Interval-Valued Neutrosophic Extension of EDAS Method

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Abstract. EDAS (Evaluation Based on Distance from Average Solution) is based on the distances of each alternative from the average solution with respect to each criterion. This method is similar to distance based multi-attribute decision making methods such as TOPSIS and VIKOR. It simplifies the calculation of distances to ideal solution and determines the final decision rapidly. EDAS method has been already extended to its ordinary fuzzy, intuitionistic fuzzy and Type-2 fuzzy versions. In this paper, we extend EDAS method to its interval-valued neutrosophic version with the advantage of considering a decision maker's truthiness, falsity and indeterminacy simultaneously. The proposed method has been applied to a multi-criteria and multi-expert supplier selection problem and a sensitivity analysis is conducted to check the robustness of the given decisions, also the deneutrosophicated decision matrix and weight of the criteria are applied to crisp EDAS and crisp TOPSIS method to check the robustness of our method.

Keywords: EDAS · Interval-valued neutrosophic sets · Multi-criteria · Supplier selection · Deneutrosophication · Aggregation

1 Introduction

In traditional set theory, an element can belong to a set or not; in optimization, a solution is either feasible or not; and in conventional Boolean logic, a statement can be true or false but nothing in between (Zimmerman 2011). But considering real life conditions, component of life and its brings are generally not precise and cannot define as deterministic with a single number. Hence, the ability to make precise statements is hard and even it is, the conclusion is devoid from reality. In order to regard the uncertainty, fuzzy sets were introduced by Zadeh (1965) which are used for to represent the degree of membership to correspond the complexity. Since the development of fuzzy sets, it is extended in many forms. Type-n fuzzy set was developed by Zadeh (1975) for handling the uncertainty of the membership function in the fuzzy set theory. After that, interval-valued fuzzy sets (IVFSs) were introduced independently by (Zadeh 1975; Grattan-Guiness 1975; Jahn 1975; Sambuc 1975). In 1986, intuitionistic fuzzy sets (IFSs) presented by Atanassov to deal with the problem that how the non-membership

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degrees should be assigned (Atanassov 1986). Hesitant fuzzy sets (HFSs), initially described by Torra (2010), are the extensions of regular fuzzy sets where a set of values are possible for the membership of a single element. Despite all these extensions, the insufficiency that the fuzzy sets cannot identify commensurately is inconsistent information about the system or indeterminate decisions of the experts. Therefore, some new extensions are required and need to be performed.

In order the to surpass this incapability, Smarandache (1995) developed neutrosophic logic and neutrosophic sets (NSs) as an extension of intuitionistic fuzzy sets. The neutrosophic set is defined as the set where each element of the universe has a degree of truthiness, indeterminacy and falsity which are between]−0, 1+[the non-standard unit interval (Rivieccio 2008). In the neutrosophic sets, uncertainty is represented as truth and falsity values where degrees of belongingness and non-belongingness and indeterminacy value where the factor incorporated as the percent of hesitancy. With this notation, neutrosophic sets do not only determine the uncertainty of the system or experts but also add indecisiveness that revealed from the inconsistent information. We consider the truth and falsity values as membership and non-membership functions and the indeterminacy value as the hesitancy. All of these properties of neutrosophic sets are the answer to why we use neutrosophic sets in this study. Through this, deneutrosophication and subtraction functions are developed and applied for the interval-valued neutrosophic Evaluation Based on Distance from Average Solution (EDAS) (Keshavarz Ghorabaee et al. 2015) technique.

In this study, an interval-valued neutrosophic EDAS method is developed and applied to a supplier selection problem of a facility. This method is similar to distance based multi-attribute decision making methods such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwan and Yoon 1981) and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) (Opricovic 1998). The criteria and alternatives are determined by an expert group and the weights of criteria and the scores of the decision matrices are aggregated by their opinions. The rest of this paper is organized as follows. In Sect. 2, proposed IVN EDAS method is given with all its perspective. In Sect. 3, an illustrative example is applied and sensitivity analysis is implemented for the check of robustness. The paper ends with the conclusion and suggestions.

2 Interval-Valued Neutrosophic EDAS

In this section, we propose interval-valued neutrosophic EDAS with all its details. Deneutrosophication technique for the interval-valued neutrosophic sets is enhanced and subtraction operation for the interval-valued neutrosophic sets is developed.

2.1 Preliminaries

Definition 1. Let $x_j = \left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$, be a collection of interval-valued neutrosophic number (IVNN) where $j = 1, 2, \ldots, n$ is the decision maker. Based on the weighted aggregation operators of IVNNs, the interval-valued neutrosophic weighted arithmetic average operator (INWAA) is given as below (Zhang et al. 2014): INWAA $(x_1, x_2, \ldots, x_n) = \sum_{k=1}^{n} y_k \mathrm{x_j}$, where

$$\left\langle \left[1 - \prod_{k=1}^{n}\left(1 - T_j^L\right)^{y_k}, 1 - \prod_{k=1}^{n}\left(1 - T_j^U\right)^{y_k}\right], \left[\prod_{k=1}^{n}\left(I_j^L\right)^{y_k}, \prod_{k=1}^{n}\left(I_j^U\right)^{y_k}\right], \left[\prod_{k=1}^{n}\left(F_j^L\right)^{y_k}, \prod_{k=1}^{n}\left(F_j^U\right)^{y_k}\right] \right\rangle \tag{1}$$

and y_k is the weight vector of decision maker.

Definition 2. The deneutrosophication function of an IVNN which is given above is calculated as below:

$$\mathfrak{D}(x) = \frac{((T_x^L * ((1 - I_x^L) + (1 - I_x^U))) + (T_x^U * ((1 - I_x^L) + (1 - I_x^U))) + ((1 - F_x^L) * ((1 - I_x^L) + (1 - I_x^U))) + ((1 - F_x^U) * ((1 - I_x^L) + (1 - I_x^U))))}{8} \tag{2}$$

where $\mathrm{x} = \left\langle \left[T_x^L, T_x^U\right], \left[I_x^L, I_x^U\right], \left[F_x^L, F_x^U\right] \right\rangle$.

