

Professor Romualdas BAUSYS Dr.Sc.
Vilnius Gediminas Technical University
Vilnius, Lithuania

E-mail: romuldass.bausys@vgtu.lt

Professor Edmundas-Kazimieras ZAVADSKAS Dr.Sc.
Vilnius Gediminas Technical University
Vilnius, Lithuania

E-mail: edmundas.zavadskas@vgtu.lt

MULTICRITERIA DECISION MAKING APPROACH BY VIKOR UNDER INTERVAL NEUTROSOPHIC SET ENVIRONMENT

***Abstract.** The paper presents the extension of VIKOR method for the solution of the multicriteria decision making problems, namely VIKOR-IVNS. The original VIKOR method was proposed for the solution of the decision problems with the conflicting and non-common measurable criteria. In this paper, a new extension of the crisp VIKOR method has been proposed. This extension is developed in the context of interval-valued neutrosophic sets. For the realization of VIKOR method under interval-valued neutrosophic set environment the operations governed by the score functions of the interval-valued neutrosophic numbers are implemented. For the comparison obtained results an approach based on the degree of possibility is applied. The solution of the practical example of the selection of location for a logistic terminal has been presented to illustrate main aspects of the proposed extension VIKOR-IVNS.*

***Key words:** multi-criteria decision making (MCDM), VIKOR method, interval neutrosophic set, selection of location, logistic terminal.*

JEL Classification: C02, C44, C61, C63

1. Introduction

Due to the advent of the modern computer technologies the amount of the information which decision maker needs to take into account increased significantly. On the other hand, decision makers have to deal with another problem, when it is difficult to define a preference in the solution of the multicriteria decision making problem. In order to overcome this difficulty, the different types of the fuzzy sets have been introduced and applied to the solution of the MCDM problems (Rostamzadeh *et al* (2014), Antucheviciene *et al* (2012), Dheena and Mohanraj (2011), Eleveli (2014), Esbouei *et al* (2014), Ghadikolei *et al* (2014), Mohaghar *et al* (2013)). These approaches can not take into account all sorts of uncertainties since they apply a single component to represent the grade of the membership under fuzzy set environment.

A new theory of the neutrosophic sets originally proposed by Smarandache (1999) allows to deal with “knowledge of neural thought”. In fact, neutrosophic sets are the generalization of fuzzy logic and allow to deal with more complex models of the uncertainty.

In the “classical” fuzzy sets each element of the universe is defined by a single grade of the membership and the existing methods governed by fuzzy sets and their particular types are not convenient to solve decision making problem with neutrosophic information. By the logic of the neutrosophic sets each aspect of the problem is represented by the degree of the truth (T), a degree of the indeterminacy (I) and a degree of the falsity (F). In contrast to intuitionistic fuzzy sets where the degree of the uncertainty depends on the degree of membership and the degree of non-membership, by neutrosophic logic the value of the indeterminacy degree is independent of truth and falsity degrees.

Nowadays the application of the neutrosophic sets for the solution multi-criteria decision making problems is under quite intensive research. Recently, Broumi and Smarandache (2014) proposed new operations on interval neutrosophic sets, Alblowi *et al*(2014) studied new concepts of the neutrosophic sets, Patrascu (2015) performed research concerning the additional components of the indeterminacy.

It is also necessary to mention the extensions of the MCDM approaches by application of the neutrosophic sets (Broumi *et al* (2015), Bausys *et al*(2015), Ye (2015), Chi and Liu (2013), Zhang *et al*(2014)).

During the recent years some approaches are proposed to extend the crisp VIKOR method into fuzzy environment to deal with uncertain information (Antuchevichiene and Zavadskas (2008), Shemshadi *et al* (2011), Park *et al* (2011), Dou *et al* (2014), Saydi *et al* (2009)).

The purpose of the present paper is to extend the crisp VIKOR method applying the interval-valued neutrosophic set environment, namely VIKOR-IVNS. Originally, the VIKOR method was proposed by Opricovic (1998), Opricovic and Tzeng (2007).

The structure of the paper is organized in the following way. Section 2 presents a description of the crisp VIKOR method. Section 3 brings the main concepts of the interval-valued neutrosophic sets. Section 4 focuses on the description of the VIKOR-IVNS method and the application of the proposed method to the selection of a location for a logistic terminal given Section 5.

