{1j}\|}{\|f_j^+ - f_j^-\|} \right\}, \qquad i = 1,2, \dots, m. \tag{10}$$

Here w_j, represents the weight of the combination for each criterion:

$$w_j = v w_j^s + 1 - v) \frac{R_i - R^+)}{R^- - R^+)}, \tag{11}$$

where v, denotes the relative importance between subjective weights and objective weights. It can be any value from 0 to 1, but is usually set to 0.5.

Step 9. The priority value $Q_i, i = 1,2, \dots, m$ is applied using the following formulas:

$$Q_i = v \frac{(S_i - S^+)}{(S^- - S^+)} + 1 - v) \frac{R_i - R^+)}{R^- - R^+)}, \tag{12}$$

$$S^+ = \min S_i, S^- = \max S_j, R^+ = \min R_i, R^- = \max R_j.$$

v, indicates the weight of the strategy of the constraints of the criteria and is usually assumed to be 0.5.

Step 10. Sort S_i, R_i *and* Q_i values by maximum criterion. Sort the ranking results in descending order of alternatives.

Step 11. List the alternatives and find the compromise solution.

At the minimum value of Q, the best alternative $A^{(1)}$ (top alternative) must satisfy the following 2 conditions.

Condition 1. Acceptable benefits.

$$Q(A^{2)}) - Q(A^{1)}) \geq \frac{1}{m-1}. \tag{13}$$

Here $A^{1)}$ and $A^{(2)}$, Q_i is also the two best alternatives.

Condition 2. Acceptable status

The best alternatives should be ranked best by S_i and R_i.

If one of the above conditions is not met, a number of compromise solutions have been proposed:

I. $A^{1)}$ and $A^{(2)}$ alternatives are also acceptable if only stability requirement is not achieved.

II. Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(u)}$ are accepted if the advantage condition is not met. $A^{(u)}$ for max u $Q\left(A^{u)}\right) - Q\left(A^{1)}\right) \geq \frac{1}{m-1}$, it is determined by the formula (the positions of these alternatives are close to each other.)

4 | Application of Cyber Wars of VIKOR Method for Decision-Making Problems

The increase in cyber war threats in the world obliges states to take precautions in this regard. Although developed countries have come a long way in this regard, there are still many countries that do not take adequate steps in this regard. Especially underdeveloped and developing countries, as they are insufficient in cyber warfare, can be vulnerable and suffer victimization in case of any cyber-attack. In order to prevent this situation, a few developing countries that decided to take action have taken the models of the countries that have achieved success in this subject to examination and have decided to take the model they found suitable for them as an example. As a result of the examination, the policies that developed countries have already implemented and are considering to implement in the near future have been taken into consideration. Especially developing countries wants to use proposed method when choosing a model. The models he can take to are Türkiye model (A1), England model (A2), USA model (A3) and $Q = \{q_1, q_2, q_3\}$. It considers four criteria for three alternatives; models price (C1), usability (C2), speed (C3) and security after buy. When making this choice, 3 different cyber warfare experts (DM1, DM2, DM3) are consulted.

Then we can take a model on the basis of their parameters using Q-SVNS, by applying the following algorithm.

Step 1. Criteria are defined and measurement scales are created.

Compiling the perspectives of 3 different decision makers (DM1, DM2, DM3), the student, who met with his family, carefully selected the decision makers by considering the cost and benefit. *Tables 2* and *3* describe the decision makers' perspectives on the weight of the criteria and the evaluation of alternatives according to the criteria.

Table 2. Impact score of the three decision makers on the importance of the criteria.

	C1	C2	C3	C4
DM1	5	6	5	4
DM2	6	6	6	4
DM3	6	5	6	4

Table 3. Rating of evaluation of alternatives according to criteria.

		C1	C2	C3	C4
	DM1	6	6	1	3
$A1(x_1, q_1)$	DM2	3	4	2	2
	DM3	5	6	1	3
$A2(x_1, q_2)$	DM1	6	6	7	7
	DM2	6	6	5	7
	DM3	6	6	6	7
$A3(x_1, q_3)$	DM1	3	4	5	4
	DM2	3	3	4	6
	DM3	3	5	4	4

Step 2 and **Step 3.** A direct relationship matrix is constructed in the Q-single-valued neutrophic set. The linguistic terms of Q-SVNN's are modified *Table 3* to create the Q-SVNN direct relationship matrix (*Table 4*).

Table 4. Q-SVNS direct relationship matrix.