Definition 3. A function is defined in the following to find the maximum between interval-valued neutrosophic set and zero.

$$Z(x_j) = \begin{cases} x_j & if\, \kappa(x_j) > 0 \\ 0 & if\, \kappa(x_j) \leq 0 \end{cases} \tag{3}$$

where $\mathrm{x_j} = \left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$ and $0 = \langle [0, 0], [1, 1], [1, 1] \rangle$.

Definition 4. Let X be a universe of discourse. An IVN set N in X is independently characterized by a truth-membership function $T_N(x)$, an indeterminacy-membership function $I_N(x)$, and a falsity-membership function $F_N(x)$ for each $x \in X$, where $T_N(x) = \left[T_{N(x)}^L, T_{N(x)}^U \subseteq [0, 1]\right]$, $I_N(x) = \left[I_{N(x)}^L, I_{N(x)}^U \subseteq [0, 1]\right]$, and $F_N(x) = \left[F_{N(x)}^L, F_{N(x)}^U \subseteq [0, 1]\right]$, then they satisfy the condition $0 \leq T_N^L(x) + I_N^L(x) + F_N^L(x) \leq 3$. Thus, the IVNS N can be denoted as (Li et al. 2016):

$$\mathrm{N} = \left\{ \left\langle \mathrm{x}, \left[T_N^L(x), T_N^U(x)\right], \left[I_N^L(x), I_N^U(x)\right], \left[F_N^L(x), F_N^U(x)\right] \right\rangle | x \in X \right\}. \tag{4}$$

We will denote Eq. (1) as $\left[T_N^L, T_N^U\right], \left[I_N^L, I_N^U\right], \left[F_N^L, F_N^U\right]$ for short.

Let $a = \left[T_a^L, T_a^U\right], \left[I_a^L, I_a^U\right], \left[F_a^L, F_a^U\right]$ and $b = \left[T_b^L, T_b^U\right], \left[I_b^L, I_b^U\right], \left[F_b^L, F_b^U\right]$ be two INNs, the relations of them are shown as below (Zhang et al. 2014):

1. $a^c = \left[T_a^L, T_a^U\right], \left[1 - I_a^U, 1 - I_a^U\right], \left[F_a^L, F_a^L\right]$.
2. $a \subseteq b$ if and only if $T_a^L \leq T_b^L, T_a^U \leq T_b^U; I_a^L \geq I_b^L, I_a^U \geq I_b^U; F_a^L \geq F_b^L, F_a^U \geq F_b^U$.
3. $a = b$ if and only if $a \subseteq b$ and $b \subseteq a$.
4. $a \oplus b = \left\langle \left[T_a^L + T_b^L - T_a^L T_b^L, T_a^U + T_b^U - T_a^U T_b^U\right], \left[I_a^L I_b^L, I_a^U I_b^U\right], \left[F_a^L F_b^L, F_a^U F_b^U\right] \right\rangle$.
5. $a \otimes b = \left\langle \left[T_a^L T_b^L, T_a^U T_b^U\right] \left[I_a^L + I_b^L - I_a^L I_b^L, I_a^U + I_b^U - I_a^U I_b^U\right], \left[F_a^L + F_b^L - F_a^L F_b^L, F_a^U + F_b^U - F_a^U F_b^U\right] \right\rangle$.

Definition 5. Subtraction operation of two interval-valued neutrosophic sets is given as below:

$$x \ominus y = [T_x^L - F_y^U, T_x^U - F_y^L], [\mathrm{Max}\left(I_x^L, I_y^L\right), \mathrm{Max}(I_x^U, I_y^U)], [F_x^L - T_y^U, F_x^U - T_y^L] \quad (5)$$

where $x = \langle [T_x^L, T_x^U], [I_x^L, I_x^U], [F_x^L, F_x^U] \rangle$ and $y = \left\langle \left[T_y^L, T_y^U\right], \left[I_y^L, I_y^U\right], \left[F_y^L, F_y^U\right] \right\rangle$.

2.2 Interval-Valued Neutrosophic EDAS Method

In this section, we use interval-valued neutrosophic sets in EDAS method to surpass of incompleteness, indeterminacy, and inconsistency information of the system. The steps of the extended method are as follows:

Step 1: Construct the IVN decision matrix (D_j) with regards to experts (j), where the benefit and cost variables are b_{mn} and c_{mn} respectively. The columns are the alternatives (n) and the rows are the criteria (m). The scale used to construct IVN decision matrix is given in Table 1.

Table 1. Scale for IVN decision matrix

Linguistic terms		<T, I, F>
CL	Certainly low	<[0.1, 0.2], [0.6, 0.7], [0.8, 0.9]>
VL	Very low	<[0.2, 0.3], [0.5, 0.6], [0.7, 0.8]>
L	Low	<[0.3, 0.4], [0.4, 0.5], [0.6, 0.7]>
BA	Below average	<[0.4, 0.5], [0.3, 0.4], [0.5, 0.6]>
A	Average	<[0.5, 0.5], [0.1, 0.2], [0.4, 0.5]>
AA	Above average	<[0.5, 0.6], [0.3, 0.4], [0.4, 0.5]>
H	High	<[0.6, 0.7], [0.4, 0.5], [0.3, 0.4]>
VH	Very high	<[0.7, 0.8], [0.5, 0.6], [0.2, 0.3]>
CH	Certainly high	<[0.8, 0.9], [0.6, 0.7], [0.1, 0.2]>

Through the scale, IVN decision matrix with respect to Expert j is given in Table 2. In here, we use $xj_{mn} = \left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$ notation to express IVN number with respect to Expert j.

