Article

A Bipolar Neutrosophic Multi Criteria Decision Making Framework for Professional Selection

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Abstract: Professional selection is a significant task for any organization that aims to select the most appropriate candidates to fill well-defined vacancies up. In the recruitment process, various individual characteristics are involved, such as leadership, analytical skills, independent thinking, innovation, stamina and personality, ambiguity and imprecision. It outlines staff contribution and therefore plays a significant part in human resources administration. Additionally, in the era of the Internet of Things and Big Data (IoTBD), professional selection would face several challenges not only to the safe selection and security but also to make wise and prompt decisions especially in the large-scale candidates and criteria from the Cloud. However, the process of professional selection is often led by experience, which contains vague, ambiguous and uncertain decisions. It is therefore necessary to design an efficient decision-making algorithm, which could be further escalated to IoTBD. In this paper, we propose a new hybrid neutrosophic multi criteria decision making (MCDM) framework that employs a collection of neutrosophic analytical network process (ANP), and order preference by similarity to ideal solution (TOPSIS) under bipolar neutrosophic numbers. The MCDM framework is applied for chief executive officer (CEO) selection in a case study at the Elsewedy Electric Group, Egypt. The proposed approach allows us to assemble individual evaluations of the decision makers and therefore perform accurate personnel selection. The outcomes of the proposed method are compared with those of the related works such as weight sum model (WSM), weight product model (WPM), analytical hierarchy process (AHP), multi-objective optimization based on simple ratio analysis (MOORA) and ANP methods to prove and validate the results.

1. Introduction

Human resources are considered as one of the most important assets for an organization to improve its advantages of real wealth in knowledge economy [1,2]. The interest of organizations and large institutions in human capitals contributes to significant investment. Therefore, many organizations give a clear interest in the process of personnel selection to represent a positive turning point in relation to the organization, relying on them to achieve growth rates; thus supporting in the acquisition of the entire business sector in which the company is located, determining the input quality of human resources and personnel recruitments and choosing directly [3]. Personnel selection

is the procedure of selecting candidates who accord the desired employees and match the skills, knowledge and experience for the respective jobs [4]. Certainly, one of the major causes for the down grade of performance and the productivity of the enterprise is due to poor personnel selection. Inappropriate choices affect not only the level of the individual, but also the production [5–8].

Personnel selection is complicated in the real world, as decision makers tend to decide and forecast based on the qualitative methods, such as interviewing the candidates and knowing them well through conversations and group activities. In contrast, they may have poor judgment on the team and individual performance based on their quantitative metrics, such as productivity, outputs of their contributions and so on. Most often, there are vague expressions and imprecise terms used throughout the process that can make the judgment imprecise and investment on human capitals less productive. To make this forward, a neutrosophic theory is usually applied in decision problems. Neutrosophic research has been well established and demonstrated in supplier selection [9], developing supplier selection criteria [10,11], smart medical device selection [12] or quantifying risks in supply chain [13]. A neutrosophic set is also used to solve complex problems and design interrelationships and interdependencies among criteria and alternatives.

In real life, personnel selection is a Multi-Criteria Decision Making (MCDM) problem, and from the MCDM perspective, it has attracted the attention of many researchers [14]. Jasemi et al. [15] used a new fuzzy ELimination Et Choix Traduisant la REalité (ELECTRE) method for personnel selection. Karabasevic et al. [16] presented an approach for the selection of personnel. Ji et al. [17] used multi-valued neutrosophic sets with a projection-based difference measurement in an acronym in Portuguese for Interactive and Multicriteria Decision Making (TODIM) method. A collection of extensions of the order preference by similarity to ideal solution by Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for personnel selection using the interval neutrosophic set has been presented in [18]. Pramanik et al. [19] raised the idea of personal biases in decision making. Personnel selection for IT using Evaluation based on Distance from Average Solution (EDAS) has been demonstrated by [20]. Apart from these researches, other researchers' works could be found in the literature.

Based on the observation, the hybridization could offer better results than the standalone method. The objective of this study is to develop a decision-making approach to a multiple information sources problem, which enables us to incorporate neutrosophic data represented as linguistic variables or bipolar neutrosophic numbers into the analysis, and disregards the troublesome neutrosophic number ranking process that may yield inconsistent results when different ranking methods are used.

In this paper, we propose a new hybrid neutrosophic multi criteria decision making (MCDM) framework that employs a collection of neutrosophic analytical network process (ANP), and order preference by similarity to ideal solution (TOPSIS) under bipolar neutrosophic numbers. This paper hence aims at extending the neutrosophic ANP–TOPSIS for linguistic reasoning under decision making. The extended neutrosophic ANP–TOPSIS is applied for solving a personnel selection problem. Here, neutrosophic ANP can be applied to handle the difficulty of dependency in the problem, in addition to feedback between each quantification criteria. TOPSIS is lastly used to find the best alternative or candidate for professional selection. The MCDM framework is applied for chief executive officer (CEO) selection in a case study at the Elsewedy Electric Group, Egypt. The proposed approach allows us to assemble individual evaluations of the decision makers and therefore perform stronger personnel selection procedures. The outcomes of the proposed method are compared with those of the related works such as weight sum model (WSM), weight product model (WPM), analytical hierarchy process (AHP), multi-objective optimization based on simple ratio analysis (MOORA) and ANP methods to prove and validate the results.

The article is planned as follows: Section 2 presents the literature review. Section 3 describes the background theory including some inceptions on bipolar neutrosophic numbers and proposed model. Section 4 describes a case study to approve the practicality of the ANP–TOPSIS method. Section 5 provides the comparative results. In Section 6, a sensitivity analysis is recognized. Lastly, we conclude our research with some observations.

2. Literature Review

ANP is an inclusive decision-making approach that depends on the dependency between criteria [21]. ANP is an extension for analytical hierarchy process (AHP). By pairwise comparisons, weights or priorities are determined as in AHP. The priority determined to each prospect and criterion may be predestined subjectively by decision makers (DMs), or from the data. ANP provides a scale by the consistency ratio (CR), which is a pointer of the dependability of the method or model, and it is preferred to measure the CR of the DMs' comparison judgment. The CR is determined in such a way that the ratio equals 0.1, denoting compatible judgment, in the case that the ratio overrides 0.1, it denotes incompatible judgment [22]. ANP works for complicated interrelationships between rules, decisions and attributes [21]. ANP method can solve complex problems as in Figure 1.
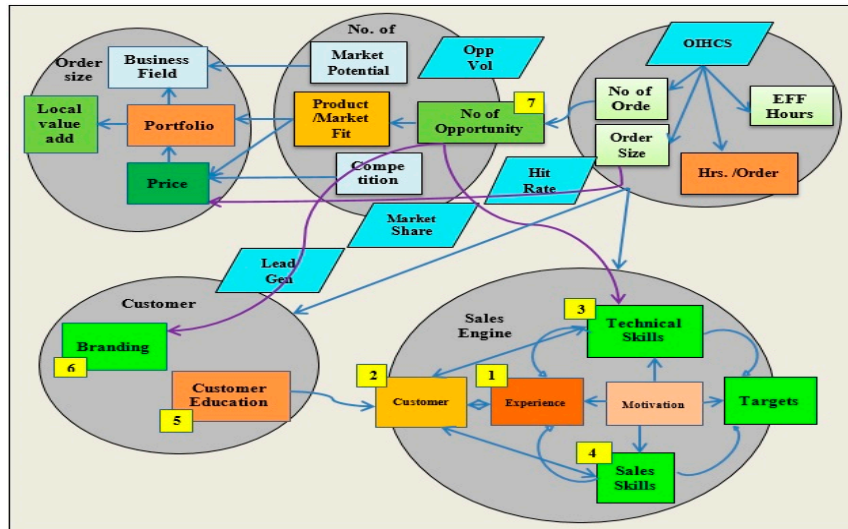
Figure 1. Complex decision problem by the analytical network process (ANP) method.

The ANP method structure allows for feedback and enables us to deal with direct and indirect problems, as in Figure 2. In the ANP method, the relationships and interrelationships among criteria, sub criteria and alternatives cannot be simply designed as direct or indirect, predominant or subsidiary [23].
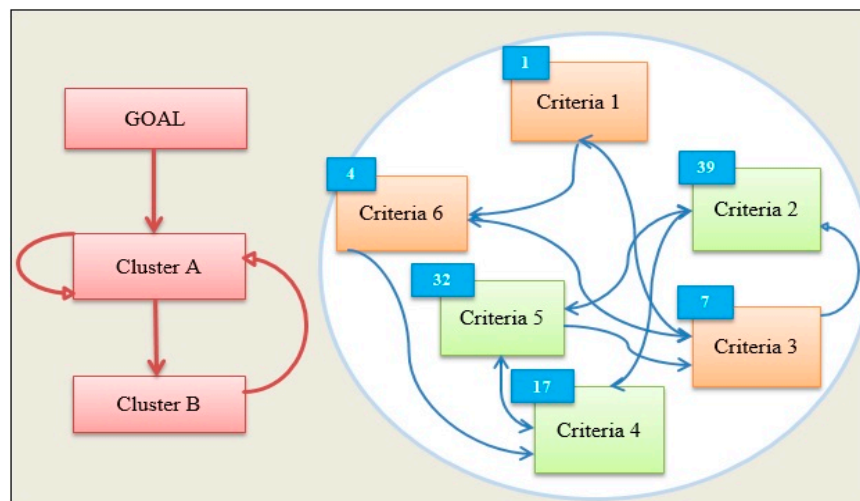

Figure 2. Feedback connections and loop in the ANP method.