2. The VIKOR method

The VIKOR method was proposed by Opricovic (1998) for the solution of the multi-criteria decision making problem under non-commensurable and conflicting criteria environment. In general MCDM problem can be expressed as follows: decision-making problem is considered, which consists of m alternatives A that must be assessed applying n criteria c , and x_{ij} can be expressed as the value

of the j^{th} alternative by the i^{th} criterion. The main idea of the VIKOR method consists of the steps described below:

Step1. Calculate the best rating x_i^+ and the worst rating x_i^- for all criteria. In the case, when the criterion j represents benefit, these ratings are determined by

$$x_i^+ = \max_j x_{ij}, x_i^- = \min_j x_{ij} \quad (1)$$

For the cost functions, these ratings have the form

$$x_i^+ = \min_j x_{ij}, x_i^- = \max_j x_{ij}, \quad (2)$$

where x_{ij} is an element decision-making matrix X :

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (3)$$

Step2. Determine the values S_j and R_j ; $j = 1, 2, \dots, m$ applying these equations

$$S_j = \sum_{i=1}^n w_i \frac{(x_i^+ - x_{ij})}{(x_i^+ - x_i^-)} \quad (4)$$

$$R_j = \max_i w_i \frac{(x_i^+ - x_{ij})}{(x_i^+ - x_i^-)} \quad (5)$$

where w_i are the weights of the criteria, denoting their relative importance.

Step 3. Calculate the Q_j values for $j = 1, 2, \dots, m$ applying equation

$$Q_j = v \frac{(S_j - S^+)}{(S^- - S^+)} + \frac{(1-v)(R_j - R^+)}{(R^- - R^+)} \quad (6)$$

where

$$S^+ = \min_j S_j, S^- = \max_j S_j \quad (7)$$

$$R^+ = \min_j R_j, R^- = \max_j R_j \quad (8)$$

And v is the weight, which determines decision making strategy of the maximum group utility. Here, $(1-v)$ represents the individual regret strategy. These strategies are compromised by choosing $v=0.5$.

Step 4. Perform ranking of the alternatives by sorting each S , R and Q values in the decreasing order. The result of this step is three ranking lists $S_{[.j]}$, $R_{[.j]}$ and $Q_{[.j]}$.

Step 5. Select the alternative A_{j1} corresponding to $Q_{[1j]}$ (the minimum value among Q_j) as a compromise solution if the following conditions are satisfied: C1. The alternative A_{j1} has an acceptable advantage in the case, if $Q_{[2j]} - Q_{[1j]} \geq DQ$, where $DQ = \frac{1}{(m-1)}$ and m is the number of the alternatives,
C2. The alternative A_{j1} is stable within the decision making framework, if this alternative has the best ranking in $S_{[.j]}$ and/or $R_{[.j]}$.

In the case, when one of these conditions is not satisfied, then a set of the compromise solutions is created. This set consists of:

- Alternatives A_{j1} and A_{j2} , where $A_{j2} = Q_{[2j]}$ when the condition C2 is not satisfied;
- Alternatives $A_{j1}, A_{j2}, \dots, A_{jk}$ when the condition C1 is not satisfied and $A_{jk} = Q_{[kj]}$ with the maximum value, which still satisfies the equation $Q_{[kj]} - Q_{[1j]} < DQ$.

3. Neutrosophic sets

We present a brief review of general concepts of neutrosophic set (Smarandache (1999)).

Definition 1. Let X be space of the objects and $x \in X$. A neutrosophic set A in X is defined by three functions: truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and falsity-membership function $F_A(x)$. These functions $T_A(x)$, $I_A(x)$ and $F_A(x)$ are defined on real standard or real non-standard subsets of $]0^-, 1^+[$. That is $T_A(x): X \rightarrow]0^-, 1^+[$, $I_A(x): X \rightarrow]0^-, 1^+[$ and $F_A(x): X \rightarrow]0^-, 1^+[$. We have no any restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$, so $0^- \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$.