Table 2. IVN decision matrix with respect to expert j

Criterion	Type	AL_1	AL_2	…	AL_n
C_1	Linguistic cost	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\cdots$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$
C_2	Numerical cost	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\cdots$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
C_m	Linguistic benefit	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$	$\cdots$	$\left\langle \left[T_j^L, T_j^U\right], \left[I_j^L, I_j^U\right], \left[F_j^L, F_j^U\right] \right\rangle$

Step 2: Aggregate the decision matrix for obtaining average IVN decision matrix. We use Eq. (1) for aggregation operation. Aggregated IVN decision matrix (A) is constructed as in Table 3. In here, $x_{mn} = \langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$ notation is used to express aggregated IVN number.

Table 3. Aggregated IVN decision matrix

Criterion	Type	AL_1	AL_2	…	AL_n
C_1	Linguistic cost	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	$\cdots$	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$
C_{12}	Numerical cost	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	$\cdots$	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
C_m	Linguistic benefit	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$	…	$\langle [T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U] \rangle$

Step 3: Construct the average solution matrix of criteria weights with regards to experts (j). The criteria weights are determined by Table 4. The weights are shown as follows:

$$W = [w_j]_{1xm} \tag{6}$$

Where w_j is obtained by using Eq. (1).

Table 4. Scale for weighting the criteria

Linguistic term		<(T, I, F)>
CLI	Certainly low importance	<[0.06, 0.22], [0.67, 0.78], [0.83, 1.00]>
VLI	Very low importance	<[0.22, 0.33], [0.56, 0.67], [0.72, 0.83]>
LI	Low importance	<[0.33, 0.44], [0.44, 0.56], [0.61, 0.72]>
BAI	Below average importance	<[0.44, 0.56], [0.33, 0.44], [0.50, 0.61]>
AI	Average importance	<[0.50, 0.56], [0.11, 0.22], [0.44, 0.50]>
AAI	Above average importance	<[0.50, 0.61], [0.33, 0.44], [0.44, 0.56]>
HI	High importance	<[0.61, 0.72], [0.44, 0.56], [0.33, 0.44]>
VHI	Very high importance	<[0.72, 0.83], [0.56, 0.67], [0.22, 0.33]>
CHI	Certainly high importance	<[0.83, 1.00], [0.67, 0.78], [0.06, 0.22]>

Step 4: Construct the matrix of average criteria weights (AV) with regards to scores that are determined in Table 5. The constructed criteria weight matrix is shown as below:

In here, $av_n = \langle [T_{AV}^L, T_{AV}^U], [I_{AV}^L, I_{AV}^U], [F_{AV}^L, F_{AV}^U] \rangle$ where the average weight of criteria x_{mn} with respect to scores taken from the decision matrix.

Table 5. Average criteria weights with regards to scores

Criterion	Type	Average criteria weights
C_1	Linguistic cost	$\left\langle [T^L_{av}, T^U_{av}], [I^L_{av}, I^U_{av}], [F^L_{av}, F^U_{av}] \right\rangle$
C_{12}	Numerical cost	$\left\langle [T^L_{av}, T^U_{av}], [I^L_{av}, I^U_{av}], [F^L_{av}, F^U_{av}] \right\rangle$
$\vdots$	$\vdots$	$\vdots$
C_m	Linguistic benefit	$\left\langle [T^L_{av}, T^U_{av}], [I^L_{av}, I^U_{av}], [F^L_{av}, F^U_{av}] \right\rangle$

Step 5: Calculate the positive distance from average (PDA) and negative distance from average (NDA) according to benefit and cost criteria, respectively. As we mentioned above benefit and cost variables are shown as b_{mn} and c_{mn}.

$$PDA = [pda_{mn}]_{mxn} \tag{7}$$

$$NDA = [nda_{mn}]_{mxn} \tag{8}$$

where pda_{mn} and nda_{mn} denote the positive and negative distance performance value of the n^{th} alternative from average solution in terms of m^{th} criterion respectively.

$$pda_{mn} = \begin{cases} \frac{Z(x_{mn} \ominus av_n)}{\kappa(av_n)} & if\ m \in B \\ \frac{Z(av_n \ominus x_{mn})}{\kappa(av_n)} & if\ m \in C \end{cases} \tag{9}$$

$$nda_{mn} = \begin{cases} \frac{Z(av_n \ominus x_{mn})}{\kappa(av_n)} & if\ m \in B \\ \frac{Z(x_{mn} \ominus av_n)}{\kappa(av_n)} & if\ m \in C \end{cases} \tag{10}$$

Step 6: Calculate the weighted sum of positive and negative distances for all alternatives as follows:

$$sp_n = \sum\nolimits_{n=1}^{l} (w_j \otimes pda_{mn}) \tag{11}$$

$$np_n = \sum\nolimits_{n=1}^{l} (w_j \otimes nda_{mn}) \tag{12}$$

Step 7: Normalize the sp_n and np_n values. The normalize values of sp_n and np_n for all alternatives are calculated as follows:

$$nsp_n = \frac{sp_n}{\max(\kappa(sp_n))} \tag{13}$$

$$nsn_n = 1 - \frac{sn_n}{\max(\kappa(sn_n))} \tag{14}$$

Step 8: Calculate the appraisal score (as_n) for all alternatives as follows:

$$as_n = \frac{1}{2}(nsp_n \oplus nsn_n) \tag{15}$$

Step 9: Rank the alternatives according to the decreasing values of appraisal score (as_n).

3 Illustrative Example

In this section, we will first define the multi-criteria problem and then give the solution of the problem and finally make a sensitivity analysis to check the robustness of the given decisions by the developed method.