TOPSIS depends on the idea that the preferable candidate should not just have the shortest path from the favorable ideal solution, but also has the longest path from the negative ideal solution [24]. The preferable candidate would be the one that is closest to the positive ideal solution and furthest from the negative ideal solution, according to this method [25]. We show that TOPSIS depends on Euclidean distance as in Figure 3.
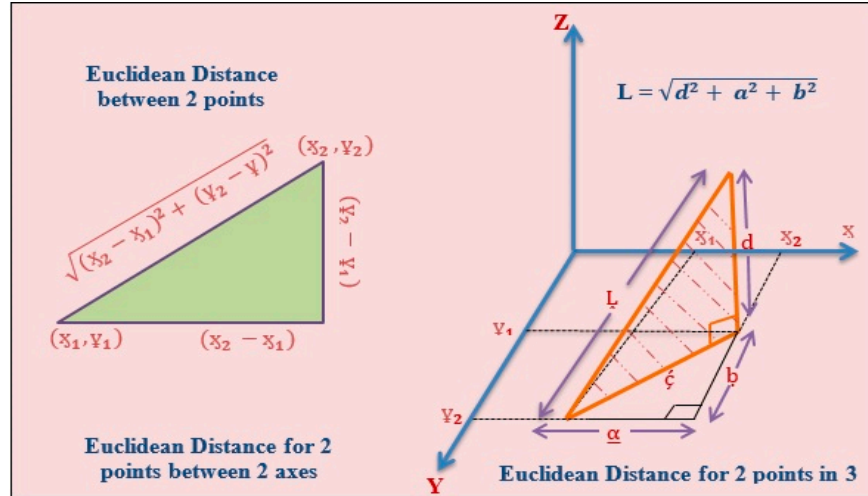

Figure 3. Euclidean distance in the order preference by similarity to ideal solution (TOPSIS) method.

3. Proposed Methodology

In this section, we proposed definitions of bipolar neutrosophic set (BNS), score, accuracy and certainty functions [26–30].

Definition 2.1: A BNS A in X is defined as an object of the form A = {⟨x, $T^+(x)$, $I^+(x)$, $F^+(x)$, $T^-(x)$, $I^-(x)$, $F^-(x)$ ⟩: x ∈ X}, where T^+, I^+, F^+ : X→ [1, 0] and T^-, I^-, F^-: X → [-1, 0]. The certain membership standards $T^+(x)$, $I^+(x)$,$F^+(x)$ denote the truth, indeterminate and falsity memberships of a component x ∈ X corresponding to a BNS A, and the uncertain membership standards $T^-(x)$, $I^-(x)$ and $F^-(x)$ denote the truth, indeterminate and falsity memberships of an element x ∈ X to some implicit counter property corresponding to a BNS A.

Definition 2.2: Let A_1 = {⟨ x, $T_1^+(x)$, I_1^+ (x), $F_1^+(x)$, $T_1^-(x)$, $I_1^-(x)$, $F_1^-(x)$ ⟩ and A_2 = {⟨ x, $T_2^+(x)$, I_2^+ (x), $F_2^+(x)$, $T_2^-(x)$, $I_2^-(x)$, $F_2^-(x)$ ⟩ be two bipolar neutrosophic numbers (BNNs). Then their union is distinct as: $(A_1 ∪ A_2)$ (x) = (max($T_1^+(x)$, $T_2^+(x)$), $\frac{I_1^+(x) + I_2^+(x)}{2}$, min(($F_1^+(x)$, $F_2^+(x)$), min($T_1^-(x)$, = $T_2^+(x)$),$\frac{I_1^-(x)+ I_2^-(x)}{2}$, max(($F_1^-(x)$, $F_2^-(x)$)) for all x ∈ X.

Definition 2.3: Let $\tilde{a}_1$ = ($T_1^+,I_1^+,F_1^+,T_1^-,I_1^-,F_1^-$) then $\tilde{a}_2$= ($T_2^+,I_2^+,F_2^+,T_2^-,I_2^-,F_2^-$) be two BNNs. After that the procedures for NNs are explained as follows:

$γ\tilde{a}_1$ =(1 − $(1 − T_1^+)^γ$, ⟨ $I_1^+)^γ$, ⟨ $F_1^+)^γ$, - ⟨− $T_1^-)^γ$,- ⟨− $I_1^-)^γ$, -⟨ 1 − $(1 − F_1^-))^γ$))

$\tilde{a}_1^γ$ =⟨ $(T_1^+)^γ$, 1 − $(1 − I_1^+)^γ$, 1 − $(1 − F_1^+)^γ$, -$(1 − (1 − T_1^-))^γ$),-($I_1^-)^γ$),-$(−F_1^-)^γ$)

$\tilde{a}_1 + \tilde{a}_2$ = ($T_1^++T_2^+- T_1^+ T_2^+,I_1^+ I_2^+,F_1^+ F_2^+,− T_1^- T_2^-$, - (- $I_1^-- I_2^-$ - $I_1^- I_2^-$),-(- $F_1^-- F_2^-$ - $F_1^- F_2^-$))

$\tilde{a}_1.\tilde{a}_2$ = ($T_1^+ T_2^+,I_1^++I_2^+$ - $I_1^+ I_2^+$ + $F_1^+ + F_2^+$ - $F_1^+ F_2^+$, - (- $T_1^-- T_2^-$ - $T_1^- T_2^-$), - $I_1^- I_2^-$, - $F_1^- F_2^-$) when **γ**> 0.

Definition 2.4: Let $\tilde{a}_1$= ($T_1^+,I_1^+,F_1^+,T_1^-,I_1^-,F_1^-$) be a BNN. Then, the score, accuracy and certainty functions $P(\tilde{a}_1)$, $A(\tilde{a}_1)$ and $C(\tilde{a}_1)$ respectively, of an NBN are well-defined as below:

$$\widetilde{P}(\tilde{a}_1) = (T_1^+ + 1 - I_1^+ +1 - F_1^+ + 1 + T_1^- - I_1^- - F_1^-) / 6 \tag{1}$$

$$\widetilde{A}(\tilde{a}_1) = T_1^+ - F_1^+ + T_1^- - F_1^- \tag{2}$$

$$\tilde{C}(\tilde{a}_1) = T_1^+ - F_1^- \tag{3}$$

Definition 2.5: Let $\tilde{a}_1 = (T_1^+, I_1^+, F_1^+, T_1^-, I_1^-, F_1^-)$ and $\tilde{a}_2 = (T_2^+, I_2^+, F_2^+, T_2^-, I_2^-, F_2^-)$ be two BNNs. We will present the comparisons as follows:

if $\widetilde{P}(\tilde{a}_1) > \widetilde{P}(\tilde{a}_2)$, then $\tilde{a}_1 > \tilde{a}_2$;
$\widetilde{P}(\tilde{a}_1) = \widetilde{P}(\tilde{a}_2)$ and $\widetilde{A}(\tilde{a}_1) > \widetilde{A}(\tilde{a}_2)$, then $\tilde{a}_1 > \tilde{a}_2$;
if $\widetilde{P}(\tilde{a}_1) = \widetilde{P}(\tilde{a}_2), \widetilde{A}(\tilde{a}_1) = \widetilde{A}(\tilde{a}_2)$ and $\tilde{C}(\tilde{a}_1) > \tilde{C}(\tilde{a}_2)$, then $\tilde{a}_1 > \tilde{a}_2$;
if $\widetilde{P}(\tilde{a}_1) = \widetilde{P}(\tilde{a}_2), \widetilde{A}(\tilde{a}_1) = \widetilde{A}(\tilde{a}_2)$ and $\tilde{C}(\tilde{a}_1) > \tilde{C}(\tilde{a}_2)$, then $\tilde{a}_1 = \tilde{a}_2$.

Definition 2.6: Let $\tilde{a}_j = (T_j^+, I_j^+, F_j^+, T_j^-, I_j^-, F_j^-)$ (j = 1, 2,…,n) be a collection of BNNs. A mapping A_w: $Q_n \to Q$ is named bipolar neutrosophic weighted average factor if it fulfills the condition:

$$A_w(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \sum_{j=1}^{n} w_j \tilde{a}_j = \langle 1 - \prod_{j=1}^{n} (1 - T_j^+)^{w_j}, \prod_{j=1}^{n} I_j^{+w_j}, \prod_{j=1}^{n} F_j^{+w_j}, - \prod_{j=1}^{n} (-T_j^-)^{w_j}, - \prod_{j=1}^{n} (-I_j^-)^{w_j}, - (1 - \prod_{j=1}^{n} (1 - (-F_j^-))^{w_j})),$$

when w_j is the weight of $\tilde{a}_j$ (j = 1,2, …,n), $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$.

Then, the steps of the suggested ANP with TOPSIS under neutrosophic environment are presented in details. Illustration of the suggested technique for CEO selection is exhibited in Figure 4.

Step 1. Build the structure of a problem.

The problem or issue should be obviously pointed, and the hierarchy framework established. The hierarchy framework can be designed by DMs' judgments via exchanges of ideas or other suitable techniques, as shown in literature reviews.

Step 2. Estimate of the criteria priority using the pairwise comparisons.