3.1. Interval-valued neutrosophic set

An interval-valued neutrosophic set (IVNS) has been defined as presented in (Zhang et al (2014))

Definition 2. Let X be a universal space of the generic objects and $x \in X$. An interval-valued neutrosophic set (IVNS) $N \subset X$ can be expressed as

$$N = \{ \langle x, T_N(x), I_N(x), F_N(x) \rangle : x \in X \} \quad (9)$$

where $T_N(x): X \rightarrow [0,1]$, $I_N(x): X \rightarrow [0,1]$ and $F_N(x): X \rightarrow [0,1]$ with $0 \leq T_N(x) + I_N(x) + F_N(x) \leq 3$ or all $x \in X$. The values $T_N(x)$, $I_N(x)$ and $F_N(x)$ correspond to truth-membership degree function, the indeterminacy-membership degree function and the falsity-membership degree function of x to N , respectively. For the case when X consists of the interval elements, these functions can be expressed as $T_N(x) = [\inf T_N(x), \sup T_N(x)] \subseteq [0,1]$, $I_N(x) = [\inf I_N(x), \sup I_N(x)] \subseteq [0,1]$, $F_N(x) = [\inf F_N(x), \sup F_N(x)] \subseteq [0,1]$ and $0 \leq \sup T_N(x) + \sup I_N(x) + \sup F_N(x) \leq 3, x \in X$.

Definition 3. (Zhang et al (2014)) If

$N_1 = \langle [\inf T_{N1}, \sup T_{N1}], [\inf I_{N1}, \sup I_{N1}], [\inf F_{N1}, \sup F_{N1}] \rangle$ and $N_2 = \langle [\inf T_{N2}, \sup T_{N2}], [\inf I_{N2}, \sup I_{N2}], [\inf F_{N2}, \sup F_{N2}] \rangle$ are two interval-valued neutrosophic numbers (IVNN), then N_1 is contained in the other neutrosophic element N_2 , $N_1 \subseteq N_2$ if and only if

$$\begin{aligned} \inf T_{N1} &\leq \inf T_{N2}, \sup T_{N1} \leq \sup T_{N2}, \\ \inf I_{N1} &\geq \inf I_{N2}, \sup I_{N1} \geq \sup I_{N2}, \text{ for any } x \in X \\ \inf F_{N1} &\geq \inf F_{N2}, \sup F_{N1} \geq \sup F_{N2}. \end{aligned} \quad (10)$$

Definition 4. (Zhang et al (2014)) Two IVNNs N_1 and N_2 are equal, expressed as $N_1 = N_2$, if and only if $N_1 \subseteq N_2$ and $N_1 \supseteq N_2$.

Definition 5. ((Zhang et al (2014)) Comparison of the interval-valued neutrosophic numbers is performed applying the score, accuracy and certainty functions. For the interval-valued neutrosophic number

$N_1 = \langle [\inf T_{N1}, \sup T_{N1}], [\inf I_{N1}, \sup I_{N1}], [\inf F_{N1}, \sup F_{N1}] \rangle$ these functions have the expressions

$$\begin{aligned}
 s(N_I) &= \left[\begin{array}{l} \inf T_{N_I} + 1 - \sup I_{N_I} + 1 - \sup F_{N_I}, \\ \sup T_{N_I} + 1 - \inf I_{N_I} + 1 - \inf F_{N_I} \end{array} \right] \\
 a(N_I) &= \left[\begin{array}{l} \min\{\inf T_{N_I} - \inf F_{N_I}, \sup T_{N_I} - \sup F_{N_I}\}, \\ \max\{\inf T_{N_I} - \inf F_{N_I}, \sup T_{N_I} - \sup F_{N_I}\} \end{array} \right] \\
 c(N_I) &= [\inf T_{N_I}, \sup T_{N_I}]
 \end{aligned} \tag{11}$$

where $s(N_I)$, $a(N_I)$ and $c(N_I)$ denotes the score, accuracy and certainty functions of the IVNN N_I , respectively.

Definition 6. Let N_I and N_2 be two IVNNs, then the comparison of these two IVNNs can be performed as follows:

- 1) If $p(s(N_I) \geq s(N_2)) > 0.5$, then N_I is greater than N_2 or in other words, N_I is superior to N_2 and that can be expressed as $N_I \succ N_2$.
- 2) If $p(s(N_I) \geq s(N_2)) = 0.5$ and $p(a(N_I) \geq a(N_2)) > 0.5$, then N_I is greater than N_2 or in other words, N_I is superior to N_2 and that can be expressed as $N_I \succ N_2$.
- 3) If $p(s(N_I) \geq s(N_2)) = 0.5$, $p(a(N_I) \geq a(N_2)) = 0.5$ and $p(c(N_I) \geq c(N_2)) > 0.5$, then N_I is greater than N_2 or in other words, N_I is superior to N_2 and that can be expressed as $N_I \succ N_2$.
- 4) If $p(s(N_I) \geq s(N_2)) = 0.5$, $p(a(N_I) \geq a(N_2)) = 0.5$ and $p(c(N_I) \geq c(N_2)) = 0.5$, then N_I is equal to N_2 or in other words, N_I is indifferent to N_2 and that can be expressed as $N_I \sim N_2$.