3.1 Problem Definition

Supply chain managers of an agriculture company want to select the best fertilizer supplier for their plantation areas to satisfy their needs. Experts group which is composed of an academician and two managers from supply chain management department suggest *AL1-Bagfas*, *AL2-Gubretas*, *AL3-Gubrf*, *AL4-Bagfs*, and *AL5-Igdas* as supplier alternatives. The relevant criteria which are determined by expert opinions and literature review (Kannan et al. 2013; Govindan et al. 2014; Junior et al. 2014; Deng et al. 2014; Hamdan and Cheaitou 2016; Qin et al. 2017; Türk et al. 2017) decided as 4 main criteria and 15 sub-criteria which is given in Table 6:

Table 6. Determined criteria for the application

Cost (C)	Quality (Q)	Service Performance (SD)	Environmental Design (ED)
Freight cost (C1)	Complexity level of monitoring of supplier (Q1)	Delivery time (SD1)	Performance history (ED1)
Product price (C2)	Rejection rate of product (Q2)	Degree of cooperation (SD2)	Pollution production (ED2)
Total product life cycle (C3)	Increased lead time (Q3)	Response to changes (SD3)	Green Image (ED3)
	Stock availability (Q4)	Order fulfillment ratio (SD4)	
	Quality control rejection rate (Q5)		

The cost criteria among these are *C1 Freight cost*, *C2 Product price*, *Q1 Complexity level of monitoring supplier*, *Q2 Rejection rate of product*, *Q3 Increased lead time*, *Q5 Quality control rejection rate*, *SD1 Delivery time*, and *ED2 Pollution* *production* whereas the others benefit criteria. Expert group cannot assign exact values of alternatives' scores with respect to criteria due to the exchange rate, fluctuant environmental conditions, and human factors. In order to deal with this difficulty academician expert suggested upper and lower limits for the scores. Far beyond, interval-valued neutrosophic sets are introduced for handling uncertainty and indeterminacy of the system. EDAS method has been selected to make an MCDM since the relations of alternatives and criteria allow to define the superiorities and ranks. Experts used the scales in Tables 1 and 4 for scoring in the decision matrices and for weighting the criteria for the EDAS method, respectively. The hierarchy in Fig. 1 represents the multi-criteria structure of the considered problem.

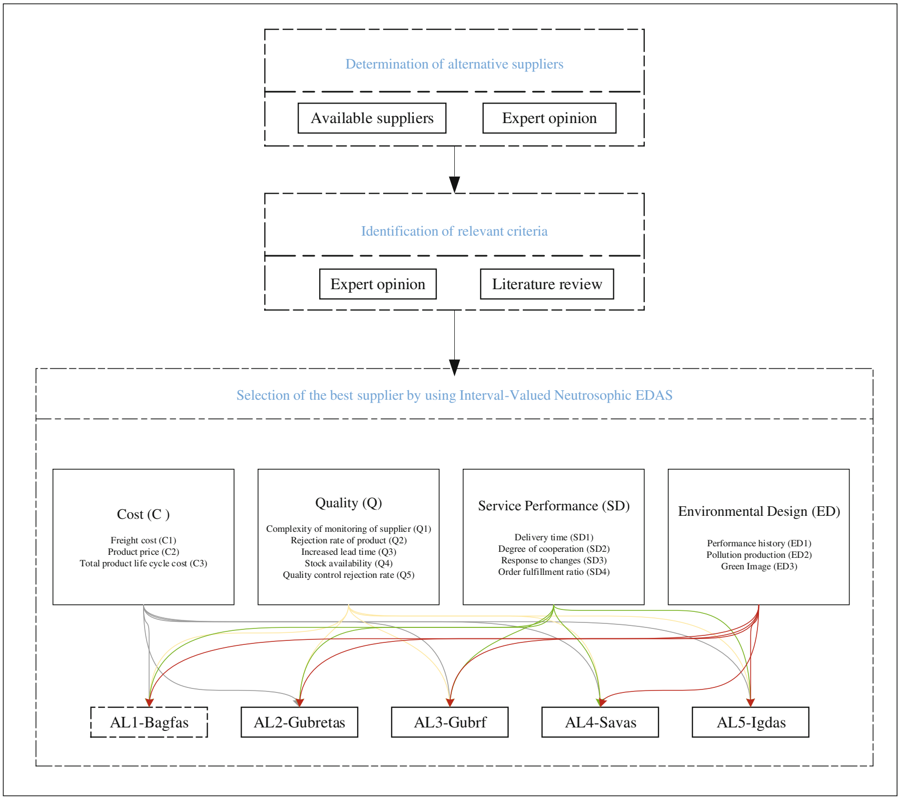

Fig. 1. Hierarchy of the proposed EDAS method

3.2 Problem Solution

In this sub-section, we give the solution of the problem defined in Sect. 3.1 by using the steps of the proposed method given in Sect. 2.2.

Step 1: Constructed decision matrices with respect to experts are given in Table 7:

