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RESEARCH

Selection of Academic Staff Based on a Hybrid Multi-criteria Decision Method Under Neutrosophic Environment

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Abstract

Multi-criteria decision-making (MCDM) is a decision-making process that involves assessing and selecting the best alternative from a group of options based on various criteria or qualities. In this research work, we propose and elucidate the theory of neutrosophic logic, which is unique in its approach to evaluating candidates' performance in a manner that takes into account significant elements and criteria that are essential for the overall process when dealing with unclear, inaccurate, or incomplete data. We propose a novel hybrid integrated MCDM methodology based upon neutrosophic Delphi (N-Delphi) and neutrosophic AHP (N-AHP) methods, which takes into consideration the importance of each decision-maker and their preferences per evaluation criterion. A new MAXMIN threshold value technique treats the criteria under consideration as the decision alternatives and their score functions as their payoff values, thus reducing unnecessary resources by eliminating unimportant criteria during the personnel selection process.

Keywords MCDM method · Neutrosophic logic · Neutrosophic analytical hierarchy process · Neutrosophic Delphi method · Staff selection

1 Introduction

It would be common logic to utter that the advent of information sciences has revitalized interest in human knowledge representation and reasoning since the last part of the twentieth century. Reasoning, which is an important trait to comprehend human intelligence, is often characterized by ambiguity, inconsistency, and

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contradiction. One of the major issues and challenges that artificial intelligence's research community encounters is simulating uncertainty. The main objective of decision-makers is to manage uncertainties, especially in indeterminate situations where the case is not simply true or false.

Real-world problems involving multiple criterion decision-making methods (MCDM) with quantitative or qualitative attribute values are employed in a variety of scientific domains, such as operation research, management science, and economics. Because of the ambiguity and complexity of the criteria involved, the attribute values of MCDM issues cannot always be described properly using crisp numbers. In this case, the decision-makers' preference assessment for evaluating alternatives showcases a strong possibility to be vague, imprecise, or incomplete. If a piece of knowledge in a specific context is not sufficient for a decision-maker to interpret, it is said to be incomplete in that context. Due to the fact that an imprecise response only offers partial information, we perceive imprecision as a sort of incomplete information.

As a consequence, new methods that seek for effective solutions are emerging, e.g., fuzzy logic, intuitionistic fuzzy logic, interval-valued fuzzy, and more recently neutrosophic logic. The fuzzy logic theory,[1] which was first introduced by Zadeh in 1965 [1], deals with the notion of partial truth, where the truth value might be either true or false. Within the context of fuzzy theory, Zadeh showed that a kind of uncertainty, the imprecision which hides no randomness, can be perfectly described by fuzzy sets.

Meanwhile, in 1995, Smarandache, commencing from a philosophical consideration on multi-valued logics, began to use the non-standard analysis with a tri-component logic/set/probability theory. As a result, he proposed the theory of neutrosophic logic since fuzzy logic is considered incapable of demonstrating indeterminacy on its own [2]. Quoting the definition cited in [2], "Neutrosophic logic is a logic variety that generalizes fuzzy logic, paraconsistent logic, intuitionistic logic, and other logic variants. The degree of membership (T) of each set element is the first part of neutrosophic logic, indeterminacy (I) is the middle part, and falsehood (F) is the third part respectively" (i.e. if we would like to formulate a simplified neutrosophic triplet that is shown as $A = (T, I, F)$).

In recent years, neutrosophic logic is used in many studies as an effective mathematical tool used in uncertain and indeterminate problem-solving instances.

The recruitment of teaching staff is the process of finding individuals within an academic setting who possess the necessary contemporary knowledge, research proficiency, and language ability, as well as who possess the essential qualities required to carry out a particular task in the most effective manner [3, 4].

There are numerous approaches available in the literature that attempt to address the issue of academic staff selection. Traditionally, staff selection relies on experimental and statistical approaches. In the experimental method, decision-makers use their expertise and understanding of job criteria to select individuals. Statistical tools allow decision-makers to make decisions based on test results and measures of accomplishment

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[1] Actually, the theory of fuzzy logic originated from the pioneer work of Bertrand Russell, namely "Theory of Vagueness" in the early part of the twentieth century.

for candidates. Interviewing applicants is a common strategy for staff selection. According to [5], conducting interviews can accurately predict job success. Numerous studies exist to help organizations make better personnel selection decisions. Human resource management studies often rely on interviews, work sample tests, assessment centers, resumes, job knowledge exams, and personality assessments [6]. Selecting the right people based on company circumstances allows managers to optimize production costs and achieve corporate goals [7]. The goal of a selection process is to differentiate between applicants and predict future performance.

However, the majority of these studies demonstrate a limitation in the fact that this type of problem is heavily reliant on human judgment and intuition, thus resulting in a high level of uncertainty and inadequate and/or inconsistent data. Therefore, it is needed to employ “intelligent” inference techniques that can handle uncertain data and knowledge.

Integrating intelligent inference techniques such as soft computing techniques within MCDM frameworks presents a promising avenue for addressing the limitations associated with human judgment, uncertainty, and inconsistent data.

Nevertheless, due to the fact that the information on multiple criteria corresponding to decision importance is often incomplete, researchers have proposed several approaches, based on decision theory, for situations in which the decision-maker has little confidence in their ability to assess probabilities, or when a simple best-case and worst-case analysis is desired. Within this context, three broad categories can be identified: the optimistic approach, the conservative approach, and the minimax approach. In the optimistic approach, the decision-maker evaluates each decision alternative based on the best possible outcome. The conservative approach, on the other hand, assesses each decision alternative in terms of the worst possible outcome. The minimax regret approach to decision-making falls between these two categories.