Definition 7. The degree of the possibility of the score function is calculated by following equation

$$p(s(N_I) \geq s(N_2)) = \max \left\{ 1 - \max \left(\frac{\sup(s(N_2)) - \inf(s(N_I))}{l_{N_I} + l_{N_2}}, 0 \right), 0 \right\} \tag{12}$$

where $l_{N_I} = \sup(s(N_I)) - \inf(s(N_I))$ and $l_{N_2} = \sup(s(N_2)) - \inf(s(N_2))$. The degrees of the possibility for the accuracy and certainty functions are determined in the same way.

4. VIKOR method under environment of an interval-valued neutrosophic set (VIKOR-IVNS)

In this section, the extended VIKOR method is presented. The extension is realized by the application of the interval-valued neutrosophic sets to model the information for the decision making problem. All initial information for the

solution of the decision making problem is expressed by the interval-valued neutrosophic numbers. This information includes a description of the importance of the decision makers, individual expert evaluations regarding the ratings of alternatives via attributes and attribute weights. The set of linguistic terms used to rate the importance of the alternatives for the decision makers is presented in Table 1.

Table 1. Linguistic terms to rate importance of the alternatives

Linguistic terms	SVNNs
Extremely good (EG) / 10 points	(1.00, 0.00, 0.00)
Very very good (VVG) / 9 points	(0.90, 0.10, 0.10)
Very good (VG) / 8 points	(0.80, 0.15, 0.20)
Good (G) / 7 points	(0.70, 0.25, 0.30)
Medium good (MG) / 6 points	(0.60, 0.35, 0.40)
Medium (M) / 5 points	(0.50, 0.50, 0.50)
Medium bad (MB) / 4 points	(0.40, 0.65, 0.60)
Bad (B) / 3 points	(0.30, 0.75, 0.70)
Very bad (VB) / 2 points	(0.20, 0.85, 0.80)
Very very bad (VVB) / 1 point	(0.10, 0.90, 0.90)
Extremely bad (EB) / 0 points	(0.00, 1.00, 1.00)

The performance of the group decision making applying VIKOR-IVNS approach can be presented by the following steps.

Step 1. Determine the importance of the experts. In the case when the decision is made by a group of the experts (decision makers), firstly the importance or share to the final decision of the each expert is determined. If a vector $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_k)$ is the vector describing the importance of the each expert, where $\lambda_k \geq 0$ and $\sum_{k=1}^K \lambda_k = 1$.

Step 2. In the framework of this step, each decision maker performs his evaluations concerning the ratings of the alternatives with respect to the attributes and the attribute weights. If we denote by $x_{ij}^k, i = 1, 2, \dots, n; j = 1, 2, \dots, m$ the k^{th} expert's evaluation of the i^{th} alternative by the j^{th} criterion. This evaluation is expressed in linguistic terms presented in the table 1. So the decision matrix for any particular expert can be constructed

$$X^k = \begin{bmatrix} x^k_{11} & x^k_{12} & \cdots & x^k_{1m} \\ x^k_{21} & x^k_{22} & \cdots & x^k_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x^k_{n1} & x^k_{n2} & \cdots & x^k_{nm} \end{bmatrix} \quad (13)$$

Step 3. Calculate the weights of the criteria. The aggregated weights of the criteria are determined by

$$w_i = \lambda_1 w_i^{(1)} \cup \lambda_2 w_i^{(2)} \cup \dots \cup \lambda_k w_i^{(k)} = \left\langle \left[\left(I - \prod_{k=1}^K \left(I - \inf T_{Ni}^{(w_k)} \right)^{\lambda_k} \right), \left(I - \prod_{k=1}^K \left(I - \sup T_{Ni}^{(w_k)} \right)^{\lambda_k} \right) \right], \right. \\ \left. \left[\prod_{k=1}^K \left(\inf I_{Ni}^{(w_k)} \right)^{\lambda_k}, \prod_{k=1}^K \left(\sup I_{Ni}^{(w_k)} \right)^{\lambda_k} \right], \right. \\ \left. \left[\prod_{k=1}^K \left(\inf F_{Ni}^{(w_k)} \right)^{\lambda_k}, \prod_{k=1}^K \left(\sup F_{Ni}^{(w_k)} \right)^{\lambda_k} \right] \right\rangle \quad (14)$$