Table 7. Decision matrices with respect to experts

Criterion	Type	DM1 – Weight (y_k) 0,42					DM2 – Weight (y_k) 0,35					DM3 – Weight (y_k) 0,23				
		AL1	AL2	AL3	AL4	AL5	AL1	AL2	AL3	AL4	AL5	AL1	AL2	AL3	AL4	AL5
C1	Cost	AA	AA	A	AA	H	L	AA	A	H	AA	H	VH	L	BA	BA
C2	Cost	BA	AA	H	A	A	H	VH	L	BA	BA	BA	AA	H	A	A
C3	Benefit	L	AA	A	H	BA	BA	AA	H	A	A	VH	L	H	H	BA
Q1	Cost	H	VH	L	BA	A	L	BA	H	H	BA	AA	H	L	AA	H
Q2	Cost	CL	H	A	L	AA	H	A	L	AA	H	BA	H	L	AA	A
Q3	Cost	VH	A	AA	BA	L	A	AA	A	AA	A	H	BA	L	AA	A
Q4	Benefit	L	BA	H	AA	VH	BA	H	L	BA	AA	H	AA	AA	L	BA
Q5	Cost	AA	H	A	VH	VL	H	BA	L	BA	H	CL	H	AA	H	VH
SD1	Cost	CH	A	AA	A	L	H	AA	AA	A	BA	BA	BA	H	L	AA
SD2	Benefit	A	L	BA	AA	H	CL	BA	L	BA	H	VH	L	BA	L	BA
SD3	Benefit	H	VH	A	AA	L	BA	AA	H	VH	A	AA	H	A	AA	BA
SD4	Benefit	BA	L	BA	H	VL	AA	BA	L	AA	A	BA	H	H	AA	A
ED1	Benefit	AA	AA	A	BA	H	H	AA	H	VH	L	A	L	AA	L	BA
ED2	Cost	VH	VH	L	H	A	A	VH	CL	H	A	CL	BA	L	BA	VH
ED3	Benefit	A	H	A	BA	L	H	CL	BA	A	H	BA	AA	H	VH	BA

In here scores are determined as linguistic terms. Besides, because of the space constraints, we will give the next tables by representative lines.

Step 2: Aggregated decision matrix which expresses the average IVN decision matrix (A) is given in Table 8.

Step 3: Constructed aggregated weight matrix of criteria is given in Table 9.

Step 4-5: Constructed matrix of average criteria weights (AV) with regards to scores and the distance of positive and negative averages is given in Table 10.

Step 6-7-8: The steps are performed and the results are given in Table 11.

As a result of the steps, the ranking of the alternatives is $AL1 - Bagfas > AL2 - Gubretas > AL5 - Igdas > AL4 - Bagfs > AL3 - Gubrf$.

3.3 Sensitivity Analysis

Sensitivity analysis is conducted in order to measure the robustness of the results obtained from the applied method. The pattern that we develop for the sensitivity analysis is given in Table 13. By using this pattern, both the effects of the criteria on the results are measured and the changes of this effect are observed by using linguistic terms interval.

Table 12 gives the result of sensitivity analysis with respect to each criterion. When the resulting graphs of the sensitivity analysis are examined, the criterion affect to the final result is minimal and verifies the robustness of the proposed model's decisions.

3.4 Comparison of Interval-Valued Neutrosophic EDAS with Crisp EDAS and Crisp TOPSIS

The proposed method is compared with the other methods in the literature where are based on distance measured like EDAS and TOPSIS. Before comparison, the

Table 8. Aggregated decision matrix

	Type	AL1	…	AL5
C1	Cost	<[0,78, 0,85], [0,35, 0,46], [0,42, 0,52]>	…	<[0,84, 0,89], [0,33, 0,43], [0,36, 0,46]>
C2	Cost	<[0,86, 0,91], [0,33, 0,43], [0,39, 0,49]>	…	<[0,81, 0,88], [0,26, 0,37], [0,36, 0,45]>
C3	Benefit	<[0,81, 0,87], [0,38, 0,48], [0,41, 0,51]>	…	<[0,82, 0,88], [0,23, 0,34], [0,36, 0,44]>
Q1	Cost	<[0,79, 0,85], [0,37, 0,47], [0,4, 0,5]>	…	<[0,82, 0,89], [0,36, 0,46], [0,34, 0,44]>
Q2	Cost	<[0,84, 0,89], [0,44, 0,55], [0,48, 0,61]>	…	<[0,87, 0,92], [0,29, 0,4], [0,32, 0,41]>
Q3	Cost	<[0,87, 0,91], [0,27, 0,39], [0,28, 0,37]>	…	<[0,81, 0,88], [0,17, 0,29], [0,35, 0,42]>
Q4	Benefit	<[0,8, 0,86], [0,36, 0,46], [0,45, 0,55]>	…	<[0,86, 0,89], [0,33, 0,43], [0,36, 0,46]>
Q5	Cost	<[0,85, 0,9], [0,39, 0,49], [0,42, 0,53]>	…	<[0,86, 0,93], [0,42, 0,52], [0,27, 0,37]>
SD1	Cost	<[0,91, 0,95], [0,44, 0,55], [0,16, 0,32]>	…	<[0,79, 0,88], [0,33, 0,43], [0,36, 0,47]>
SD2	Benefit	<[0,6, 0,77], [0,27, 0,4], [0,42, 0,52]>	…	<[0,87, 0,92], [0,37, 0,47], [0,32, 0,43]>
SD3	Benefit	<[0,83, 0,88], [0,34, 0,44], [0,37, 0,47]>	…	<[0,81, 0,88], [0,23, 0,34], [0,36, 0,44]>
SD4	Benefit	<[0,83, 0,88], [0,3, 0,4], [0,43, 0,53]>	…	<[0,8, 0,88], [0,17, 0,29], [0,35, 0,42]>
ED1	Benefit	<[0,87, 0,91], [0,26, 0,37], [0,36, 0,45]>	…	<[0,78, 0,84], [0,37, 0,47], [0,4, 0,51]>
ED2	Cost	<[0,84, 0,89], [0,3, 0,42], [0,35, 0,45]>	…	<[0,85, 0,89], [0,25, 0,37], [0,3, 0,39]>
ED3	Benefit	<[0,87, 0,91], [0,21, 0,32], [0,37, 0,45]>	…	<[0,85, 0,92], [0,37, 0,47], [0,32, 0,43]>