		C1	C2	C3	C4
		0.7	0.7	0	0.1
	DM1	0.9	0.9	0	0.3
		1	1	0.1	0.5
		0.1	0.3	0	0
$A1(x_1, q_1)$	DM2	0.3	0.5	0.1	0.1
		0.5	0.7	0.3	0.3
		0.5	0.7	0	0.1
	DM3	0.7	0.9	0	0.3
		0.9	1	0.1	0.5
		0.7	0.7	0.9	0.9
	DM1	0.9	0.9	1	1
$A2(x_1, q_2)$		1	1	1	1
		0.7	0.7	0.5	0.9
	DM2	0.9	0.9	0.7	1
		1	1	0.9	1
		0.7	0.7	0.7	0.9
	DM3	0.9	0.9	0.9	1
		1	1	1	1
		0.1	0.3	0.5	0.3
	DM1	0.3	0.5	0.7	0.5
$A3(x_1, q_3)$		0.5	0.7	0.9	0.7
		0.1	0.1	0.3	0.7
	DM2	0.3	0.3	0.5	0.9
		0.5	0.5	0.7	1
		0.1	0.5	0.3	0.3
	DM3	0.3	0.7	0.5	0.5
		0.5	0.9	0.7	0.7

Step 4. Determine the weights of the decision makers. The weights of the decision makers are obtained by the following equation:

$$\mu_k + \eta_k\left(\frac{\mu_k}{\mu_k + \vartheta_k}\right),$$

$$\text{OY}: 0.5 + .07\left(\frac{0.5}{0.5 + 0.9}\right) = 0.85,$$

$$\text{OY}: 0.5 + .07\left(\frac{0.5}{0.5 + 0.9}\right) = 0.85,$$

$$\text{O}: 0.3 + .05\left(\frac{0.3}{0.3 + 0.7}\right) = 0.45,$$

$$\sum_{k=1}^{p}(\mu_k + \eta_k(\frac{\mu_k}{\mu_k + \vartheta_k}) = 0.85 + 0.85 + 0.45 = 2.15,$$

$$\text{DM1} = \frac{0.85}{2.15} = 0.3953\,, \text{DM2} = \frac{0.85}{2.15} = 0.3953\,, \text{DM3} = \frac{0.45}{2.15} = 0.2094.$$

Step 5. An aggregated Q-SVN decision matrix is generated. The importance weights of the decision makers are shown in *Table 5*.

Table 5. Importance weight of decision makers.

	Linguistic Data	Impact Score	Weight
DM1	Medium high	(0.5, 0.7, 0.9)	0.85
DM2	Medium high	(0.5, 0.7, 0.9)	0.85
DM3	Medium	(0.3, 0.5, 0.7)	0.45

To aggregate the weights of all decision makers, the Q-SVNA operator is applied.

$$\mu_{11} = 1 - ((1-0.7)^{0.3953} \times (1-0.1)^{0.3953} \times \left(1-0.5)^{0.2094}\right) = 0.4845.$$

$$\eta_{11} = 0.9^{0.3953} \times 0.3^{0.3953} \times 0.7^{0.2094} = 0.5530.$$

$$\vartheta_{11} = 1^{0.3953} \times 0.5^{0.3953} \times 0.9^{0.2094} = 0.7437.$$

The remaining calculations are calculated in a similar way. The detailed calculation of the aggregated Q-SVNS matrix is shown in *Table 6*.

Table 6. Aggregate Q-SVNS matrix.

	C1	C2	C3	C4
$A1(x_1q_1)$	0.4845	0.5806	0	0.0617
	0.5530	0.7134	0	0
	0.7437	0.2158	0.1543	0.4085
	0.7	0.7	0.7621	0.9
$A2(x_1q_2)$	0.9	0.9	0.8495	1
	1	1	0.9592	1
	0.1	0.2794	0.3871	0.4992
$A3(x_1q_3)$	0.3	0.4384	0.5711	0.6307
	0.5	0.6459	0.7731	0.3243

Step 6. The optimal weight of the criterion is obtained. Linguistic variables are shown in *Table 2*. The overall subjective weight of the criterion is calculated as follows:

$$\mu_1 = 1 - ((1-0.5)^{0.3953} \times (1-0.7)^{0.3953} \times \left(1-0.7)^{0.2094}\right) = 0.6328.$$

$$\eta_1 = 0.7^{0.3953} \times 0.9^{0.3953} \times 0.9^{0.2094} = 0.8148,$$

$$\vartheta_1 = 0.9^{0.3953} \times 1^{0.3953} \times 1^{0.2094} = 0.9592.$$

The result of the collective subjective weight calculation is shown in *Table 7*.