The committee comprises the DMs, collecting pairwise comparisons to determine the proportional weight of criteria and perspectives. In pairwise comparisons, we depended on the scale exhibited in Table 1. In the comparison matrix, the result of a_{ij} illustrates the relative significance of the element on row (*i*) over the element on column (*j*), i.e., $a_{ij} = w_i/w_j$. The reciprocal value of the term $\frac{1}{a_{ij}}$, which we replaced by $1/\Delta$ in our comparison matrices, was utilized when the element (*j*) was more significant than the element (*i*). The comparison judgment matrix A is outlined below:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} = \begin{bmatrix} 0.5 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 0.5 & \cdots & a_{2n} \\ \vdots & \vdots & 0.5 & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 0.5 \end{bmatrix} \tag{4}$$

Table 1. Indications expression for the significance weight of all criteria.

Linguistic Expressions	Bipolar Neutrosophic Numbers Scale for Proportional Significance of Comparison Matrix [$T^+(x)$, $I^+(x)$, $F^+(x)$, $T^-(x)$, $I^-(x)$, $F^-(x)$]
Absolutely Significant (AS)	[0.90, 0.10, 0.10, - 0.40, - 0.80, - 0.90]

Very Highly Significant (VHS)	[0.80, 0.50, 0.50, - 0.30, - 0.80, - 0.80]
Equally Significant (ES)	[0.50, 0.50, 0.50, - 0.50, - 0.50, - 0.50]
Significant (S)	[0.40, 0.20, 0.70, - 0.50, - 0.20, - 0.10]
Almost Significant (ALS)	[0.10, 0.80, 0.70, - 0.90, - 0.20, - 0.10]

Step 3. Build the super matrix.

The acquired vectors are normalized to explain the native priority vector. The super matrix is constructed, and the native priority vectors are entered in the suitable columns of the matrix of impact between the components, to gain comprehensive weights. The super matrix is formed of three stages as follows:

$$
w = \begin{matrix} & \begin{matrix} G & C & A \end{matrix} \\ \begin{matrix} \text{Goal (G)} \\ \text{Criteria (C)} \\ \text{Alternative (A)} \end{matrix} & \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & w_{22} & 0 \\ 0 & w_{32} & I \end{bmatrix} \end{matrix} \tag{5}
$$

Zero in the super matrix can be exchanged by a matrix if there is an interdependency of components in a group or among to groups. I is the symmetry matrix, w_{21} illustrates the influence of the goal on the criteria, w_{22} illustrates the influence of the interrelationships between criteria and w_{32} illustrates the influence of criteria on each of substitutions.

Step 4. Construct the weighted super matrix.

The obtained eigenvector from the pairwise comparison matrix of the row clusters with esteem to the column cluster, which in transformation yields an eigenvector for each column cluster.

In physical situations, DMs cannot present their decisions about confirmed characteristics, like being healthy, etc. So, we defined neutrosophic scales and measures. In our application, BNNs, as in Table 1, were applied by DMs to indicate their judgments to compare characteristics and attributes to determine the priorities of criteria. In the suggested approach, pairwise comparison judgments are created with the aid of BNNS, and the neutrosophic ANP is utilized to settle the problem of personnel selection. The neutrosophic ANP can simply accommodate interdependencies existent between the activities. The notion of super matrices is used to acquire the composite priorities that cope with the existent interdependencies [31,32]. We use BNNs $[T^+(x),\ I^+(x),\ F^+(x),\ T^-(x),\ I^-(x),\ F^-(x)]$ to construct pairwise comparison matrices, the neutrosophic matrix being constructed as follows:

$$
\tilde{A} = \begin{bmatrix} a_{11}{}^{T^+}, a_{11}{}^{I^+}, a_{11}{}^{F^+}, a_{11}{}^{T^-}, a_{11}{}^{I^-}, a_{11}{}^{F^-}\rangle & \cdots & \cdots & a_{1n}{}^{T^+}, a_{1n}{}^{I^+}, a_{1n}{}^{F^+}, a_{1n}{}^{T^-}, a_{1n}{}^{I^-}, a_{1n}{}^{F^-}\rangle \\ a_{21}{}^{T^+}, a_{21}{}^{I^+}, a_{21}{}^{F^+}, a_{21}{}^{T^-}, a_{21}{}^{I^-}, a_{21}{}^{F^-}\rangle & \cdots & \cdots & a_{2n}{}^{T^+}, a_{2n}{}^{I^+}, a_{2n}{}^{F^+}, a_{2n}{}^{T^-}, a_{2n}{}^{I^-}, a_{2n}{}^{F^-}\rangle \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1}{}^{T^+}, a_{n1}{}^{I^+}, a_{n1}{}^{F^+}, a_{n1}{}^{T^-}, a_{n1}{}^{I^-}, a_{n1}{}^{F^-}\rangle & \cdots & \cdots & a_{nn}{}^{T^+}, a_{nn}{}^{I^+}, a_{nn}{}^{F^+}, a_{nn}{}^{T^-}, a_{nn}{}^{I^-}, a_{nn}{}^{F^-}\rangle \end{bmatrix} \tag{6}
$$

The pairwise comparison matrix $\tilde{A}$ is supposed as reciprocal

$$
\tilde{A} = \begin{bmatrix} 0.5, 0.5, 0.5, - 0.5, - 0.5, - 0.5\rangle & & a_{1n}{}^{T^+}, a_{1n}{}^{I^+}, a_{1n}{}^{F^+}, a_{1n}{}^{T^-}, a_{1n}{}^{I^-}, a_{1n}{}^{F^-}\rangle \\ \frac{1}{\Delta_{21}} & 0.5 & a_{2n}{}^{T^+}, a_{2n}{}^{I^+}, a_{2n}{}^{F^+}, a_{2n}{}^{T^-}, a_{2n}{}^{I^-}, a_{2n}{}^{F^-}\rangle \\ \vdots & & \vdots \\ \frac{1}{\Delta_{n1}} & & 0.5, 0.5, 0.5, - 0.5, - 0.5, - 0.5\rangle \end{bmatrix} \tag{7}
$$

The ANP method can be applied to compute the priority of criteria and rank of the alternatives. In the suggested technique, neutrosophic ANP will be applied only to compute the weights of the criteria. Equation (8) will be applied to help neutrosophic TOPSIS for ranking the candidates.

$$
w = \begin{bmatrix} 0 & 0 \\ w_{21} & w_{22} \end{bmatrix} \tag{8}
$$

Step 5. Determine the linguistic valuations $\widetilde{X} = \{\tilde{x}_{ij}, i = 1, 2, 3, \ldots, n, j = 1, 2, 3, \ldots, j\}$ for alternatives with regard to criteria and construct matrix as in Equation (9). Bipolar neutrosophic numbers, as in Table 2, have also been used by DMs to indicate their judgments on the alternatives according to each criterion. The linear measure conversion is utilized here to convert the different criteria measures into comparable measures to avert difficulty of mathematical procedures in a decision process.

The trouble can be presented by the next sets:

A collection of j potential applicant described $A = \{A_1, A_2, A_3, \ldots, A_j\}$;

A collection of n criteria, $C = \{C_1, C_2, C_3, \ldots, C_i\}$;

A collection of performance valuations of A_j $(j = 1, 2, 3, \ldots, j)$ with regard to criteria C_j $(i = 1, 2, 3, \ldots, n)$ described $\tilde{X} = \{\tilde{x}_{ij}, i = 1, 2, 3, \ldots, n, j = 1, 2, 3, \ldots, j\}$;

A collection of significant priorities of every criterion $w_i = (i = 1, 2, 3, \ldots, n)$.

As mentioned, a professional selection issue can be briefly stated in matrix shape as follows:

$$\widetilde{X} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{j1} & \tilde{X}_{j2} & \cdots & \tilde{X}_{jn} \end{bmatrix} \tag{9}$$

Table 2. Linguistic expressions for valuation.

Linguistic Expressions	Bipolar Neutrosophic Numbers Scale for Proportional Significance of Comparison Matrix $[T^+(x), I^+(x), F^+(x), T^-(x), I^-(x), F^-(x)]$
Extremely Low (EL)	$[0.15, 0.90, 0.80, 0.65, -0.10, -0.10]$
Very Low (VL)	$[0.25, 0.70, 0.80, -0.55, -0.15, -0.30]$
Low (L)	$[0.30, 0.40, 0.60, -0.30, -0.20, -0.10]$
Medium (M)	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$
Perfect (P)	$[0.75, 0.20, 0.25, -0.25, -0.60, -0.50]$
Very Perfect (VP)	$[0.85, 0.15, 0.20, -0.20, -0.70, -0.90]$
Extremely Perfect (EP)	$[1.00, 0.00, 0.10, -0.10, -0.90, -1.00]$

Step 6. Construct the normalized matrix.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{10}$$

where i refers to the alternatives, j refers to the choosing criteria and X_{ij} refers to the i alternative under the j criterion to be evaluated.

Step 7. Build the weighted united assessment matrix.

Priorities of choosing criteria $w = (w_1, w_2, w_3, \ldots, w_n)$ multiplied by the normalized matrix, may be presented as

$$V = \begin{bmatrix} V_{11} & V_{12} & \cdots & V_{1n} \\ V_{21} & V_{22} & \cdots & V_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ V_{j1} & V_{j2} & \cdots & V_{jn} \end{bmatrix} = \begin{bmatrix} w_1V_{11} & w_2V_{12} & \cdots & w_nV_{1n} \\ w_1V_{21} & w_2V_{22} & \cdots & w_nV_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1V_{j1} & w_2V_{j2} & \cdots & w_nV_{jn} \end{bmatrix} \tag{11}$$

Step 8**.** Determine the positive and negative ideal solution.