Table 9. Linguistic weights and aggregated weights

	C1	C2	C3	Q1	Q2	Q3	Q4	Q5	SD1	SD2	SD3	SD4	ED1	ED2	ED3
DM1	AAI	HI	AAI	LI	HI	HI	AI	AI	CHI	HI	VHI	HI	LI	LI	CLI
DM2	VHI	HI	AI	BAI	AI	AAI	AAI	AI	VHI	VHI	VHI	CHI	LI	VLI	VLI
DM3	VHI	HI	HI	LI	AAI	AAI	VHI	AI	HI	LI	HI	HI	LI	AI	BAI
Aggregated weights	<[0,64, 0,76], [0,44, 0,56], [0,29, 0,41]>	<[0,61, 0,72], [0,44, 0,55], [0,33, 0,44]>	<[0,52, 0,62], [0,24, 0,36], [0,41, 0,5]>	<[0,37, 0,48], [0,4, 0,51], [0,56, 0,68]>	<[0,55, 0,64], [0,25, 0,38], [0,39, 0,48]>	<[0,55, 0,66], [0,37, 0,48], [0,39, 0,5]>	<[0,56, 0,66], [0,23, 0,36], [0,37, 0,47]>	<[0,5, 0,55], [0,11, 0,22], [0,44, 0,5]>	<[0,75, 1], [0,56, 0,68], [0,13, 0,3]>	<[0,6, 0,72], [0,48, 0,59], [0,33, 0,44]>	<[0,69, 0,81], [0,52, 0,63], [0,24, 0,35]>	<[0,71, 1], [0,51, 0,62], [0,17, 0,34]>	<[0,33, 0,44], [0,44, 0,55], [0,61, 0,72]>	<[0,34, 0,43], [0,34, 0,47], [0,6, 0,69]>	<[0,21, 0,35], [0,53, 0,64], [0,7, 0,83]>

Table 10. Average solutions of criteria and distances

Criterion	Average Solution (AV)	Positive distance from AV	AL1	…	AL5	Negative distance from AV	AL1	…	AL5
C1 Cost	<[0.41, 0.58], [0.5, 0.58], [0.51, 0.63]>		<[-6.8, -10.04], [-12.45, -14.53], [12.11, 6.4]>	…	<[5.43, -2.47], [-12.45, -14.53], [-2.42, -8.13]>		<[6.8, 10.04], [12.45, 14.53], [-12.11, -6.4]>	…	<[-5.43, 2.47], [12.45, 14.53], [2.42, 8.13]>
C2 Cost	<[0.7, 0.72], [0.3, 0.39], [0.39, 0.48]>		<[-2.82, -3.81], [-2.42, -3.16], [0.64, -0.75]>	…	<[-2.45, -3.24], [-2.28, -3.15], [-0.47, -1.88]>		<[2.82, 3.81], [2.42, 3.16], [-0.64, 0.75]>	…	<[2.45, 3.24], [2.28, 3.15], [0.47, 1.88]>
C3 Benefit	<[0.41, 0.58], [0.5, 0.58], [0.51, 0.63]>		<[8.14, 12.02], [16.61, 18.16], [11.06, 14.67]>	…	<[3.15, 7.6], [16.61, 18.16], [18.21, 20]>		<[-8.14, -12.02], [-16.61, -18.16], [-11.06, -14.67]>	…	<[-3.15, -7.6], [-16.61, -18.16], [-18.21, -20]>
Q1 Cost	<[0.69, 0.73], [0.34, 0.43], [0.38, 0.48]>		<[-2.55, -3.88], [-3.09, -3.92], [0.66, -0.97]>	…	<[-2.97, -3.82], [-3.54, -4.39], [-0.26, -2.03]>		<[2.55, 3.88], [3.09, 3.92], [-0.66, 0.97]>	…	<[2.97, 3.82], [3.54, 4.39], [0.26, 2.03]>
Q2 Cost	<[0.69, 0.72], [0.31, 0.4], [0.41, 0.5]>		<[-2.61, -3.76], [-3.49, -4.3], [0.16, -1.51]>	…	<[-2.85, -3.76], [-2.71, -3.67], [0.26, -1.3]>		<[2.61, 3.76], [3.49, 4.3], [-0.16, 1.51]>	…	<[2.85, 3.76], [2.71, 3.67], [-0.26, 1.3]>
Q3 Cost	<[0.68, 0.71], [0.26, 0.36], [0.4, 0.49]>		<[-2.59, -3.4], [-1.83, -2.65], [1.4, 0.23]>	…	<[-2.44, -2.91], [-1.78, -2.44], [-0.23, -1.35]>		<[2.59, 3.4], [1.83, 2.65], [-1.4, -0.23]>	…	<[2.44, 2.91], [1.78, 2.44], [0.23, 1.35]>
Q4 Benefit	<[0.66, 0.69], [0.34, 0.43], [0.41, 0.51]>		<[2.89, 4.44], [6, 6.84], [6.41, 7.35]>	…	<[3.09, 4.39], [6.17, 7], [6.8, 7.69]>		<[-2.89, -4.44], [-6, -6.84], [-6.41, -7.35]>	…	<[-3.09, -4.39], [-6.17, -7], [-6.8, -7.69]>
Q5 Cost	<[0.69, 0.73], [0.34, 0.43], [0.37, 0.48]>		<[-3.13, -4.45], [-3.24, -4.1], [0.51, -1.33]>	…	<[-2.92, -4.24], [-4.34, -5.18], [-0.54, -2.56]>		<[3.13, 4.45], [3.24, 4.1], [-0.51, 1.33]>	…	<[2.92, 4.24], [4.34, 5.18], [0.54, 2.56]>
SD1 Cost	<[0.7, 0.72], [0.31, 0.4], [0.38, 0.48]>		<[-3.27, -4.4], [-3.39, -4.17], [2.46, 0.43]>	…	<[-2.32, -3.42], [-3.27, -4.06], [-0.81, -2.48]>		<[3.27, 4.4], [3.39, 4.17], [-2.46, -0.43]>	…	<[2.32, 3.42], [3.27, 4.06], [0.81, 2.48]>
SD2 Benefit	<[0.65, 0.69], [0.32, 0.41], [0.42, 0.51]>		<[0.74, 2.85], [2.63, 3.36], [-0.73, 0.84]>	…	<[2.99, 3.85], [3.91, 4.75], [-0.05, 1.72]>		<[-0.74, -2.85], [-2.63, -3.36], [0.73, -0.84]>	…	<[-2.99, -3.85], [-3.91, -4.75], [0.05, -1.72]>
SD3 Benefit	<[0.71, 0.74], [0.33, 0.42], [0.35, 0.44]>		<[3.02, 4.15], [2.61, 3.38], [-0.52, 0.97]>	…	<[2.85, 3.7], [2.54, 3.23], [0.95, 2.39]>		<[-3.02, -4.15], [-2.61, -3.38], [0.52, -0.97]>	…	<[-2.85, -3.7], [-2.54, -3.23], [-0.95, -2.39]>
SD4 Benefit	<[0.68, 0.71], [0.29, 0.38], [0.41, 0.5]>		<[2.41, 3.46], [2.21, 2.95], [-0.49, 0.89]>	…	<[2.27, 3.11], [2.15, 2.8], [0.17, 1.41]>		<[-2.41, -3.46], [-2.21, -2.95], [0.49, -0.89]>	…	<[-2.27, -3.11], [-2.15, -2.8], [-0.17, -1.41]>
ED1 Benefit	<[0.71, 0.73], [0.33, 0.42], [0.38, 0.48]>		<[3.13, 4.21], [2.61, 3.3], [-0.91, 0.54]>	…	<[2.41, 3.2], [3.52, 4.34], [0.96, 2.64]>		<[-3.13, -4.21], [-2.61, -3.3], [0.91, -0.54]>	…	<[-2.41, -3.2], [-3.52, -4.34], [-0.96, -2.64]>
ED2 Cost	<[0.66, 0.71], [0.34, 0.43], [0.37, 0.46]>		<[-3.22, -4.36], [-2.86, -3.65], [0.99, -0.64]>	…	<[-3.27, -4.12], [-2.86, -3.67], [0.16, -1.51]>		<[3.22, 4.36], [2.86, 3.65], [-0.99, 0.64]>	…	<[3.27, 4.12], [2.86, 3.67], [-0.16, 1.51]>
ED3 Benefit	<[0.66, 0.71], [0.3, 0.4], [0.37, 0.47]>		<[3.02, 4.01], [2.27, 2.96], [-0.7, 0.58]>	…	<[2.92, 3.87], [3.32, 4.1], [0.14, 1.72]>		<[-3.02, -4.01], [-2.27, -2.96], [0.7, -0.58]>	…	<[-2.92, -3.87], [-3.32, -4.1], [-0.14, -1.72]>