Table 7. Total subjective weight.

	μ	η	ϑ
C1	0.6328	0.8148	0.9592
C2	0.6661	0.8538	0.1584
C3	0.8456	0.8148	0.9592
C4	0.3	0.5	0.7

The subjective weight of the criterion is calculated and presented as follows:

$$\mu_k + \eta_k\left(\frac{\mu_k}{\mu_k + \vartheta_k}\right).$$

$$C1 = 0.9566, C2 = 1.3358, C3 = 1.2273, C4 = 0.18.$$

$$\sum_{k=1}^{n}(\mu_k + \eta_k(\frac{\mu_k}{\mu_k + \vartheta_k})) = 3.7197.$$

$$w_1^s = \frac{0.9566}{3.7197} = 0.2571.$$

$$w_2^s = \frac{1.3558}{3.7197} = 0.3664.$$

$$w_3^s = \frac{1.2273}{3.7197} = 0.3299.$$

$$w_4^s = \frac{0.18}{3.7197} = 0.0483.$$

$$s(x_{ij}) = \frac{2 + \mu_{ij} - \eta_{ij} - \vartheta_{ij}}{3}.$$

$$s(x_{11}) = \frac{2 + 0.4845 - 0.5530 - 0.7437}{3} = 0.3959.$$

The aggregated net matrix is given in *Table 8*.

Table 8. Aggregate net matrix.

	C1	C2	C3	C4
$A1(x_1, q_1)$	0.3959	0.5504	0.6152	0.5510
$A2(x_1, q_2)$	0.2666	0.2666	0.3178	0.3
$A3(x_1, q_3)$	0.4333	0.3983	0.3476	0.5147

The criteria evaluation is then normalized as follows:

$$P_{11} = \frac{0.3959}{0.3959 + 0.2666 + 0.4333} = 0.3612.$$

$$P_{21} = \frac{0.2666}{0.3959 + 0.2666 + 0.4333} = 0.2432.$$

$$P_{31} = \frac{0.4333}{0.3959 + 0.2666 + 0.4333} = 0.3954.$$

$$P_{12} = 0.4528.$$

$$P_{22} = 0.2193.$$

$$P_{23} = 0.3277.$$

$$P_{13} = 0.4803.$$

$$P_{23} = 0.2481.$$

$$P_{33} = 0.2714.$$

$$P_{14} = 0.4034.$$

$$P_{24} = 0.2196.$$

$$P_{34} = 0.3768.$$

Next, entropy *Ej* is calculated. lnP_{ij}:

$$\ln P_{11} = -1.01832.$$

$$\ln P_{21} = -1.4114.$$

$$\ln P_{31} = -0.9278.$$

$$\ln P_{12} = -0.7923.$$

$$\ln P_{22} = -1.5173.$$

$$\ln P_{23} = -1.1156.$$

$$\ln P_{13} = -0.7333.$$

$$\ln P_{23} = -1.3939.$$

$$\ln P_{33} = -1.3041.$$

$$\ln P_{14} = -0.9078.$$

$$\ln P_{24} = -1.5159.$$

$$\ln P_{34} = -0.9769.$$

$$\sum_{i=1}^{m} P_{x_i q_j} \ln P_{x_i q_j} = 0.3612 \times -1.01832) + 0.2432 \times -1.4114) + 0.3954 \times -0.9278)$$
$$= -1.07792.$$

$$\therefore E_1 = -\left(\frac{1}{\ln 3}\right) -1.07792) = 0.9811.$$
$$\therefore E_2 = 0.96218.$$
$$\therefore E_3 = 0.95753.$$

After that, the distance value is calculated.

$$div_1 = 1 - 0.9811 = 0.0189.$$
$$div_2 = 0.0378.$$
$$div_3 = 0.0424.$$
$$div_4 = 0.0289.$$
$$\sum_{j=1}^{n} div_j = 0.0189 + 0.0378 + 0.0424 + 0.0289 = 0.128.$$

Objective weights are calculated:

$$w_1^o = \frac{div1}{\sum div_j} = \frac{0.0189}{0.128} = 0.1476.$$
$$w_2^o = 0.2953.$$
$$w_3^o = 0.3312.$$
$$w_4^o = 0.2257.$$

The remaining objective weights are calculated similarly. The calculated objective weight and subjective weight results are shown in *Table 9*.

Table 9. Objective weight and subjective weight of the criteria.