Step 4. Construction of the aggregated weighted interval-valued decision matrix is performed as follows

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1m} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nm} \end{bmatrix} \quad (15)$$

where any particular element of the decision matrix $\tilde{x}_{ij} = \left\langle \left[\inf \tilde{T}_{Nij}, \sup \tilde{T}_{Nij} \right], \left[\inf \tilde{I}_{Nij}, \sup \tilde{I}_{Nij} \right], \left[\inf \tilde{F}_{Nij}, \sup \tilde{F}_{Nij} \right] \right\rangle$ represents the rating of the alternative A_j with respect to i criterion and is determined as follows

$$\tilde{x}_{ij} = \lambda_1 x_{ij}^{(1)} \cup \lambda_2 x_{ij}^{(2)} \cup \dots \cup \lambda_k x_{ij}^{(k)} = \left\langle \left[\left(1 - \prod_{k=1}^K \left(1 - \inf T_N^{(x_{ij}^k)} \right)^{\lambda_k} \right), \left(1 - \prod_{k=1}^K \left(1 - \sup T_N^{(x_{ij}^k)} \right)^{\lambda_k} \right) \right], \left[\prod_{k=1}^K \left(\inf I_N^{(x_{ij}^k)} \right)^{\lambda_k}, \prod_{k=1}^K \left(\sup I_N^{(x_{ij}^k)} \right)^{\lambda_k} \right], \left[\prod_{k=1}^K \left(\inf F_N^{(x_{ij}^k)} \right)^{\lambda_k}, \prod_{k=1}^K \left(\sup F_N^{(x_{ij}^k)} \right)^{\lambda_k} \right] \right\rangle \quad (16)$$

Step 5. Determine the positive and negative ideal solutions for the criteria applying the following equation

$$P^+ = \{x_1^+, \dots, x_n^+\} = \left\{ \left(\max_i (s(\tilde{x}_{ij})) / i \in L_{max} \right) \text{ or } \left(\min_i (s(\tilde{x}_{ij})) / i \in L_{min} \right) \right\}$$

$$P^- = \{x_1^-, \dots, x_n^-\} = \left\{ \left(\min_i (s(\tilde{x}_{ij})) / i \in L_{max} \right) \text{ or } \left(\max_i (s(\tilde{x}_{ij})) / i \in L_{min} \right) \right\} \quad (17)$$

$i = 1, \dots, n$

where L_{max} is representing the set of the benefit criteria and L_{min} is associated with the cost criteria. Here, P^+ and P^- express positive and negative ideal solutions, respectively.

Step 6. Determine the values S_j and $R_j; j = 1, 2, \dots, m$ applying the following equations

$$\inf S_j = \sum_{i \in L_{max}} \inf(s(w_i)) \frac{x_i^+ - \sup(s(\tilde{x}_{ij}))}{x_i^+ - x_i^-} + \sum_{i \in L_{min}} \inf(s(w_i)) \frac{\inf(s(\tilde{x}_{ij})) - x_i^+}{x_i^- - x_i^+} \quad (18)$$

$$\sup S_j = \sum_{i \in L_{max}} \sup(s(w_i)) \frac{x_i^+ - \inf(s(\tilde{x}_{ij}))}{x_i^+ - x_i^-} + \sum_{i \in L_{min}} \sup(s(w_i)) \frac{\sup(s(\tilde{x}_{ij})) - x_i^+}{x_i^- - x_i^+} \quad (19)$$

$$\inf R_j = \max \left\{ \begin{array}{l} \inf(s(w_i)) \frac{x_i^+ - \sup(s(\tilde{x}_{ij}))}{x_i^+ - x_i^-} / i \in L_{max}, \\ \inf(s(w_i)) \frac{\inf(s(\tilde{x}_{ij})) - x_i^+}{x_i^- - x_i^+} / i \in L_{min} \end{array} \right\} \quad (20)$$

$$\sup R_j = \max \left\{ \begin{array}{l} \sup(s(w_i)) \frac{x_i^+ - \inf(s(\tilde{x}_{ij}))}{x_i^+ - x_i^-} / i \in L_{max}, \\ \sup(s(w_i)) \frac{\sup(s(\tilde{x}_{ij})) - x_i^+}{x_i^- - x_i^+} / i \in L_{min} \end{array} \right\} \quad (21)$$