Table 11. Deneutrosoficated results of the alternatives

	AL1	AL2	AL3	AL4	AL5
sp	<[−3.15, −3.01], [9.28, 8.13], [28.1, 24.7]>	<[3.22, 0.39], [10.45, 9.72], [25.2, 21.21]>	<[4.41, 1.09], [9.37, 8.21], [22.96, 17.63]>	<[4.21, 1.3], [10.55, 9.62], [22.66, 18.16]>	<[3.91, 0.75], [10.51, 9.33], [23.59, 19.06]>
np	<[3.15, 3.01], [2.59, 3.74], [−16.23, −12.83]>	<[−3.22, −0.39], [1.42, 2.15], [−13.33, −9.34]>	<[−4.41, −1.09], [2.5, 3.65], [−11.09, −5.76]>	<[−4.21, −1.3], [1.32, 2.25], [−10.79, −6.29]>	<[−3.91, −0.75], [1.36, 2.54], [−11.72, −7.19]>
nsp	<[0.01, 0.01], [−0.03, −0.03], [−0.1, −0.08]>	<[−0.01, 0], [−0.04, −0.03], [−0.09, −0.07]>	<[−0.02, 0], [−0.03, −0.03], [−0.08, −0.06]>	<[−0.01, 0], [−0.04, −0.03], [−0.08, −0.06]>	<[−0.01, 0], [−0.04, −0.03], [−0.08, −0.07]>
nsn	<[0.19, 0.18], [0.15, 0.22], [−0.96, −0.76]>	<[−0.19, −0.02], [0.08, 0.13], [−0.79, −0.56]>	<[−0.26, −0.06], [0.15, 0.22], [−0.66, −0.34]>	<[−0.25, −0.08], [0.08, 0.13], [−0.64, −0.37]>	<[−0.23, −0.04], [0.08, 0.15], [−0.7, −0.43]>
as	<[0.1, 0.09], [0.06, 0.1], [−0.53, −0.42]>	<[−0.1, −0.01], [0.02, 0.05], [−0.44, −0.31]>	<[−0.14, −0.03], [0.06, 0.09], [−0.37, −0.2]>	<[−0.13, −0.04], [0.02, 0.05], [−0.36, −0.22]>	<[−0.12, −0.02], [0.02, 0.06], [−0.39, −0.25]>
$\mathfrak{D}(\mathrm{AL}_{\mathbf{J}})$	0.49	0.33	0.51	0.49	0.46
Rank	1	2	5	4	3