We could define the neutrosophic positive ideal solution (NPIS, A^*) and the neutrosophic negative ideal solution (NNIS, A^-)

$$I^+ = \{V_1^*, V_2^*, \dots, V_j^*, \dots, V_n^*\} = \left\{\left(\max_j V_{ij} \mid j \in J\right) \mid i = 1, \dots, m\right\}, \tag{12}$$

$$I^- = \{V_1^-, V_2^-, \dots, V_j^-, \dots, V_n^-\} = \left\{\left(\min_j V_{ij} \mid j \in J\right) \mid i = 1, \dots, m\right\}, \tag{13}$$

Step 9. Compute the Euclidean distance between the positive ideal solution (D^*_i) and negative ideal solution (D^-_i) for all alternatives.

$$D^*_i = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^*)^2}, \quad i = 1, 2, \dots, m, \tag{14}$$

$$D^-_i = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^-)^2}, \quad i = 1, 2, \dots, m, \tag{15}$$

Step 10. Compute the proportional closeness to the positive ideal solution for each alternative. A closeness coefficient is outlined to locate the classification order of all potential alternatives where D^*_i and D^-_i of each alternative A_j ($j = 1, 2, 3, \dots, j$) has been computed.

$$CC_i = \frac{D^-_i}{D^*_i + D^-_i}; \quad i = 1, 2, \dots, m \tag{16}$$

Rank the alternatives according to CC_i; major index values refer to the best selection of the alternatives.

4. Case Study

We presented a practical application to apply the suggested approach in real world problems. The case study was based on the Elsewedy Electric Group. The employment department needs to hire a new CEO every five years, according to Elsewedy Electric Group's policy. The judgment commission consists of three DMs. They recommend four candidates from all the applicants. The general criteria for selections are mentioned in Table 3. The criteria were divided according to three factors, which were the physical factor, functional factor and personal factor.

The suggested technique for the professional selection difficult is comprised of neutrosophic ANP and neutrosophic TOPSIS techniques, composed of three major points: (1) determine the criteria to be utilized in the suggested approach, (2) neutrosophic ANP calculations and (3) valuation of appropriate applicant with neutrosophic TOPSIS, which we will divide into several steps:

Step 1. For the valuation process, the DMs decided to select 10 criteria for the selection of the CEO from four current alternatives (efficient managers).

Step 2. Determine the subordination among the criteria according to the group decision, as in Table 4.

Step 3. Establish the structure of the problem.

In our research, criteria could impact the goal with dependency for each other. The alternatives are also influenced by the criteria to confirm a dependency among the components of the problem. Obviously, the ANP method is more capable of dealing with the problem than AHP. We presented a schematic diagram of the problem in Figure 5.

Table 3. Criteria for CEO selection.

Factors	Criteria	A Shortened Form of a Phrase
Physical	C_1	Stamina and physical strength
	C_2	Good health
Functional	C_3	Leadership and analytical thinking ability

C_4	Communication skills
C_5	Being good at marketing
C_6	Sentimental stability
C_7	Self confidence
Personal C_8	Ability to work independently
C_9	Patience
C_{10}	Quietness

Table 4. Mutuality through criteria.

Subordinate Criteria	Relying On	Subordinate Criteria	Relying On
C_1	C_2, C_7, C_9	C_6	C_7, C_8, C_9, C_{10}
C_2	C_1, C_6, C_{10}	C_7	C_1, C_3, C_5
C_3	C_2, C_6, C_7, C_8	C_8	C_1, C_3, C_5, C_6
C_4	C_3, C_6, C_{10}	C_9	C_6, C_8, C_{10}
C_5	C_1, C_3, C_7	C_{10}	C_4, C_6, C_9
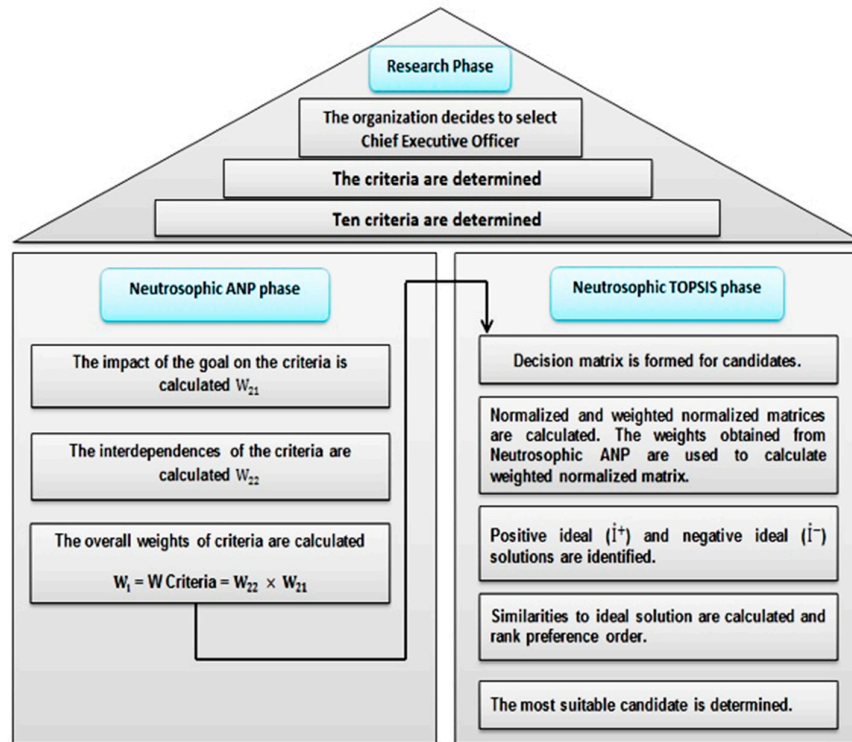
Figure 4. Suggested method.

Step 4. Construct the comparison matrices among criteria and calculate weights of the criteria

Using the scales mentioned previously in Table 1, we constructed the pairwise comparison matrix between criteria.

- We used Equation (1) to calculate the score value of linguistic terms.
- Computed the CR of the comparison matrices with less or equal 0.1.
- Computed W_{21} as presented in Table 5.
- Calculated the interdependences for criteria C_i $(i = 1, 2, 3, \ldots, 10)$ as exhibited in Tables 6–15.
- Constructed the pair-wise comparison for values of W_{22} as presented in Table 16.
- Constructed the weight matrix using Equation (8).
- We calculated the final weight of criteria by $W_{\text{criteria}} = W_{21} \times W_{22}$, as shown in Table 16 and exhibited in Figure 6.

Figure 5. The analytic network process model for selecting CEO.

Table 5. Pairwise discrimination for W_{21}.

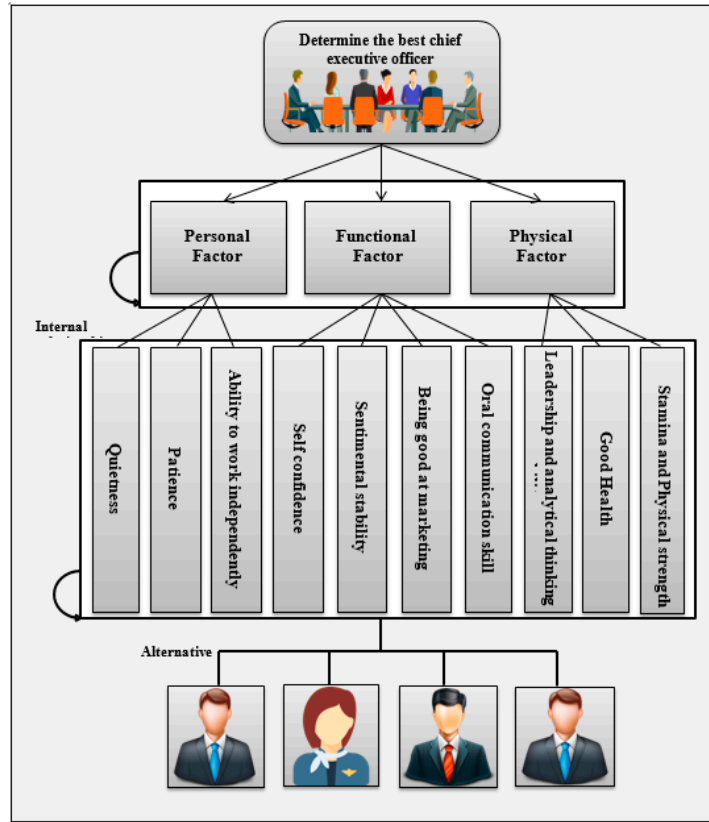|	Ci_1	Ci_2	Ci_3	Ci_4
Ci_1	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.5$	$1/_\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.1$	$1/_\Delta$
Ci_2	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.1$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.5$	$1/_\Delta$	$1/_\Delta$
Ci_3	$1/_\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.8$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.5$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.9$
Ci_4	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.9$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.1$	$1/_\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.5$
Ci_5	$1/_\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.8$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.9$	$1/_\Delta$
Ci_6	$1/_\Delta$	$1/_\Delta$	$1/_\Delta$	$1/_\Delta$
Ci_7	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.1$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.9$	$1/_\Delta$	$1/_\Delta$
Ci_8	$1/_\Delta$	$1/_\Delta$	$1/_\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.1$
Ci_9	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.5$	$1/_\Delta$	$1/_\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.1$
Ci_{10}	$1/_\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.8$	$1/_\Delta$	$1/_\Delta$