More specifically, the optimistic criterion prioritizes future progress and considers optimal conditions. It selects the plan with the lowest value from the minimum yearly cost value created in each scenario as the optimal plan. The pessimistic criterion differs from the optimistic decision criterion in that it assumes the worst-case scenario will occur. The optimal plan is determined by selecting the plan with the lowest yearly cost value among the maximum values obtained in each scenario [8]. Lastly, the minimax regret criterion identifies the optimal goal as the lowest annual cost value in each scenario, with the regret value being the difference between the other annual cost values. The regret value for each scenario is calculated for every plan [9, 10].

In response to the aforementioned issues, our goal is to address the gap in the literature by proposing a concise and comprehensive technique that combines AHP and Delphi methodologies within a neutrosophic framework in the context of the recruiting academic staff. This technique utilizes a new score function, as a threshold approach, which focuses on eliminating unnecessary decision criteria. Thus, experts can use this method to identify the most suitable candidate who “closely” aligns with their preferences. Our method will prove its efficiency and accuracy in the selection of academic personnel by addressing the inherent inefficiency that traditional multi-criteria decision-making methods reveal when dealing with indeterminate circumstances. At the same time, our conceptual framework will serve as a useful toolkit to the management by proposing and applying a new enhanced algorithm in a real-world problem taken from the literature.

The remainder of current manuscript is structured as follows: Firstly, relevant scholar's studies that deal with the personnel selection problem in general and with the recruitment of academic staff particularly, under a multi-criteria decision-making perspective, are presented in Section 2. Also, key challenges and key contributions of our study are given in the same section. Then in Section 3, the steps that form the algorithm of our method are given. In addition, fundamental definitions about neutrosophic set theory and its operational laws are analyzed. In Section 4, we demonstrate how our method works in a real case study based on the selection of academic personnel. Section 5 provides a comprehensive comparative analysis between our work and the work of scholars in [11] and explains the advantages of the proposed methodology. Finally in Section 6, conclusions and possible future work are outlined.

2 Literature Review

According to recent studies, teaching staff is evaluated and rated during the selection process through written and oral exams, which serve as the primary basis for selection [12]. Even though this formula is necessary, the criteria and weightings for the examination and evaluation of academic personnel should be determined more precisely, given the importance of such a selection. Selecting the appropriate teaching staff and ensuring they meet all qualifications among the chosen criteria, which include both qualitative and quantitative aspects, can be seen as a multiple criteria decision making (MCDM) problem greatly influenced by various competing factors, especially when considering institution-specific goals [13].

The personnel selection procedure is suggested by many researchers to be utilized by decision support system tools so as to improve the judgments of decision-makers [14, 15]. Authors in [16] apply MCDM methods for personnel selection while an aggregating function is used in [17]. In order to improve the judgments of decision-makers, AHP technique divides the problem into a top-down hierarchical structure [18]. The fuzzy methods are provided to improve the judgments of decision-makers during the process of personnel selection due to vague and imprecise information [19]. In the literature, such as in [20], fuzzy techniques and AHP method are employed to handle information system problems related to personnel selection. Fuzzy AHP is used as a tool to rank applicants and choose the best candidate [21]. For the purpose to resolve ambiguities and ambiguities in the paired comparison matrix and reduce biases in personnel selection, an analytical network method (ANP) is proposed in [22]. In a similar context, an integrated method of fuzzy AHP and TOPSIS is used to improve the training and education of academic personnel selection in an MCDM environment [23]. The AHP and TOPSIS methods combined with neutrosophic logic are used in a variety of fields, including supplier selections and risks, and support of decision-makers resulting in the best decisions under uncertainty and inconsistency conditions [24, 25].

When representing information that is ambiguous, partial, or inconsistent, neutrosophic sets/logic are preferred over fuzzy sets/logic and interval fuzzy sets because of their versatility and usefulness [26, 27]. In recent studies, many researchers have applied the concept of neutrosophic sets and their properties to resolve some multi-criteria decision-making (MCDM)–based problems [28–31].

To focus on studies that employ techniques within a similar methodological context, we should reference the work of scholars in [32] who proposed a neutrosophic AHP approach aimed at selecting the most suitable learning management system. They claimed that neutrosophic set theory makes the experts' judgments more flexible whereas conventional AHP method takes into account the definite judgments of decision-makers. Another research work which is related to neutrosophic AHP is published in [33]. They formed a neutrosophic AHP Delphi group decision-making model based on trapezoidal neutrosophic numbers with the objective to deal with the non-deterministic evaluation values of experts. A different approach is followed in [34] where the researchers proposed a method for group decision-making based on N-AHP which utilized triangular neutrosophic numbers and solved a real-world problem structured by the experts. A limitation that could be cited in their approach is the fact that the evaluation of the suitable candidate is made by only one decision-maker as opposed to ours, in which three decisions makers fuse their opinions so as to choose the best candidate, thus rendering our approach more realistic and unbiased.

Delphi's central idea was founded on the axiom stating that "*n brains are better than one*" [35]. Delphi is a method for gathering information from individuals based on their areas of expertise. The Delphi technique aims to reach "*what could/should be*," while most surveys focus on identifying "*what is*" [36]. A study in which researchers combined successfully AHP with Delphi methods to address conflict resolution in recruiting decisions is found in [37]. A comparable method, in which the researchers used Delphi-AHP methodologies to classify discarded electrical and electronic devices, is described in [38]. In the previous study, the fuzzy Delphi-AHP approach was utilized to rate effective material selection criteria. Recently, in [11], researchers formed a model which uses fuzzy AHP and fuzzy Delphi and applied it in the selection of an academic at Neapolis University Pafos, Cyprus. Their work is used as a benchmark for our research, and comparative results are presented in Section 5.