	Subjective Weight	Objective Weight
C1	0.2571	0.1476
C2	0.3644	0.2953
C3	0.3299	0.3312
C4	0.0483	0.2257

According to the result of the subjective weight for each criterion, it is seen that education (C3) is the most important criterion, and employment opportunity (C4) is the least important criterion according to the decision makers. According to the analysis of the objective weights of the criteria, we have seen that education (C3) is again the most important criterion and transportation (C1) is the least important criterion.

Step 7. The Q-single-valued neutrosophic value of the PIS and the NIS is determined. Benefit and Cost criteria are determined.

Benefit criteria; It is determined as placement (C2), education (C3) and employment opportunity (C4), on the other hand cost criteria; available as transport (C1).

The PIS and NIS in *Table 8* are obtained, respectively. PIS and NIS values of all criteria are given in *Table 10*.

Table 10. PIS and NIS of all criteria.

	PIS	NIS
C1	0.2666	0.4333
C2	0.5504	0.2666
C3	0.6152	0.3178
C4	0.5510	0.3

Step 8. The utility measure (S_i) and regret measure (R_i) are calculated for the alternative.

$v = 0.5.$

$w_{c1} = \ 0.5) \times \ 0.2571) + \ 1 - 0.5) \times 0.1476 = 0.2023.$

$w_{c2} = 0.3298.$

$w_{c3} = 0.3305.$

$w_{c4} = 0.137.$

Then,

$$S_{11} = \frac{w_{c1}||f_1^+ - f_{11}||}{\left\|f_1^+ - f_1^-\right\|} = \frac{||0.2023(0.2666 - 0.3959)||}{||0.2666 - 04333||} = 0.1569.$$

$S_{21} = 0.$

$S_{31} = 0.2023,$

$S_{12} = 0,$

$S_{13} = 0,$

$S_{14} = 0,$

$S_{22} = 0.3298,$

$S_{24} = 0.137.$

$S_{32} = 0.1767,$

$S_{34} = 0.0198,$

$S_{23} = 0.3305,$

$S_{33} = 0.2973.$

From here,

$S_{A1} = 0.1569 + 0 + 0 + 0 = 0.1519.$

$S_{A2} = 0.7973.$

$S_{A3} = 0.6961.$

and

$$R_i = \max\left\{\frac{w_{c1}||f_1^+ - f_{11}||}{\left\|f_1^+ - f_1^-\right\|}\right\}.$$

Table 11. S_i **and** R_i **values.**

	S_i	R_i
C1	0.1569	0.1569
C2	0.7973	0.3305
C3	0.6961	0.2973
C4	0	0

Step 9. Calculate the priority value.

$S_i^+ \min = 0.1569,$

$R_i^+ \min = 0.1569.$

$S_i^- \max = 0.7973,$

$R_i^- \max = 0.3305.$

$$Q_i = v\frac{(S_i - S^+)}{(S^- - S^+)} + \ 1 - v)\frac{R_i - R^+)}{(R^- - R^+)},$$

$Q_{A1} = 0.$

$Q_{A2} = 1.$

$Q_{A3} = 0.8253.$

Step 10. S_i, R_i and Q_i are sorted by maximum criteria.

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Table 12. Calculated of S_i , R_i and Q_i.

	S	Rank	R	Rank	Q	Rank
$A1(x_1, q_1)$	0.1569	1	0.1569	1	0	1
$A2(x_1, q_2)$	0.7973	3	0.3305	3	1	3
$A3(x_1, q_3)$	0.6961	2	0.2973	2	0.8253	2

Step 11. Sort alternatives by rank.

$$A_{(x_1 q_1)} > A_{(x_1 q_2)} > A_{(x_1 q_3)}.$$

5 | Conclusion

In our article, we proposed the VIKOR method on Q-single-valued neutrosophic sets, which is a new method for MCDM methods. Firstly, we introduced the concepts, operation formulas and the distance calculating method of Q-single-valued neutrosophic sets. Thereafter, the calculating steps of the VIKOR model for Q-single-valued neutrosophic sets MCDM problems were simply presented using our proposed method, which is more scientific and reasonable for considering the conflicting attributes.

The article mainly discusses the methods of choosing the best model in the fight against cyber warfare. These methods can be used efficiently in such cases. The specific characteristic of these methods is that they deal with the three aggregated arguments instead of two or one. This makes these methods more sensitive. This is why the application of these methods in cyber war performs well. In the future, new mathematical modelling will be proposed for selection problems in many areas which draw attention such as zero waste, artificial intelligence, machine learning, deep learning, big data etc.

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Conflicts of Interest

The authors declare no conflict of interest.

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