	Ci_5	Ci_6	Ci_7
Ci_1	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/_\Delta$
Ci_2	$1/_\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$1/_\Delta$
Ci_3	$1/_\Delta$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$
Ci_4	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$
Ci_5	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$
Ci_6	$1/_\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/_\Delta$
Ci_7	$1/_\Delta$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$
Ci_8	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	$1/_\Delta$	$1/_\Delta$
Ci_9	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/_\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$

	Ci_{10}			
	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$		$1/\Delta$

	Ci_8	Ci_9	Ci_{10}	N weight W_{21}
Ci_1	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.098
Ci_2	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	0.091
Ci_3	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	0.084
Ci_4	$1/\Delta$	$1/\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	0.094
Ci_5	$1/\Delta$	$1/\Delta$	$1/\Delta$	0.104
Ci_6	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	0.114
Ci_7	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	0.071
Ci_8	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	0.108
Ci_9	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	0.071
Ci_{10}	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.165

Table 6. Interior interdependencies matrix of factor C_1.

	Ci_2	Ci_7	Ci_9	W_{22}
Ci_2	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$1/\Delta$	0.23
Ci_7	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	0.43
Ci_9	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.34

The prior matrix a(CR) = 0.099.

Table 7. Interior interdependencies matrix of factor C_2.

	Ci_1	Ci_6	Ci_{10}	W_{22}
Ci_1	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	0.44
Ci_6	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.29
Ci_{10}	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.27

The prior matrix a(CR) = 0.020.

Table 8. Interior interdependencies matrix of factor C_3.

	Ci_2	Ci_6	Ci_7	Ci_8	W_{22}
Ci_2	$[0.50, 0.50, 0.50, -0.50, -0.50$	$[0.50, 0.50, 0.50, -0.50, -0.50$	$[0.80, 0.50, 0.50, -0.30, -0.80$	$1/\Delta$	0.16
Ci_6	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50$	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20$	0.31
Ci_7	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20$	$[0.50, 0.50, 0.50, -0.50, -0.50$	$1/\Delta$	0.26
Ci_8	$[0.90, 0.10, 0.10, -0.40, -0.80$	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20$	$[0.50, 0.50, 0.50, -0.50, -0.50$	0.27

The prior matrix a(CR) = 0.1.

Table 9. Interior interdependencies matrix of factor C_4.

	Ci_3	Ci_6	Ci_{10}	W_{22}
Ci_3	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	0.45
Ci_6	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.24
Ci_{10}	$1/\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.31

The prior matrix a(CR) = 0.1.

Table 10. Interior interdependencies matrix of factor C_5.

	Ci_1	Ci_3	Ci_7	W_{22}
Ci_1	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	0.38
Ci_3	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.29
Ci_7	$1/\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.33

The prior matrix a(CR) = 0.005.

Table 11. Interior interdependencies matrix of factor C_6.

	Ci_7	Ci_8	Ci_9	Ci_{10}	W_{22}
Ci_7	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	0.18
Ci_9	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	0.32
Ci_9	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.24
Ci_{10}	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.26

The prior matrix a(CR) = 0.1.

Table 12. Interior interdependencies matrix of factor C_7.

	Ci_1	Ci_3	Ci_5	W_{22}
Ci_1	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$1/\Delta$	0.23
Ci_3	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	0.43
Ci_5	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.34

The prior matrix a(CR) = 0.080.

Table 13. Interior interdependencies matrix of factor C_8.

	Ci_1	Ci_3	Ci_5	Ci_6	W_{22}
Ci_1	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	0.18
Ci_3	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	0.32
Ci_5	$1/\Delta$	$[0.40, 0.20, 0.70, -0.50, -0.20, -0.10]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.24
Ci_6	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$1/\Delta$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.26

The prior matrix a(CR) = 0.020.

Table 14. Interior interdependencies matrix of factor C_9.

	Ci_6	Ci_8	Ci_{10}	W_{22}
Ci_6	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	$[0.90, 0.10, 0.10, -0.40, -0.80, -0.90]$	0.45
Ci_8	$[0.10, 0.80, 0.70, -0.90, -0.20, -0.10]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.24
Ci_{10}	$1/\Delta$	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.31

The prior matrix a(CR) = 0.080.

Table 15. Interior interdependencies matrix of factor C_{10}.

	Ci_6	Ci_9	Neutrosophic weight W_{22}
Ci_6	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	$1/\Delta$	0.59
Ci_9	$[0.80, 0.50, 0.50, -0.30, -0.80, -0.80]$	$[0.50, 0.50, 0.50, -0.50, -0.50, -0.50]$	0.41

The prior matrix a(CR) = 0.005.

Step 5. Essentially, all the previous steps were within the neutrosophic ANP phase for calculating the weights of criteria. In the second stage of the study, the neutrosophic TOPSIS stage began by initiating neutrosophic valuations of alternatives candidates A_1, A_2, A_3, A_4 with regard to the criteria by applying bipolar neutrosophic numbers.

- Table 17 indicates the performance classification of the candidates with respect to the criteria using Equation (9).
- Applying the linguistic expressions in Table 2 to establish the decision matrix.
- Deneutrosophication values of judgments matrix using Equation (1) as in Table 18.
- After establishing the decision matrix, by using Equation (10) a normalized decision matrix was computed, as represented in Table 19.
- Multiply the weights $W_{criteria}$ of criteria from Table 16 by the normalized matrix in order to produce the weighted matrix in Table 20, by using Equation (11).
- Furthermore, the positive (I^+) and negative (I^-) ideal solutions were specified. The neutrosophic positive and negative ideal solution (NPIS,I^+) and (NNIS,I^-) were computed using Equations (12) and (13) as presented in Table 21.
- Compute the Euclidean distance between positive (D^*_i) and negative (D^-_i) ideal solution by applying Equations (14) and (15), as presented in Table 21.
- Compute the closeness coefficient and rank the candidates ascending according to the maximum index of CC_i, by using Equation (16) as in Table 21 and in Figure 7.

Step 6. Lastly, after completing the steps of the solution, we found that the candidate A_4 is the most appropriate candidate to occupy the role of CEO of the company in accordance with all the criteria that were approved by DMs.

　The candidate A_4 was considered to be the best because his features met the judgments of DMs and criteria to achieve goals in a company. We believed that we had successfully passed this step in selecting the best candidate for the job. Given, we had taken most of the important criteria in consideration, which we mentioned earlier to choose any candidate for this problem. The numerical example exhibited possibilities for improvement of human resources management by applying ANP–TOPSIS. However, further studies might be useful for extending the method by introducing both application of different aggregation operators and application of neutrosophic numbers.

Table 16. Final weight for criteria using the ANP method.

	Pair-Wise Comparison for Values of W_{22}										Neutrosophic Weight W_{21}	W_i criteria
	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}		
Ci_1	0.00	0.44	0.00	0.00	0.38	0.00	0.23	0.18	0.00	0.00	0.098	0.12
Ci_2	0.23	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.091	0.04
Ci_3	0.00	0.00	0.00	0.45	0.29	0.00	0.43	0.32	0.00	0.00	0.084	0.14
Ci_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.094	0.00
Ci_5	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.24	0.00	0.00	0.104	0.05
Ci_6	0.00	0.29	0.31	0.24	0.00	0.00	0.00	0.26	0.45	0.59	0.114	0.23
Ci_7	0.43	0.00	0.26	0.00	0.33	0.18	0.00	0.00	0.00	0.00	0.071	0.11
Ci_8	0.00	0.00	0.27	0.00	0.00	0.32	0.00	0.00	0.24	0.00	0.108	0.08
Ci_9	0.34	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.41	0.071	0.13
Ci_{10}	0.00	0.27	0.00	0.31	0.00	0.26	0.00	0.00	0.31	0.00	0.165	0.10
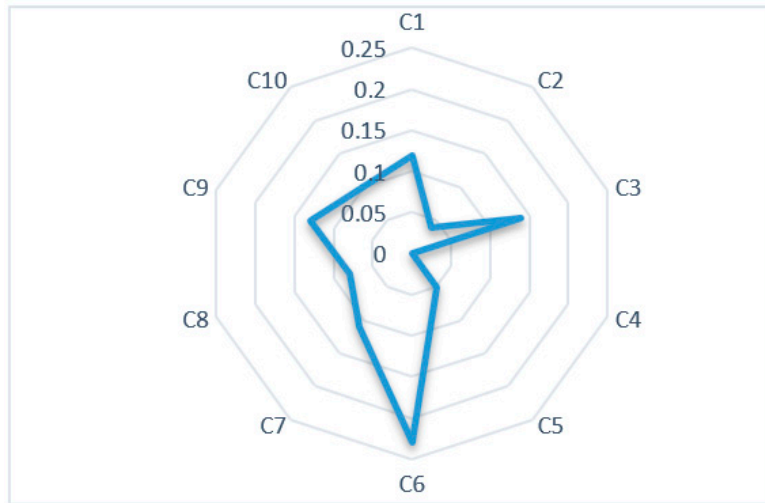
Figure 6. The weight of personnel selection criteria