There are very few studies in the literature that utilize the Delphi method in a neutrosophic environment. For example, in [39], N-Delphi method is proposed for evaluating academic research projects that are supported by neutrosophic logic. Their model is based on the Delphi method which supports consensus index to avoid slow convergence of Delphi although this may require multiple rounds to reach agreement between experts, which is used to forecast future scenarios or occurrences using expert judgment. The neutrosophic framework has the advantage of incorporating both uncertainty and indeterminacy into decision-making. Another benefit is that experts use linguistic scales to conduct evaluations, which increases the validity of the results. A limitation that could be mentioned is that they did not apply their proposed conceptual framework to a real case study but illustrated its applicability through a hypothetical problem. Another research work found in the literature is described in [40] where a variant of Delphi method is used for the selection of experts and the measurement of intellectual capital in a hotel case study activity. For the purpose of their study, single-valued triangular neutrosophic numbers are used for the implementation of their model.

It is acknowledged that modern business management and organization is both science and art. By suggesting our conceptual framework, we attempt to transcend human biases, sympathies, and intellectual frailty by emphasizing an objective systematic process for the accumulation of knowledge. Thus, we propose an integrated neutrosophic decision analysis method for academic recruitment that fits the needs of the position and leaves no room for intuitive approach to decision-making.

The following are the primary challenges of the current study:

- Because of the scientific nature of the suggested solution to the stated problem, we have to ensure the following for our methodology: (i) definitions should be clear, (ii) the decision process must be contagious, (iii) the data must be unbiased, (iv) the decision-making process can be replicated, and (v) information should always be evaluated based on the credibility of the source.
- Traditional MCDM techniques have been adapted to perform in a variety of uncertain contexts; however, most current MCDM techniques experience challenges with inconsistent and indeterminate data.
- The majority of the methods currently used in the literature for selecting academic personnel are ineffective when dealing with vague, ambiguous, and unreliable knowledge.
- The plurality of current methods for extending MCDM methods in a fuzzy and intuitionistic fuzzy environment relies on crisp and constrained linguistic scales that ignore indeterminacy and “force” decision-makers to associate linguistic variables to fixed degrees of confirmation. Furthermore, while neutrosophic-based methods discussed in the related literature adequately address incomplete and vague data, we have identified some limitations in these studies. These include the improper use of linguistic terms for criteria and alternatives and decision-making by a single expert without cross-verification of the alternatives by multiple experts.
- To the best of our knowledge, there does not exist any study in the related literature with the proposed Delphi method in neutrosophic environment for academic staff selection; therefore, we consider that it is significant and useful for the research community to introduce a new decision-making framework based on this modified version of N-Delphi.

The key contributions and novelties of this study are stated below:

- To select qualified academic staff, a novel extended MCDM methodology based on N-Delphi and N-AHP methods is developed. The use of a neutrosophic framework introduces a level of flexibility and adaptability to handle indeterminate or uncertain information.
- A new threshold value, inspired by utility decision theory, which adds additional value to the efficiency of our algorithm, is explained and implemented. Introducing a new score function with a threshold approach helps streamline the decision-making process by focusing on essential decision criteria. This ensures that experts can focus on evaluating candidates based on the most critical factors aligned with their preferences.

- A suitable scale for evaluating criteria and alternatives is presented.
- To validate the usefulness, reliability, and objectivity of the suggested method, a descriptive study of academic staff selection is introduced.
- By using the proposed method and especially our novel threshold value, unnecessary costs will be reduced, and the value of human resources for managerial decision-making will increase.

Summarizing, the suggested method integrates:

1. Neutrosophic logic (for assigning weights to the decision-makers)
2. Neutrosophic Delphi (for shortlisting the criteria thus reducing the computational cost)
3. Neutrosophic AHP (for determining the importance of criteria and providing with the final ranking of candidates)

In conclusion, our research contributes to the literature in two ways. Firstly, we aim to emphasize the importance of formulating a comprehensive model that will make the process of hiring academic personnel more precise and productive. Secondly, we intend to introduce new perspectives on performance dimensions and related criteria. This can be achieved by presenting a hybrid neutrosophic conceptual model that stands out for its unique approach to assessing candidates' overall performance. This model takes into account significant aspects and criteria that are crucial in the overall process, especially when dealing with ambiguous, imprecise, or incomplete information.

3 Materials and Methods

3.1 Proposed Framework

In this subsection, we briefly describe the overall framework proposed in this article as a means to introduce the reader with the core methods used in our method.

In Fig. 1, our proposed improved algorithm for the problem of academic staff selection is depicted in the form of a flowchart.

In a nutshell, it can be observed that our methodology consists of the following steps that correspond to the respective methods used:

- Neutrosophic logic concepts to assign proper weightage to the decision-makers (DMs) according to their academic credentials
- A novel approach to neutrosophic Delphi method is utilized so as to determine the weightage of the criteria used for the evaluation of candidates and to eliminate unimportant criteria based on the minimum requirements defined from the DMs. The latter is succeeded due to the conception and implementation of our proposed threshold value which significantly contributes to the efficiency of our algorithm