Step 7. Calculate the Q_j values for $j = 1, 2, \dots, m$ applying following equations

$$\inf Q_j = v \frac{(\inf S_j - S^+)}{(S^- - S^+)} + \frac{(1-v)(\inf R_j - R^+)}{(R^- - R^+)} \quad (22)$$

$$\sup Q_j = v \frac{(\sup S_j - S^+)}{(S^- - S^+)} + \frac{(1-v)(\sup R_j - R^+)}{(R^- - R^+)} \quad (23)$$

where

$$S^+ = \min_j(\inf S_j), S^- = \max_j(\sup S_j) \quad (24)$$

$$R^+ = \min_j(\inf R_j), R^- = \max_j(\sup R_j) \quad (25)$$

Step 8. According to VIKOR method, the best alternative must has the minimum Q_j and it can be chosen as a compromise solution. For the selection of the minimum Q_j the rules, presented in the definition 6, are applied.

5. Numerical example

For the purpose of the evaluation the proposed approach, application example of the MCDM problem is solved in order to study the aspects of the implementation of the interval-valued neutrosophic sets. The studied topic: location selection problem is quite frequently is solved by the application of the MCDM techniques: Dhenna and Mohanraj (2011) presented solution of the

distribution center location problem; Eevli (2014) performed an evaluation of locations for the logistics center at Samsun (Turkey); Turskis and Zavadskas (2010) solved a decision problem concerning the selection of the location for the logistic center; Tamosaitiene *et al* (2013) applied MCDM approach for the assessment of the location of high-rise buildings in the city urban structure.

We studied the same decision making problem concerning the selection of the location site for the logistic center (Turskis and Zavadskas (2010)) to evaluate the performance of the proposed VIKOR-IVNS method. This problem consists of four alternatives and four criteria: investment cost, operation time, expansion possibility, closeness to the demand market. In the considered case C_1-C_4 are criteria for the cost and C_2-C_3 are the benefit criteria. All initial data transformed into interval-valued neutrosophic sets. The provided decision matrix can be expressed as follows in Table 2. The scores of the weighted interval-valued neutrosophic decision matrix is determined applying Eq. (16) and Eq.(11) and are presented in Table 3.

Table 2. Collective interval-valued neutrosophic decision matrix

Criteria	Alternatives	
	I	II
C_1 min	{[0.15, 0.2], [0.85, 0.875], [0.8, 0.85]}	{[0.09, 0.14], [0.88, 0.91], [0.86, 0.91]}
C_2 max	{[0.2, 0.35], [0.7, 0.85], [0.65, 0.8]}	{[0.15, 0.45], [0.575, 0.875], [0.55, 0.85]}
C_3 max	{[0.15, 0.35], [0.7, 0.875], [0.65, 0.85]}	{[0.15, 0.35], [0.7, 0.875], [0.65, 0.85]}
C_4 min	{[0.11, 0.19], [0.855, 0.895], [0.81, 0.89]}	{[0.07, 0.15], [0.875, 0.93], [0.85, 0.93]}
	III	IV
C_1 min	{[0.15, 0.21], [0.84, 0.875], [0.79, 0.85]}	{[0.17, 0.25], [0.8, 0.865], [0.75, 0.83]}
C_2 max	{[0.25, 0.45], [0.575, 0.8], [0.55, 0.75]}	{[0.2, 0.4], [0.65, 0.85], [0.6, 0.8]}
C_3 max	{[0.2, 0.33], [0.72, 0.85], [0.67, 0.8]}	{[0.15, 0.4], [0.65, 0.875], [0.6, 0.85]}
C_4 min	{[0.06, 0.125], [0.8875, 0.94], [0.875, 0.94]}	{[0.05, 0.13], [0.885, 0.95], [0.87, 0.95]}
	Weights	
C_1 min	{[0.096, 0.195], [0.8525, 0.904], [0.805, 0.904]}	
C_2 max	{[0.129, 0.277], [0.773, 0.8855], [0.723, 0.871]}	
C_3 max	{[0.096, 0.526], [0.4601, 0.904], [0.474, 0.904]}	
C_4 min	{[0.074, 0.446], [0.581, 0.926], [0.554, 0.926]}	

Table 3. Decision matrix of the scores of the interval-valued neutrosophic numbers