Table 12. Result of the sensitivity analysis

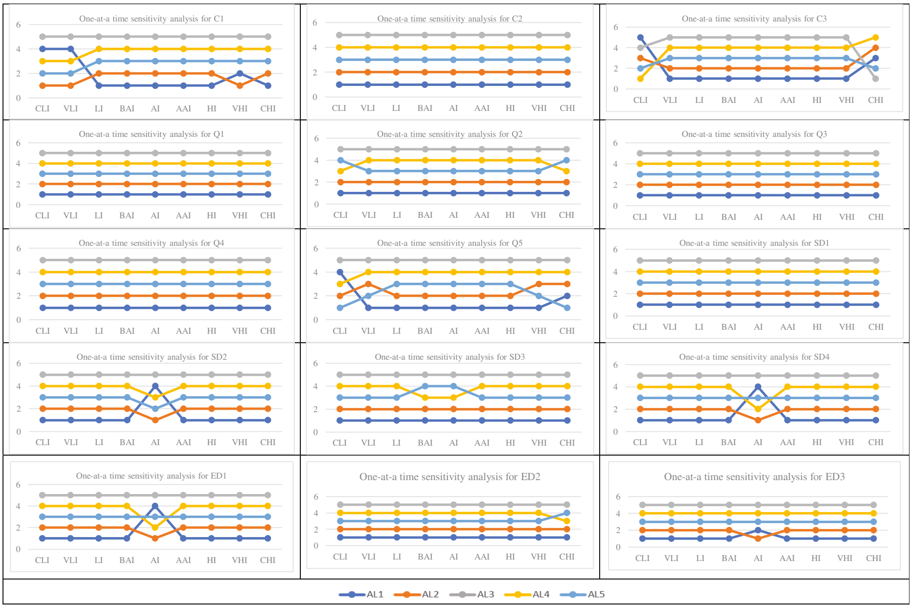

Table 13. Developed pattern for the sensitivity analysis

Pattern		Sets with respect to criteria			
		Set 1	Set 2	…	Set m
Test variables	CLI	Ranks	…	…	Ranks
	VLI	⋮	…	⋱	⋮
	LI	⋮	…	⋱	⋮
	BAI	⋮	…	⋱	⋮
	AI	⋮	…	⋱	⋮
	AAI	⋮	…	⋱	⋮
	HI	⋮	…	⋱	⋮
	VHI	⋮	…	⋱	⋮
	CHI	Ranks	…	…	Ranks

Table 14. Decision matrix of EDAS and TOPSIS methods

Decision matrix				Alternatives				
				AL1	AL2	AL3	AL4	AL5
Criteria	C1	0.333	Cost	0.3	0.1	0.1	0.1	0.1
	C2	0.319	Cost	0.4	0.5	0.3	0.4	0.4
	C3	0.387	Benefit	0.3	0.1	0.1	0.1	0.1
	Q1	0.218	Cost	0.4	0.4	0.3	0.3	0.3
	Q2	0.394	Cost	0.3	0.5	0.3	0.3	0.4
	Q3	0.328	Cost	0.5	0.3	0.4	0.3	0.5
	Q4	0.415	Benefit	0.4	0.5	0.2	0.3	0.3
	Q5	0.44	Cost	0.4	0.5	0.3	0.3	0.3
	SD1	0.311	Cost	0.4	0.4	0.3	0.4	0.3
	SD2	0.296	Benefit	0.4	0.4	0.3	0.3	0.3
	SD3	0.303	Benefit	0.4	0.4	0.3	0.3	0.4
	SD4	0.343	Benefit	0.4	0.4	0.3	0.3	0.5
	ED1	0.181	Benefit	0.5	0.4	0.3	0.3	0.3
	ED2	0.216	Cost	0.5	0.4	0.2	0.3	0.4
	ED3	0.105	Benefit	0.5	0.3	0.3	0.4	0.3

aggregated criteria weights and the aggregated decision matrix have been deneutrosophicated. The aggregated criteria weights and the aggregated decision matrix are given in Table 14 for both EDAS and TOPSIS method.

After the calculations, the results of the inter-steps of EDAS and TOPSIS methods are given in Tables 15 and 16, respectively.

Table 15. Results of the inter-steps of EDAS

	AL1	AL2	AL3	AL4	AL5
sp	0.11	−0.22	0.08	−0.02	0.05
nsp	1.00	−2.02	0.69	−0.16	0.49
np	−0.11	0.22	−0.08	0.02	−0.05
nsn.	−0.50	1.00	−0.34	0.08	−0.24
as.	0.25	−0.51	0.17	−0.04	0.12

Table 16. Results of the inter-steps of TOPSIS

	S^-	S^*	C
AL1	0.2595	0.2124	0.5499
AL2	0.1994	0.2988	0.4002
AL3	0.2377	0.2644	0.4734
AL4	0.1753	0.2619	0.401
AL5	0.2053	0.2661	0.4355

After the final calculations, Table 17 gives the ranking of the alternatives wrespect to the applied techniques.

Table 17. Ranks of the alternatives with respect to comparison methods

Method	Ranking				
	AL1	AL2	AL3	AL4	AL5
Interval-Valued EDAS	1	2	5	4	3
Crisp EDAS	1	5	2	4	3
Crisp TOPSIS	1	5	2	4	3

When the results are compared, the best alternative rank is same, only the order of AL2 and AL3 is shifted in the Crisp EDAS and Crisp TOPSIS. These results determine the rustness of the proposed method.

4 Conclusion

EDAS has been extensively used for multi-criteria decision making problems in the literature since 2 years. Intuitionistic and type-2 fuzzy extensions of this method have been successfully applied to the solutions of various decision making problems. However, these extensions do not consider the indeterminacy degree of decision makers. The proposed interval-valued neutrosophic EDAS considers degree of truthiness, degree of falsity and degree of indeterminacy in the same concept. A new deneutrosophication method has been developed in order to correspond to defuzzification in the fuzzy sets. Sensitivity analyses showed that the decision made by the proposed method is quite robust. The proposed method is also compared with the Crisp EDAS and Crisp TOPSIS. The best alternative in each technique remains same. These comparisons are also another indication of the validity of our proposed method.

For further research, the other types of neutrosophic sets such as, simplified neutrosophic sets, triangular neutrosophic sets, or trapezoidal neutrosophic sets can be used instead of interval-valued neutrosophic sets in developing neutrosophic EDAS method. Also, the proposed deneutrosophication technique and the subtraction operation can be extended other types of neutrosophic sets those are mentioned above.

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