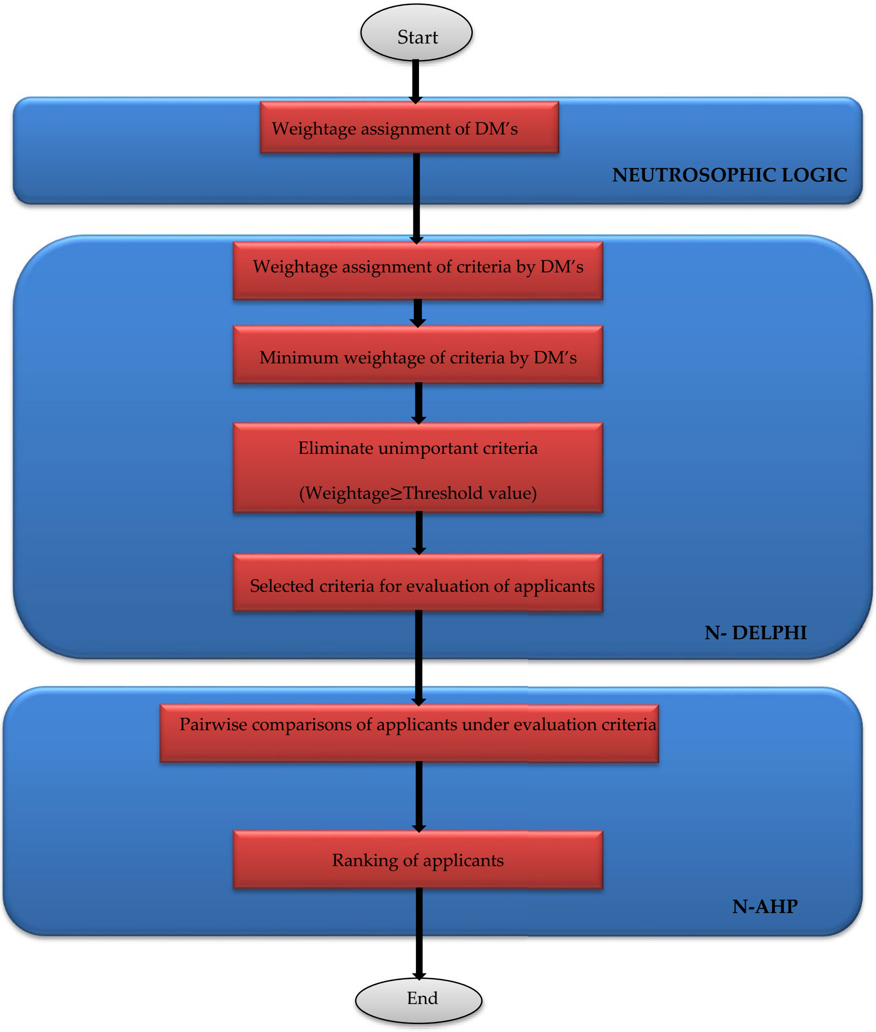

Fig. 1 Framework of the proposed method

- Neutrosophic AHP in order to perform the pairwise comparisons between the applicants under the selected criteria from step 2 and to provide the final ranking of the applicants

Next in this section, basic terminology used throughout our paper is given in more detail.

3.2 Preliminaries

Definition 1 [41] Consider X to be a space of points (objects) and x to be a generic element in X. A truth membership function T_A, an indeterminacy membership function I_A, and a falsity membership function F_A characterize a single-valued neutrosophic set (SVNs) A in X. For each point x in X, $T_A(x), I_A(x), F_A(x) \in [0, 1]$.

Then, a simplification of the neutrosophic set A is denoted by

$$A = \{\langle \mathbf{x}, \mathbf{T}(\mathbf{x}), \mathbf{I}(\mathbf{x}), \mathbf{F}(\mathbf{x})\rangle | \mathrm{x} \in \mathbf{X}\} \tag{1}$$

Definition 2 [41] Let A, B be two SVNSs. Operational relations are defined by

$$\begin{gathered} A + B \geq T_A(x) + T_B(x) - T_A(x) \times T_B(x), I_A(x) + I_B(x) \\ - I_A(x) \times I_B(x), F_A(x) + F_B(x) - F_A(x) \times F_B(x) > \end{gathered} \tag{2}$$

$$\mathrm{A} \cdot \mathrm{B} \leq T_A(x) \times T_B(x), I_A(x) \times I_B(x), F_A(x) \times F_B(x) > \tag{3}$$

$$\lambda A \leq 1 - (1 - T_A(x))\lambda, 1 - (1 - I_A(x))^{\lambda}, 1 - (1 - F_A(x))^{\lambda} >, \lambda > 0 \tag{4}$$

$$A^{\lambda} =< T_{A^{\lambda}}(x), I_{A^{\lambda}}(x), F_{A^{\lambda}}(x) >, \lambda > 0 \tag{5}$$

Definition 3 [31] If A is a single-valued neutrosophic number, a score function $S(\mathrm{A})$ is mapped into the single crisp output as follows:

$$S(\mathrm{A}) = (3 + \mathrm{T_A} - 2\mathrm{I_A} - \mathrm{F_A})/4 \tag{6}$$

$$S(\widetilde{\boldsymbol{A}}) = 1/S(\mathrm{A}) \tag{7}$$

Definition 4 [41] Let Aj ($j = 1, 2\ldots, n$) be SVNs. The simplified neutrosophic weighted arithmetic average operator is given as follows:

$$F_w(\mathrm{A}_1,\ \mathrm{A}_2 \ldots \mathrm{A}_\mathrm{n}) = \sum\nolimits_{j=1}^{n} w_j A_j \tag{8}$$

$$\begin{gathered} \text{where } W = (w_1, w_2,\ \ldots, w_n) \text{ is the weight vector of } Aj \\ (j = 1, 2, \ldots, n), w_j \in [0, 1] \text{ and } \sum\nolimits_{j=1}^{n} w_j = 1 \end{gathered} \tag{9}$$

3.3 Neutrosophic Logic to Assign Weights to the Experts

The DM's weights have been assigned based on the fact that their opinions represent different importance in the decision-making process due to their inherit characteristics, such as dissimilar experience, position, and academic qualification.