Criteria	Alternatives		
	I	II	III
C_1 min	[0.425, 0.55]	[0.27, 0.4]	[0.425, 0.58]
C_2 max	[0.55, 1.0]	[0.425, 1.325]	[0.7, 1.325]
C_3 max	[0.425, 1.0]	[0.425, 1.0]	[0.55, 0.94]
C_4 min	[0.325, 0.525]	[0.21, 0.425]	[0.18, 0.3625]
	IV	Weights	
C_1 min	[0.475, 0.7]	[0.288, 0.5375]	
C_2 max	[0.55, 1.15]	[0.3725, 0.781]	
C_3 max	[0.425, 1.15]	[0.288, 1.5919]	
C_4 min	[0.15, 0.375]	[0.222, 1.311]	

The results of the application of the extended VIKOR method of interval-valued neutrosophic numbers for the solution of the location selection problem for the logistic terminal are presented in the table 4.

Table 4. Solution results by VIKOR-IVNS

Alternatives	S	R	Q
A_1	[0.3745, 3.929]	[0.1345, 1.5919]	[0.0661, 1.0]
A_2	[0.1234, 3.5]	[0.0879, 1.5919]	[0.0015, 0.9437]
A_3	[0.205, 2.992]	[0.0834, 1.3174]	[0.0107, 0.786]
A_4	[0.2094, 3.5909]	[0.1373, 1.5919]	[0.0292, 0.956]

For the sake of comparison of the alternatives, the matrix of the possibility degree (table 5) is constructed applying eq. (12).

Table 5. The matrix of the possibility degree ($P(Q_1 > Q_2)$)

	Q_1	Q_2	Q_3	Q_4
Q_1	0.5	0.5967	0.6039	0.5925
Q_2	0.4033	0.5	0.4882	0.4713
Q_3	0.3961	0.5118	0.5	0.4797
Q_4	0.4075	0.5287	0.5203	0.5

The ranking of the alternatives can be expressed as $Q_2 \succ Q_3 \succ Q_4 \succ Q_1$ but it is necessary to take into account the fact, that alternatives Q_2 , Q_3 and Q_4 are close to each other and these alternatives must be included into the compromise solution set.

6. Conclusions

The environment of the neutrosophic sets provides a good framework to deal with uncertain information in the most consistent way for the solution of the multi-criteria decision making problems.

In this paper, we have proposed the extended VIKOR method to deal with interval-valued neutrosophic information. However, there is still no general agreement concerning ranking of the interval-valued neutrosophic numbers. Therefore, the case of the interval-valued neutrosophic sets needs additional research efforts in comparison to the case of the single value neutrosophic sets.

The facets of the application of the proposed extended VIKOR-IVNS method are studied considering the selection of the location site for logistic terminal. The performed numerical analysis represents numerical stability and consistency of the VIKOR method for the cases of the different set environments.

REFERENCES

- [1] **Alblowi, S.A., Salama, A.A., Eisa, M. (2014), *New Concepts of Neutrosophic Sets*. *Int. Journal of Mathematics and Computer Applications Research*, 4(1), 59-66;**
- [2] **Antucheviciene, J., Zavadskas, E.K., Zakarevicius, A. (2012), *Ranking Redevelopment Decisions of Derelict Buildings and Analysis of Ranking Results*. *Economic Computation & Economic Cybernetics Studies & Research*, 46(2), 37-62;**
- [3] **Antucheviciene, J., Zavadskas, E.K. (2008), *Modelling Multidimensional Redevelopment of Derelict Buildings*. *Int. Journal Environment and Pollution*, 35(2-4), 331-344;**
- [4] **Bausys, R., Zavadskas, E.K., Kaklauskas A. (2015), *Application of Neutrosophic Set to Multicriteria Decision Making by COPRAS*. *Economic Computation & Economic Cybernetics Studies & Research*, 49(2), in-press;**
- [5] **Broumi, S., Smarandache, F. (2014), *New Operations on Interval Neutrosophic Sets*. *Eds. Smarandache, F. Neutrosophic Theory and Its Applications*. EuropaNova, Brussels, 274-284;**