Table 17. Judgments matrix for alternatives.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	EP⟩	VP⟩	EL⟩	EL⟩	P⟩	M⟩	EP⟩	L⟩	EP⟩	P⟩
A_2	VL⟩	P⟩	M⟩	L⟩	EP⟩	VL⟩	L⟩	M⟩	VL⟩	EL⟩
A_3	P⟩	L⟩	VP⟩	P⟩	M⟩	EL⟩	VP⟩	P⟩	VP⟩	M⟩
A_4	VP⟩	M⟩	VP⟩	VL⟩	M⟩	VP⟩	EP⟩	VP⟩	VL⟩	VL⟩

Table 18. Deneutrosophication values of the judgments matrix.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	0.95	0.82	0.17	0.17	0.69	0.50	0.95	0.38	0.95	0.69
A_2	0.28	0.69	0.50	0.38	0.95	0.28	0.38	0.50	0.28	0.17
A_3	0.69	0.38	0.82	0.69	0.50	0.17	0.82	0.69	0.82	0.50
A_4	0.82	0.50	0.82	0.28	0.50	0.82	0.95	0.82	0.28	0.28

Table 19. The normalized values of the judgments matrix.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	0.65	0.66	0.13	0.20	0.50	0.49	0.59	0.31	0.72	0.76
A_2	0.19	0.56	0.39	0.46	0.69	0.28	0.23	0.40	0.21	0.19
A_3	0.47	0.31	0.64	0.81	0.36	0.18	0.51	0.56	0.62	0.55
A_4	0.56	0.40	0.64	0.33	0.36	0.81	0.59	0.66	0.21	0.31

Table 20. The weighted values of the judgments matrix.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	0.08	0.03	0.02	0.00	0.03	0.11	0.06	0.02	0.09	0.08
A_2	0.02	0.02	0.05	0.00	0.03	0.06	0.03	0.03	0.03	0.02
A_3	0.06	0.01	0.09	0.00	0.02	0.04	0.06	0.04	0.08	0.06
A_4	0.07	0.02	0.09	0.00	0.02	0.19	0.06	0.05	0.03	0.03

Table 21. The final result of the judgments matrix.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}	S_i^+	S_i^-	P_i	Normalized	Rank
A_1	0.08	0.03	0.02	0.00	0.03	0.11	0.06	0.02	0.09	0.08	0.11	0.13	0.54	0.29	4
A_2	0.02	0.02	0.05	0.00	0.03	0.06	0.03	0.03	0.03	0.02	0.18	0.04	0.18	0.10	1
A_3	0.06	0.01	0.09	0.00	0.02	0.04	0.06	0.04	0.08	0.06	0.15	0.11	0.42	0.23	3
A_4	0.07	0.02	0.09	0.00	0.02	0.19	0.06	0.05	0.03	0.03	0.08	0.18	0.69	0.38	2
I^+	0.08	0.03	0.09	0.00	0.03	0.19	0.06	0.05	0.09	0.08			**Final Result**		
I^-	0.02	0.01	0.02	0.00	0.02	0.04	0.03	0.02	0.03	0.02					
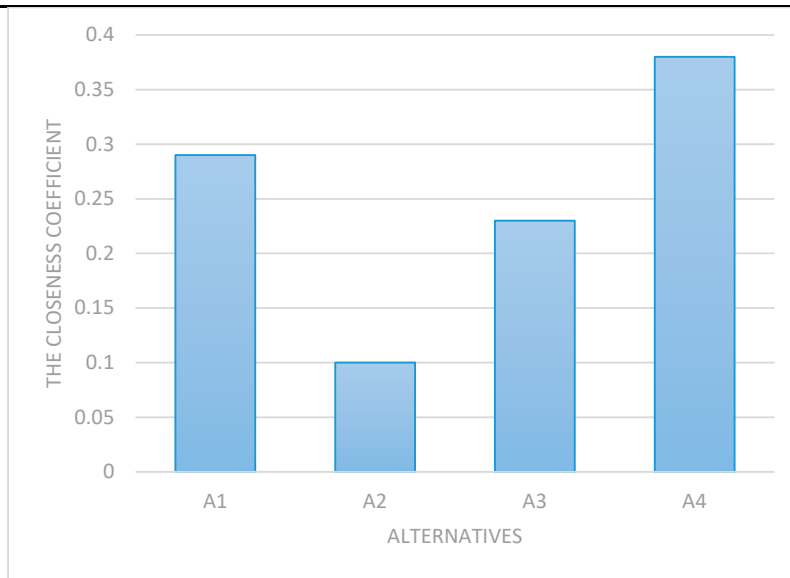
Figure 7. Final ranking using the suggested method.

5. Analysis Using Other Methods

In this section, we reviewed some MCDM methods, which would combine with the neutrosophic set to solve the same problem in order to prove the effectiveness and efficiency of the proposed method. On the other hand, we clarified the importance of the problem that we had mentioned, and that it had an important role in the success of any organization or system in the real world.

5.1. Analysis Using WSM and WPM Methods

In this subsection, we compared the results and ranking of candidates obtained from the proposed method with the obtained results from the weight sum model (WSM) and the weight product model (WPM) as follows:
- Here, we utilized the obtained weights $W_{criteria}$ of the criteria using ANP method as mentioned in Table 16.
- The normalized judgments matrix of candidates relevant to all criteria is exhibited in Table 22 as follows.
- In the last, the final result of ranking candidates exhibited in Table 23 and in Figure 8. More details on the two MCDM methods in [33].

Table 22. The normalized judgments matrix using the weight sum model (WSM) and weight product model (WPM) methods.

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	1	1	0.21	0.25	0.73	0.61	1	0.46	1	1
A_2	0.29	0.84	0.61	0.55	1	0.34	0.40	0.61	0.29	0.25
A_3	0.73	0.46	1	1	0.53	0.21	0.86	0.84	0.86	0.72
A_4	0.86	0.61	1	0.41	0.53	1	1	1	0.29	0.41

Table 23. The final result of the judgments matrix using the WSM and WPM methods.

	$\sum_{i=1}^{n} w_j\, x_{ij}$	Normalized values	Ranking WSM	$\prod_{i=1}^{n} x_{ij}{}^{w_j}$	Normalized values	Ranking WPM
A_1	0.7430	0.28	4	9.620	0.25	4
A_2	0.4375	0.17	1	9.156	0.24	1
A_3	0.6664	0.25	3	9.517	0.25	3
A_4	0.7928	0.30	2	9.697	0.26	2
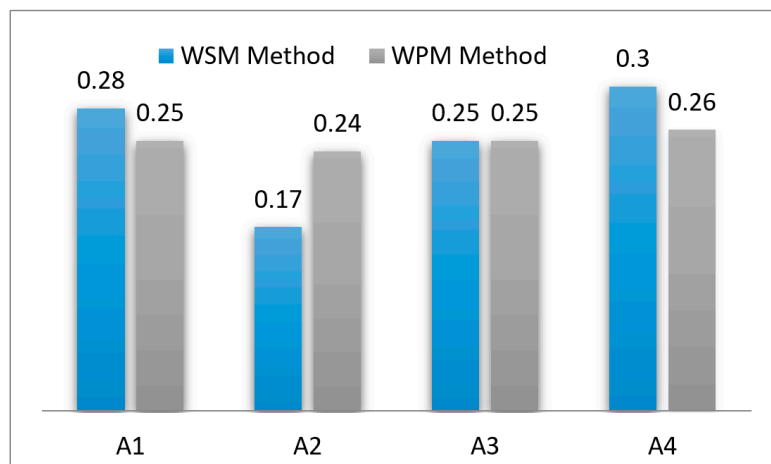
Figure 8. Final ranking using the WSM and WPM methods.

5.2. Analysis Using the AHP Method

In this subsection, we compared the results and ranking of candidates obtained from the proposed method with the results from the analytical hierarchy process (AHP) as follows:

- Here, we utilized the obtained weights of the criteria without considering the interdependencies and feedback between elements' of the problem as follows: W = $[0.098, 0.091, 0.084, 0.094, 0.104, 0.114, 0.071, 0.108, 0.071, 0.165]^T$.
- The judgment matrix of candidates related to all criteria for professional selection of chief executive officer as follows in Table 24.
- In the last, the final result of ranking candidates exhibited in Table 25 and in Figure 9.

Table 24. Judgments matrix for alternatives relevant to criteria using the analytical hierarchy process (AHP).

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	0.95	0.82	0.17	0.17	0.69	0.50	0.95	0.38	0.95	0.69
A_2	0.28	0.69	0.50	0.38	0.95	0.28	0.38	0.50	0.28	0.17
A_3	0.69	0.38	0.82	0.69	0.50	0.17	0.82	0.69	0.82	0.50
A_4	0.82	0.50	0.82	0.28	0.50	0.82	0.95	0.82	0.28	0.28

Table 25. The final result of the judgments matrix using the AHP method.