Table 1 Linguistic variables and SVNNs (adopted and modified from [11])

SVNN	*Criteria*		
	Academic level	***Experience***	***Education***
(0.9, 0.1, 0.1)	Professor	More than 20 years	Post-Doctorate
(0.8, 0.2, 0.15)	Ass. professor	10 to 20 years	Doctorate
(0.5, 0.4, 0.45)	Senior lecturer	5 to 10 years	Master degree
(0.35, 0.6, 0.7)	Lecturer	0 to 5 years	Bachelor degree

By combining the opinions, it is determined that the DM's opinion is more trustworthy if they possess at the same time more experience, a higher designation, and superior qualifications. The linguistic variables can be quantified using single-valued neutrosophic numbers as per Table 1.

Let $D^{(k)} = (d_{ij}{}^{(k)})_{m \times n}$ be the single-valued neutrosophic decision matrix of the kth decision-maker and $\Psi = (\psi_1, \psi_2, ..\psi_p)^T$ be the weight vector of decision-maker such that each $\psi_\kappa \in [0,1]$. To generate an aggregated neutrosophic decision matrix, all individual assessments must be merged into a collective opinion throughout the group decision-making process. This aggregated matrix may be constructed as follows by utilizing the single-valued neutrosophic weighted averaging (SVNWA) aggregation operator introduced by Ye [41] for SVNSs.: $D = (dij^{(k)})_{m \times n}$ where $d_{ij} = \mathrm{SVNSWA}_\psi(d_{ij}{}^{(1)}, d_{ij}{}^{(2)}, ...d_{ij}{}^{(p)} = \psi_1 d_{ij}{}^{(1)} \oplus \psi_1 d_{ij}{}^{(2)}, \oplus \ldots \ldots .. \oplus \psi_p d_{ij}{}^{(p)}$

$$= \langle 1 - \prod_{k=1}^{p} (1 - \boldsymbol{T}_{ij}^{(p)})^{\psi_\kappa}, \prod_{\kappa=1}^{\pi} (\mathbf{I}_{ij}^{p})^{\psi_\kappa} \mid \prod_{\kappa=1}^{\pi} (\boldsymbol{F}_{ij}^{p})^{\psi_\kappa} \rangle \tag{10}$$

As a result, the aggregated neutrosophic preference matrix is as follows:

$D = \langle \boldsymbol{d}_{ij} \rangle_{\ m} \times_{\ n} = \langle \boldsymbol{T}_{ij,} \boldsymbol{I}_{ij}, \boldsymbol{F}_{ij} \rangle$ where $\boldsymbol{d}_{ij} = \langle \boldsymbol{T}_{ij,} \boldsymbol{I}_{ij}, \boldsymbol{F}_{ij} \rangle$ is the aggregated element of neutrosophic decision matrix D for $i = 1, 2, \ldots.. m$ and $j = 1, 2, \ldots. n$.

3.4 N-Delphi

An innovative neutrosophic Delphi approach is utilized to narrow down the important attributes for academic staff selection. Unimportant criteria can be detected and thus deleted using this method.

According to Table 2, the university's team of experts (decision-makers—DM) should define all potential evaluation criteria.

- *Step 1*

Through a questionnaire, each DM is asked to rate the significance of each evaluation criterion. Each analyst must choose the right linguistic terminology because human judgments are frequently ambiguous and cannot be precisely quantified. Its objective is to integrate all DMs' opinions so as to remove insignificant criteria. Table 3 shows the seven linguistic phrases that can be used in the questionnaire: very low, low, medium–low, medium, medium–high, high, and very high.

Table 2 List of the criteria for academic staff [11]

1	*Comprehension of academic field*
2	*Experience*
3	*Foreign languages*
4	*Research skills*
5	*Collaboration ability*
6	*Presenting capability*
7	*Creative thinking-innovation*
8	*Efficiency in administration*
9	*Commitment to the result*
10	*Motivation-leadership*

The result of the questionnaire is formulated as in the following decision matrix:

$$\widetilde{\boldsymbol{X}1} \ldots\ldots\ldots\ldots \widetilde{\boldsymbol{Xn}}$$

$$D_1 \ldots\ldots\ldots\ldots D_n$$

$$C_1 \ldots\ldots C_N \quad \begin{bmatrix} \widetilde{\boldsymbol{L}_{11}} & \cdots & \widetilde{\boldsymbol{L}_{1n}} \\ \vdots & \ddots & \vdots \\ \widetilde{\boldsymbol{L}_{m1}} & \cdots & \widetilde{\boldsymbol{L}_{mn}} \end{bmatrix}$$

where C_i: the ith evaluation criterion, $i = 1,2,\ldots,m$. D_j: the jth analyst, $j = 1,2,\ldots,n$. $\widetilde{\boldsymbol{Xj}}$: weight of the jth analyst, $\widetilde{\boldsymbol{L}_{ij}}$: the linguistic evaluation of criterion i by the analyst j represented as a single-valued neutrosophic number.

- *Step 2*

With the objective of calculating the relative importance of each criterion of the corresponding neutrosophic pairwise comparison matrix, we first transform it into the deterministic pairwise comparison matrix using Eq. (9). Then, by using Eqs. (6) and (7), we convert the aforementioned matrix into a deterministic pairwise comparison matrix and calculate the weight of each criterion from the corresponding aggregated neutrosophic pairwise comparison matrix.