- [6] **Broumi, S., Ye, J., Smarandache, F. (2015),** *An Extended TOPSIS Method for Multiple Attribute Decision Making based on Interval Neutrosophic Uncertain Linguistic Variables. Neutrosophic Sets and Systems, 8, 22-31;*
- [7] **Chi, P.P., Liu, P.D. (2013),** *An Extended TOPSIS Method for Multiple Attribute Decision Making Problems Based on Interval Neutrosophic Set. Neutrosophic Sets and Systems, 1, 63-70;*
- [8] **Dheena, P., Mohanraj, G. (2011),** *Multicriteria Decision-Making Combining Fuzzy Set Theory, Ideal and Anti-Ideal Points for Location Site Selection. Expert Systems with Applications, 38(10), 13260-13265;*
- [9] **Dou, Y., Zhang, P., Jiang, J., Yang, K., Chen, Y. (2014),** *MCDM Based on Reciprocal Judgment Matrix: A Comparative Study of E-VIKOR and E-TOPSIS Algorithmic Methods with Interval Numbers. Appl. Math. Inf. Sci., 8(3), 1401-1411;*
- [10] **Elevli, B. (2014),** *Logistics Freight Center Locations Decision by Using Fuzzy-PROMETHEE. Transport, 29(4), 412-418;*
- [11] **Esbouei, S. B., Ghadikolei, A. S., Antucheviciene, J. (2014),** *Using FANP and Fuzzy VIKOR for Ranking Manufacturing Companies on their Financial Performance. Economic Computation & Economic Cybernetics Studies & Research, 48(3), 141-162;*
- [12] **Ghadikolei, A. S., Esbouei, S. B., Antucheviciene, J. (2014),** *Applying Fuzzy MCDM for Financial Performance Evaluation of Iranian Companies. Technological and Economic Development of Economy, 20(2), 274-291;*
- [13] **Mohaghar, A., Khanmohammadi, E., Molavi, M., Moradi-Moghadam, M. (2013),** *Applying Interval VIKOR and Fuzzy AHP Methods for Supplier Selection. New York Science Journal, 6(6),74-85;*
- [14] **Opricovic, S. (1998),** *Multicriteria Optimization of Civil Engineering Systems. Belgrade: Faculty of Civil Engineering.(in Serbian);*
- [15] **Opricovic, S., Tzeng, G.H. (2007),** *Extended VIKOR Method in Comparison with Outranking Methods. European Journal of Operational Research, 178, 514-529;*
- [16] **Park, J.P., Cho, H.J., Kwun, Y.C. (2011),** *Extension of the VIKOR Method for Group Decision Making with Interval-Valued Intuitionistic Fuzzy Information. Fuzzy Optim. Decis. Making, 10, 233-253;*
- [17] **Patrascu, V. (2015),** *The Neutrosophic Entropy and Its Five Components. Neutrosophic Sets and Systems, 7, 40-46;*
- [18] **Rostamzadeh, R., Ismail, K., Zavadskas, E.K. (2014),** *Multi Criteria Decision Making for Assisting Angels in Investments. Technological and Economic Development of Economy, 20(4), 696-720;*

- [19] **Saydi, M.K., Heydari, M., Shahanaghi, K. (2009),** *Extension of VIKOR Method for Decision Making Problem with Interval Numbers. Applied Mathematical Modelling, 33, 2257-2262;*
- [20] **Shemshadi, A., Shirazi, H., Toreihi, M., Tarokh, M.J. (2011).** *A Fuzzy VIKOR Method for Supplier Selection based on Entropy Measure for Objective Weighting. Expert Systems with Applications, 38(10), 12160–12167;*
- [21] **Smarandache, F. (1999),** *A Unifying Field in Logics. Neutrosophy: Neutrosophic Probability, Set and Logic. American Research Press, Rehoboth;*
- [22] **Tamosaitienė, J., Sipalis, J., Banaitis, A., Gaudutis, E. (2013),** *Complex Model for the Assessment of the Location of High-rise Buildings in the City Urban Structure. Int. Journal of Strategic Property Management. 17(1), 93-109;*
- [23] **Turskis, Z., Zavadskas, E.K. (2010),** *A New Fuzzy Additive Ratio Assessment Method (ARAS-F). Case Study: The Analysis of Fuzzy Multiple Criteria in Order to Select the Logistic Centers Location. Transport, 25(4), 423-432;*
- [24] **Ye, J. (2015),** *An Extended TOPSIS Method for Multiple Attribute Group Decision Making Based on Single Valued Neutrosophic Linguistic Numbers. Journal of Intelligent & Fuzzy Systems, 28(1), 247–255;*
- [25] **Zhang, H.Y., Wang, J.G., Chen, X.H. (2014).** *Interval Neutrosophic Sets and Their Application in Multicriteria Decision Making Problems. The Scientific World Journal, Article ID 645953.*