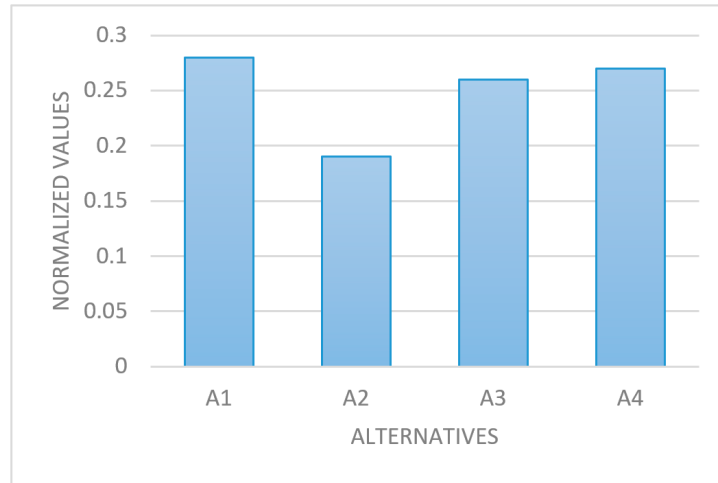| Alternatives.	values	Normalized values	Ranking
A_1	0.6165	0.28	1
A_2	0.4276	0.19	4
A_3	0.5808	0.26	3
A_4	0.5886	0.27	2

Figure 9. Final ranking using the AHP method.

5.3. Analysis Using the MOORA Method

In this subsection, we compared the results and ranking of candidates obtained from the proposed method with the obtained results from the multi-objective optimization based on simple ratio analysis (MOORA) as follows:

- Here, we utilized the obtained weights $W_{criteria}$ of the criteria using ANP method as mentioned in Table 16.
- The normalized weighted judgment matrix of candidates related to each criterion for professional selection of chief executive officer as follows in Table 26.
- Lastly, the final result of ranking candidates is presented in Table 27 and in Figure 10. More details on the equations that we used in MOORA method are accessible with the specifics in [34].
- To facilitate the problem and give a background on the results obtained from all the methods used to solve the problem, we compared the results of all applied methods used in this paper, as shown in Figure 11.

Table 26. The normalized weighted values of judgments matrix using the multi-objective optimization based on simple ratio analysis (MOORA).

	Ci_1	Ci_2	Ci_3	Ci_4	Ci_5	Ci_6	Ci_7	Ci_8	Ci_9	Ci_{10}
A_1	0.08	0.03	0.02	0.00	0.03	0.11	0.06	0.02	0.09	0.08
A_2	0.02	0.02	0.05	0.00	0.03	0.06	0.03	0.03	0.03	0.02
A_3	0.06	0.01	0.09	0.00	0.02	0.04	0.06	0.04	0.08	0.06
A_4	0.07	0.02	0.09	0.00	0.02	0.19	0.06	0.05	0.03	0.03

Table 27. The normalized weighted values of judgments matrix using the MOORA.

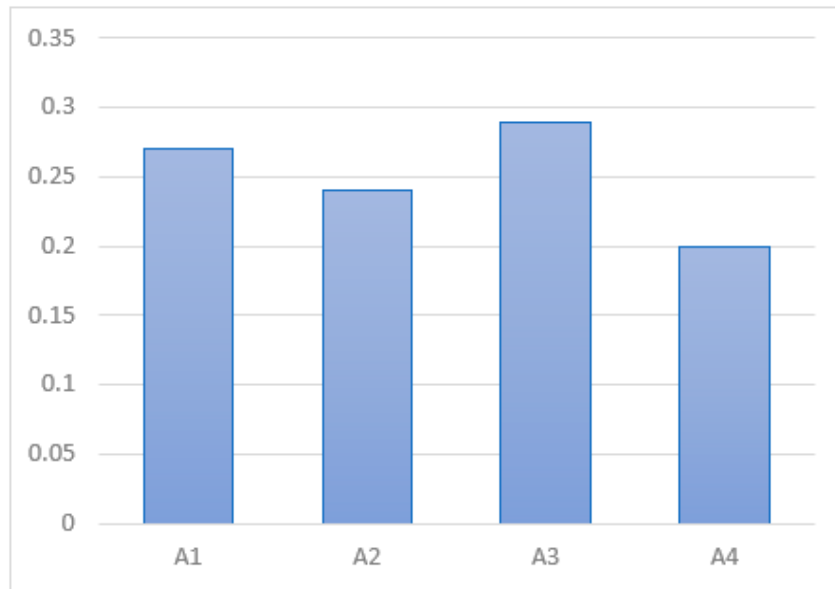| Alternatives	values	Normalized values	Ranking
A_1	0.61	0.27	3
A_2	0.57	0.24	1
A_3	0.63	0.29	2
A_4	0.51	0.20	4

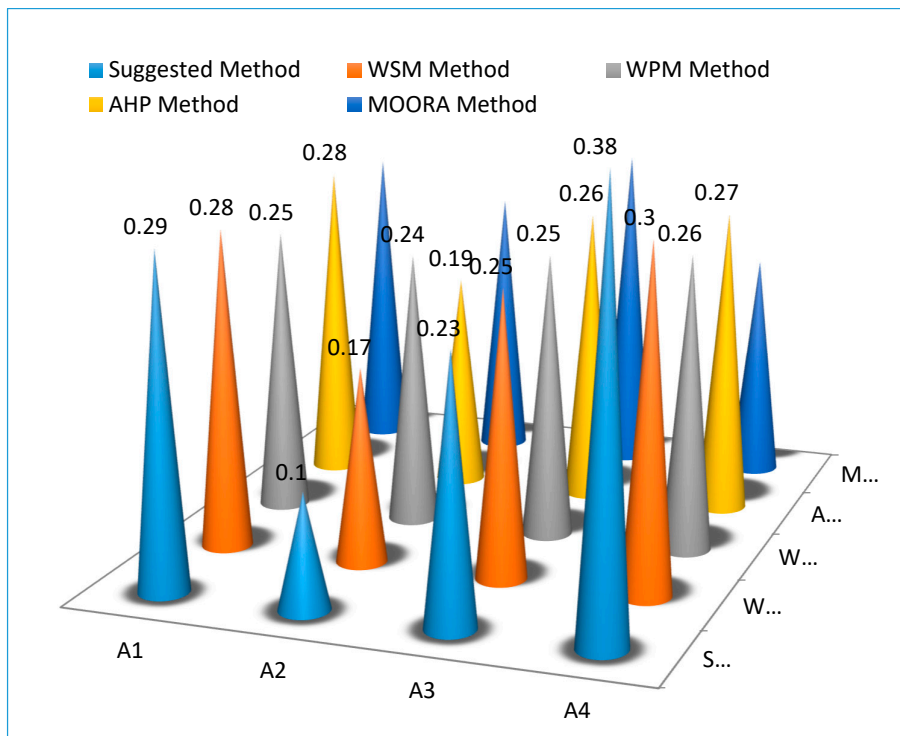**Figure 10.** Final ranking using the MOORA method.

Figure 11. Final ranking using the various applied methods.

6. Sensitivity Analysis

We conducted a sensitivity analysis using various criteria weights. Five extra cases were tested so that the rank of the substitutes varied in each once. Figure 12 illustrates the obtained results. The first case in Figure 12 was the rank of the proposed method while the others were the results of the sensitivity analysis. The criteria weights were given as the following in the tested cases. The current weights of the proposed method as following:

Case 1: W^1 = (0.12, 0.04, 0.14, 0.00, 0.05, 0.23, 0.11, 0.08, 0.13, 0.10),
Case 2: W^2 = (0.16, 0.08, 0.02, 0.04, 0.12, 0.08, 0.10, 0.15, 0.10, 0.15),
Case 3: W^3 = (0.20, 0.15, 0.05, 0.05, 0.20, 0.10, 0.05, 0.05, 0.05, 0.10),
Case 4: W^4 = (0.20, 0.10, 0.05, 0.10, 0.11, 0.15, 0.03, 0.06, 0.10, 0.10),
Case 5: W^5 = (0.25, 0.06, 0.06, 0.05, 0.20, 0.05, 0.05, 0.08, 0.10, 0.10).

When we saw Figure 12 observe that the cases in the sensitivity analysis, which were compared with respect to case 1, the following outcomes were obtained:

In case 2, considerable decreases in the weight of the criterion being good at marketing and increases in the weight of the criterion stamina and physical strength caused alternative 1 and alternatives 3 to switch their ranks.

This also caused alternative 2 and alternative 4 to remain at the same ranking. In Case 3, alternative 3 took the first order while alternative 4 moved one level lower, alternative 2 moved one level higher and alternative moved two levels lower to become the last in ordering.

In Case 4, alternative 4 moved to a level lower while alternative 2 moved one level higher. In Case 5, a slight increase in the other criteria and an unexpected increase in the weight of the criterion being good at marketing and slight decreases in good health criterion and sentimental stability caused alternative 4 to become the best choice.
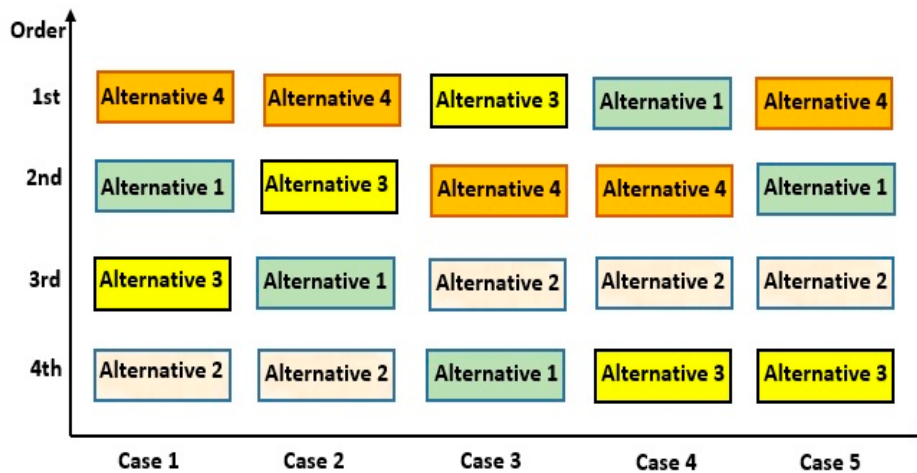

Figure 12. Results of the sensitivity analysis.