Table 3 List of linguistic terms (adopted and modified from [11])

Linguistic variable	***SVNNs***
Very low	(*0.1*, *0.8*, *0.9*)
Low	(*0.3*, *0.7*, *0.7*)
Medium low	(*0.4*, *0.65*, *0.6*)
Medium	(*0.5*, *0.5*, *0.5*)
Medium high	(*0.6*, *0.35*, *0.4*)
High	(*0.8*, *0.15*, *0.2*)
Very high	(*0.9*, *0.1*, *0.1*)

- *Step 3*

The deterministic (crisp) matrix presented below is obtained by compensating by the score value of each neutrosophic number in the neutrosophic pairwise comparison matrix:

$$A=\begin{bmatrix} \boldsymbol{a}_{11} & \cdots & \boldsymbol{a}_{1\boldsymbol{n}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{a}_{\boldsymbol{n}1} & \cdots & \boldsymbol{a}_{\boldsymbol{nn}} \end{bmatrix}$$

We can simply derive the ranking of priorities from the preceding matrix, namely, the eigenvector X, as follows [32]:

1. Normalize the column entries by dividing each one by the column total.
2. Add the totality row averages together.
3. *Step 4*

The selection process becomes more demanding and time-consuming as the number of criteria increases. Therefore, only the critical criteria are taken into consideration for the subsequent evaluation, while the unimportant criteria are rejected. In conjunctive selection procedures, threshold values for one or more criteria are specified. Alternative solutions that have evaluation values for each criterion lower than the threshold value for the specific criterion are rejected. A novel threshold value, inspired from qualitative decision rules in decision analysis, is introduced into the problem to facilitate the expression of the imprecision and/or uncertainty concerning both the criteria values and the decision-makers' preferences. Thus, by combining the judgments of all the analyst (Eq. 9), a minimum acceptable weight for all criteria is defined as a threshold value, which is computed using Eqs. (6) and (7).

Criterion *Ci* with score function below the minimum value of the defined threshold is removed. The remaining criteria will be used in the final selection stage. Therefore, Delphi supports experts in finding the most important criteria and determining the weighting of the criteria used to input the N-AHP for the evaluation of applicants.

- *Step 5*

A consistency index (CI) is provided by AHP approach to quantify inconsistency within the judgments in each comparison matrix and for the overall hierarchy [42]. AHP method employs the consistency index and consistency ratio to determine whether there is any contradiction in the neutrosophic judgment matrix (CR). If the CR is more than 0.1, the decisions are regarded as unreliable because they are too near to randomness, and the procedure is either invalid or must be redone. For this purpose and with the intention to compute CI and CR, we follow exactly the steps outlined in [26].

3.5 Neutrosophic AHP (N-AHP)

A nine-point scale is used in the conventional AHP for pairwise comparisons at each level regarding the objective of the best alternative selection. Consequently, Saaty's AHP application has the limitations listed below [11]:

1. In most cases, the AHP method is used in nearly crisp decision scenarios.
2. The AHP technique produces and deals with a highly unsteady judgment scale.
3. The ambiguity associated with converting one's judgment to a number is ignored by the AHP technique.
4. The AHP method's ranking is somewhat imprecise.
5. The decision makers' subjective assessment, selection, and preference have a substantial influence on the AHP findings.

A DM's criteria for evaluating alternatives can frequently contain ambiguity and multiple interpretations. Fuzzy sets could be integrated with the pairwise comparison extension of AHP to capture this kind of uncertainty in human preference. Fuzzy logic is used to deal with the concept of partial truth, where the truth value can be somewhere between true and false. Fuzzy sets are unable to address the uncertainty and indeterminacy that exist in the real world because they only consider the membership function and ignore non-membership and indeterminacy. To overcome the drawbacks of fuzzy sets, we implemented our proposed approach in a neutrosophic setting. The neutrosophic set extends or generalizes the intuitionistic fuzzy set. It effectively and efficiently illustrates situations from real-world challenges (i.e., truthiness, indeterminacy, and falsity) by considering all factors in a decision situation. For the purpose of avoiding the compensatory approach and AHP's incapacity to handle linguistic factors, the neutrosophic AHP (N-AHP) variation is used. The neutrosophic AHP approach may be used to better properly depict the decision-making process. Prioritizing criteria is one of the most difficult aspects of the multi-criteria decision-making process.

- *Step 1*

Experts may consider that not all attributes are equally important during the decision-making process. As a result, each expert may have a unique viewpoint on attribute weights. To obtain the combined opinion of the chosen characteristic, all decision makers' assessments of the relevance of each attribute must be aggregated. Let $\boldsymbol{w}_{\boldsymbol{k}}^{j} = (\boldsymbol{w}_{1}^{(j)},\boldsymbol{w}_{2}^{(j)}\ldots..,\boldsymbol{w}_{\boldsymbol{p}}^{(j)})$ be the neutrosophic number (NN) allocated to the criterion C_j by the kth decision-maker. Then, the combined weight $W = \{w_1,w_2 \ldots .., w_{\boldsymbol{n}}\}$ of the attribute can be determined by using *SVNWA* aggregation operator using Eq. (9) where $w_j = \langle \boldsymbol{T}_{ij},\boldsymbol{I}_{ij}, \boldsymbol{F}_{ij}\rangle$ for $j = 1, 2, \ldots .., n$.

Finally, the criteria assessment matrix was constructed by pairwise comparisons of various attributes connected to the overall goal using linguistic variables and respective neutrosophic numbers as depicted in Table 4.

Table 4 Linguistic variables describing weights of the criteria

Linguistic variable	***SVNN's***	***Reciprocal SVNN***
Just equal	$(0.5, 0.5, 0.5)$	$(0.5, 0.5, 0.5)$
Weakly important	$(0.6, 0.35, 0.4)$	$(0.4, 0.45, 0.6)$
Strongly important	$(0.7, 0.3, 0.3)$	$(0.3, 0.3, 0.7)$
Very strongly important	$(0.8, 0.25, 0.2)$	$(0.25, 0.75, 0.8)$
Extremely preferred	$(0.9, 0.1, 0.1)$	$(0.1, 0.9, 0.9)$

- *Step 2*

Follow *Step 1* through *Step 3* described in N-Delphi method so as to determine the fused criteria weight vector by which we can get the priorities of attributes.

- *Step 3*

Measure each alternative's total priority and calculate the final score of all options.

4 Application

For the application of the proposed methodology, we decided to study a real problem firstly appeared in [11]. In this way, we will use our proposed method in neutrosophic environment and compare its results with the aforementioned work. It should be mentioned that in [11], scholars utilized fuzzy Delphi and fuzzy AHP methods as their proposed framework in order to choose the best candidate amongst the final three applicants. However, we believe that their method presents some limitations. The results stemming from their method are not consistent with intuition in some situations. Specific analysis will be presented in the following section. Because DMs have varying experiences, qualifications, and designations, their opinions carry different levels of weight in the decision-making process. The decision team consists of three academics from the same academic institution that have the right to make the final choice and are referred to as DM 1, DM 2, and DM 3. The decision-maker's experience, educational level, and academic qualifications are utilized to compute their weights. For example, decision-maker 1 is a lecturer with a Ph.D. and current teaching experience of 2 years, which

Table 5 Candidate scores under the final criteria

Criteria	**Cand. A**	**Cand. B**	**Cand. C**
Criterion 1	0.32	0.35	0.33
Criterion 4	0.27	0.31	0.42
Criterion 5	0.18	0.36	0.46
Criterion 7	0.13	0.27	0.60
Criterion 9	0.26	0.31	0.42

Table 6 Candidate ranking

	Cand. A	*Cand. B*	*Cand. C*
Final ranking	**0.23**	**0.28**	**0.27**

correlates to the neutrosophic number (0.35, 0.6, 0.7) in the educational level; the number (0.8, 0.2, 0.15) in the studies level; and the number (0.35, 0.6, 0.7) in the professional experience level respectively. The same procedure is followed with the two other DMs and then we formulate a 3×3 neutrosophic matrix (Table 9) and with the help of Eq. 6, and by normalization of the matrix, we get the eigenvalue vector of DM weight given by $W = \{0.25, 0.32, 0.42\}$.

On the basis of the decision makers' weights and judgment, the processes indicated in the N-Delphi method subsection were applied to establish each criterion's weighted aggregated value and crisp value. Table 10 displays the DMs' judgments as well as the aggregate values of the five criteria specified for the first examination.

Remove unimportant criteria. It was decided to select all the criteria with score function more than 0.70 ($SF \geq 0.70$) and eliminate the rest. The notion of the threshold value adopted in our study follows a unique approach that was inspired in a loose way from the MAXMIN criterion often credited to Wald [43], treating the criteria under consideration as the decision alternatives and their score functions as their payoff values (or outcomes). We should remark that in the field of decision analysis, the states of nature are the potential outcomes for a chance event. The definition of the states of nature ensures that only one of the possible states of nature will finally occur. We refer to the consequence resulting from a specific combination of a decision alternative and a state of nature as a payoff. The maximum of the minimums or the conservative approach evaluates each decision alternative in terms of the worst payoff that can occur thus minimizing the risk taken by the decision-maker [43]. According to the MAXMIN criterion, the decision-makers' attempt is to maximize (*MAXimize*) the minimum (*MINimum*) possible profit that could be obtained in each case. In this context, the threshold value (i.e., 0.70) was chosen to be the *maximum* value or best payoff of the score functions obtained by all criteria evaluated from the team of experts when considering the *minimum* requirements of each criterion that the applicants should at least meet.

Attempting to define formally the threshold value in the context of decision analysis, we follow the concepts described in [44] which correlate a set S of states of nature and a set X of potential consequences of decisions where states encode possible situations, outcomes etc. with a utility function u which assigns a utility value $u(x) \in \mathbb{R}$ to each consequence $x \in X$.

Table 7 Comparison of methods

Model	*Selected criteria*	*Ranking (Candidates)*
F-AHP and F-DM [5]	*1, 3, 4, 5, and 9*	$A > B > C$
N-AHP and N-DM	*1, 4, 5, 7, and 9*	$B > C > A$

Table 8 Ranking of candidates [11]

	Cand. A	*Cand. B*	*Cand. C*
Final ranking	**0.52**	**0.30**	**0.18**

From the terminology used in the previous study and thinking logically in terms of our research scope, we are now able to define a novel approach for the MAXMIN criterion which will be used as our threshold value, i.e.,

$$T^{-}(f) = max\ min_{s\in S}\ u(f(s)) \tag{11}$$

In this respect, the selected main criteria are *Comprehension of academic field* (*C1*), *Research skills* (*C4*), *Collaboration* (*C5*), *Creativity-Innovation* (*C7*), and *Commitment to the result* (*C9*). It should be highlighted that by reducing the minimum acceptable weight (i.e., threshold) for all of the criteria, more criteria can be chosen for final classification.

The perceived significance of each of the selected criteria is determined for multi-criteria academic staff selection. The aggregated evaluation matrix of the criteria was then created utilizing the linguistic variables and single-valued neutrosophic numbers following steps 1 and 2 as specified in the N-AHP method sub-section (see Appendix Table 11).