7. Conclusions

An organizational success depends on selecting the utmost suitable personnel, which is considered as the most significant factor for any organization. The personnel selection's issue, affected by individual attributes of impreciseness and vagueness, could be considered as an extremely substantial decision-making problem. The traditional MCDM techniques to estimate inevitable or indiscriminate procedures should not efficaciously exhaust decision-making problems consisted of unspecific, indistinct imprecise and linguistic information. A sound MCDM procedure applied for personnel selection should be capable to combine quantitative as well as qualitative information. In this research, a neutrosophic MCDM technique was introduced to handle challenges when applying traditional decision-making procedures. The suggested method was appropriate to

handle estimated information using both numerical and linguistic measurement in a decision-making context.

A proposed model has practical implications as integrating two MCDM methods was adopted by CEO selection as an example of personnel selection. The neutrosophic set was used with all methods so as to make the valuation procedure more resilient and more accurate for the DMs. In other words, the use of the neutrosophic could determine characterizing vagueness in various factors. It could also facilitate the complicated structure of the judgment phase. The suggested neutrosophic hybrid MCDM technique included neutrosophic ANP and neutrosophic TOPSIS. The hybridization of the two MCDM methods, the comparison of results with the other MCDM methods and the proposed MCDM technique for CEO selection provided the most significant features of this research. Furthermore, the suggested technique could enable leaders or managers to deal with uncertain and unclear information. It could also create a suitable environment for the use of various semantic styles by DMs. The model provided the use of both qualitative and quantitative factors. As mentioned before the proposed hybrid structure of two MCDM techniques and proposing a MCDM approach for the professional real selection case were the unique features of the study.

The future work will include prediction of the influential factors by advanced decision-making algorithms that affect organizations by apply of variant multi criteria decision analysis techniques, so that our research contributions can be transferrable to other fields.

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Ethical Approval: This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Lin, H.-T. Personnel selection using analytic network process and fuzzy data envelopment analysis approaches. *Comput. Ind. Eng.* **2010**, *59*, 937–944.
2. Liang, G.-S.; Wang, J.M.-J. Personnel selection using fuzzy MCDM algorithm. *Eur. J. Oper. Res.* **1994**, *78*, 22–33.
3. Baležentis, A.; Baležentis, T.; Brauers, K.W. Personnel selection based on computing with words and fuzzy MULTIMOORA. *Expert Syst. Appl.* **2012**, *39*, 7961–7967.
4. Dursun, M.; Karsak, E.E. A fuzzy MCDM approach for personnel selection. *Expert Syst. Appl.* **2010**, *37*, 4324–4330, doi:10.1016/j.eswa.2009.11.067.
5. Canós, L.; Liern, V. Soft computing-based aggregation methods for human resource management. *Eur. J. Oper. Res.* **2008**, *189*, 669–681, doi:10.1016/j.ejor.2006.01.054.
6. Robertson, I.T.; Smith, M. Personnel selection. *J. Occup. Organ. Psychol.* **2001**, *74*, 441–472.
7. Zainurita, M.A. *Supplier Selection for Solar Photovoltaic (PV) Module using Analytical Hierarchy Process: Perlis Solar Plant Project*; Universiti Utara Malaysia: Changlun, Malaysia, 2016.
8. Ansoff, H.I. *Implanting strategic management*; Springer: Berlin/Heidelberg, Germany, 2019.
9. Abdel-Baset, M.; Changb, V.; Gamala, A.; Smarandache, F. An integrated neutrosophic ANP and VIKOR method for achieving sustainable supplier selection: A case study in importing field. *Comput. Ind.* **2019**, *106*, 94–110.
10. Abdel-Basset, M.; Manogaran, G.; Gamala, A.; Smarandache, F. A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria. *Des. Autom. Embed. Syst.* **2018**, *22*, 257–278.
11. Abdel-Basset, M.; Saleh, M.; Gamal, A.; Smarandache, F. An approach of TOPSIS technique for developing supplier selection with group decision making under type-2 neutrosophic number. *Appl. Soft Comput.* **2019**, *77*, 438–452.

12. Abdel-Basset, M.; Manogaran, G.; Gamala, A.; Smarandache, F. A group decision making framework based on neutrosophic TOPSIS approach for smart medical device selection. *J. Med. Syst.* **2019**, *43*, 38.

13. Abdel-Basset, M.; Gunasekaran, M.; Mohamed, M.; Chilamkurti, N. A framework for risk assessment, management and evaluation: Economic tool for quantifying risks in supply chain. *Future Gener. Comput. Syst.* **2019**, *90*, 489–502.

14. Şenel, B.; Şenel, M.; Aydemir, G. Use and Comparison of Topis and Electre Methods In Personnel Selection. In *Proceedings of the ITM Web of Conferences*; EDP Sciences: Les Ulis, France, 2018.

15. Jasemi, M.; Ahmadi, E. A New Fuzzy ELECTRE Based Multiple Criteria Method for Personnel Selection. *Sci. Iran.* **2018**, *25*, 943–953.

16. Karabasevic, D.; Zavadskas, E.K.; Turskis, Z.; Stanujkic, D. The framework for the selection of personnel based on the SWARA and ARAS methods under uncertainties. *Informatica* **2016**, *27*, 49–65.

17. Ji, P.; Zhang, H.-Y.; Wang, J.-Q. A projection-based TODIM method under multi-valued neutrosophic environments and its application in personnel selection. *Neural Comput. Appl.* **2018**, *29*, 221–234.

18. Dung, V.; Thuy, L.T.; Mai, P.Q.; Van Dan, N.; Lan, N.T.M. *TOPSIS Approach Using Interval Neutrosophic Sets for Personnel Selection*; Infinite Study: Coimbatore, India, 2018.

19. Pramanik, S.; Dalapati, S.; Roy, T.K. Neutrosophic multi-attribute group decision making strategy for logistics center location selection. *Neutrosophic Oper. Res.* **2018**, *3*, 13–32.

20. Karabasevic, D.; Zavadskas, E.K.; Stanujkic, D.; Popovic, G.; Brzakovic, M. An approach to personnel selection in the IT industry based on the edas method. *Transform. Bus. Econ.* **2018**, *17*, 44.

21. Saaty, T.L. *Decision Making with Dependence and Feedback: The Analytic Network Process*; RWS Publ: 1996; Volume 4922.

22. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw Hill: New York, NY, USA, 1980.

23. Meade, L.; Sarkis, J. Analyzing organizational project alternatives for agile manufacturing processes: An analytical network approach. *Int. J. Prod. Res.* **1999**, *37*, 241–261.

24. Hwang, C.-L.; Yoon, K. Methods for Multiple Attribute Decision Making. In *Multiple Attribute Decision Making*; Springer: Berlin/Heidelberg, Germany, 1981; pp. 58–191.

25. Ertuğrul, İ.; Karakaşoğlu, N. Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods. *Expert Syst. Appl.* **2009**, *36*, 702–715.

26. Gallego Lupianez, F. Interval neutrosophic sets and topology. *Kybernetes* **2009**, *38*, 621–624.

27. Hezam, I.M.; Abdel-Baset, M.; Smarandache, F. *Taylor Series Approximation to Solve Neutrosophic Multi-Objective Programming Problem*; Infinite Study: Coimbatore, India, 2015.

28. Haibin, W.; Smarandache, F.; Zhang, Y.; Sunderraman, R. *Single Valued Neutrosophic Sets*; Infinite Study: Coimbatore, India, 2010.

29. Peng, J.-J.; Wang, J.-Q.; Wang, J.; Zhang, H.-Y.; Chen, X.-H. Simplified neutrosophic sets and their applications in multi-criteria group decision-making problems. *Int. J. Syst. Sci.* **2016**, *47*, 2342–2358.

30. Manemaran, S.; Chellappa, B. Structures on bipolar fuzzy groups and bipolar fuzzy D-ideals under (T, S) norms. *Int. J. Comput. Appl.* **2010**, *9*, 7–10.

31. Önüt, S.; Kara, S.S.; Işik, E. Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Syst. Appl.* **2009**, *36*, 3887–3895.

32. Mohanty, R.P.; Agarwal, R.; Choudhury, A.K.; Tiwari, M.K. A fuzzy ANP-based approach to R&D project selection: A case study. *Int. J. Prod. Res.* **2005**, *43*, 5199–5216.

33. Triantaphyllou, E. Multi-criteria decision making methods. In *Multi-Criteria Decision Making Methods: A Comparative Study*; Springer: Berlin/Heidelberg, Germany, 2000; pp. 5–21.

34. Brauers, W.K.; Zavadskas, E.K. The MOORA method and its application to privatization in a transition economy. *Control Cybern.* **2006**, *35*, 445–469.