Inconsistency of SVNN used can be checked and the consistency ratio (CR) has to be calculated. The obtained findings are as follows: largest eigenvalue of matrix, $\lambda max = 5.26$; consistency index (C.I.) = 0.07; randomly generated consistency index (R.I.) = 1.12; and consistency ratio (C.R.) = 0.06 As. CR < 0.1 the amount of inconsistency in the information recorded in the comparison matrix is acceptable [23].

In accordance with the answers, we received from the group of experts (pairwise comparison of each applicant under each criterion) and by using Eqs. (6) and (7), the neutrosophic pairwise comparison table is transformed to deterministic one followed by normalization of column sums and overall average of each row. This leads us to the priority (weight) vector of each candidate under the selected criteria (Appendix, Tables 12, 13, 14, 15 and 16).

The following summary table (Table 5) is created based on the results of previous tables.

Then, the relative scores for each alternative are as follows:

$$\begin{bmatrix} 0.32 & 0.27 & 0.18 & 0.13 & 0.26 \\ 0.35 & 0.31 & 0.36 & 0.27 & 0.31 \\ 0.33 & 0.42 & 0.46 & 0.60 & 0.42 \end{bmatrix} \times \begin{bmatrix} 0.13 \\ 0.19 \\ 0.16 \\ 0.18 \\ 0.33 \end{bmatrix} = \begin{bmatrix} 0.23 \\ 0.28 \\ 0.27 \end{bmatrix}$$

According to the above, the AHP ranking of decision alternatives is shown in Table 6.

Following completion of all of the aforementioned activities, the decision-making committee can assess the choices and select the best course of action (in our example, selecting candidate B to fill the post of professor).

5 Results

In this section, we compare our proposed approach to selecting the "best" candidate as academic staff with the approach outlined in [11] in the context of a real case study. The outcomes are shown in Table 7, and according to these, we could quote the following remarks:

1. The best candidate for the intended position in our study is Applicant B while in [11], the position is occupied by Applicant A. It is obvious that the difference in the examined outcomes is due to the fact that in the present study, we take care of uncertainty and indeterminacy in a high degree, factors that are not tackled in a satisfactory way with the method used in [11]. The neutrosophic logic may manage both incomplete and inconsistent evidence, which is quite likely to occur in a multi-criteria decision-making process. Unlike other logic-based approaches, neutrosophic logic-based methods are superior indicators of true information due to their ability to overcome indeterminacy issues. Neutrosophic procedures are chosen over other classical or fuzzy techniques because of their increased accuracy and precision. The above could be supported if we examine further the scores achieved from the candidates (A, B, and C) when applying the compared methods. In our case, we obtain the results shown above in Table 6 where it can be observed that candidates' scores range in the interval [0.23, 0.28], meaning that the competence of the final applicants is about in the same level, so a method that would guarantee a high degree of accuracy is needed to make the "best" decision. On the contrary, if we examine the candidates' scores obtained in [11], we will observe that the respective range, or the "distance" between applicants, is quite wide as indicated in Table 8, i.e., the ranking values of the candidates fluctuate in the closed interval [0.18, 0.52].

   We believe that, considering the academic profiles of candidates as shown in Tables 17, 18, and 19, their results do not efficiently interpret human rationale. It can be observed that decision-makers have to deal with a decision analysis in which the final applicants appear to be almost equally qualified based on their academic qualifications. As a result, it is difficult to select the most suitable candidate for the position.
2. This high accuracy of results is the reason why we observe a minor difference in the criteria selected for the final evaluation of the suitable applicant. In our work, criteria 7 (Creative thinking-Innovation) is preferred over criteria 3 (Foreign Languages) which was instead chosen in [11] (although with a very small difference in their weightage, e.g., criterion 3 scored 1.07 as opposed to criterion 7 which scored 1.06). Our present work strengthens reality with our results, as innovation-creativity is not only intuitively, but also scientifically, considered to be a significantly more important and useful attribute that is much more appreciated than the knowledge of foreign languages when it comes to the selection of academic staff in a real situation [45]. Therefore, our method proves its suitability in weighing the criteria in an efficient way even in situations where it is not exactly clear the relative importance of a criterion over another one as shown in this example.

3. The above outcome indicates the superiority of our chosen threshold value as a manner to eliminate unnecessary computational cost whilst retaining the most important criteria for the next phase of evaluation of candidates. Our threshold value was considered under the logical assumption of maintaining only those criteria that would satisfy the condition of overcoming the maximum value among the obtained minimum score functions obtained from of all criteria. Defining and selecting a threshold veto value as described above grants an intuitive value as well, because in our case, we would like to be sure that only the most essential criteria will be selected in the next phase. This is feasible due to the unique definition we refer to the MAXMIN criterion as seen in in the previous section (see Eq. (14)). Instead, in [11], we observe that the selection of the threshold value is achieved in a more arbitrary way as it is not clearly indicated the logical meaning behind its selection.

Through the above numerical example, it can be concluded that solving multi-criteria decision-making problems using the proposed method is very reasonable and effective thus reinforcing our belief about its applicability in a wider range of scientific areas.

6 Conclusions

The field of multi-criteria decision analysis has established itself as a fundamental area in business research. The rapid growth of this field has resulted in the creation of a new methodological framework for analyzing decision-making problems. Key aspects of this framework include acknowledging the multidimensional nature of the decision-making process and incorporating the decision-maker's preferences and policies into the analysis process.

Within this general framework, selection of proper academic staff is a critical success element for a university—the process's complexity and relevance necessitates the use of analytical approaches rather than intuitive judgments. The goal of this project is to provide an integrated method for evaluating and choosing individuals at academic institutions. The model is basically an integrated implementation of Delphi and AHP method in a neutrosophic environment. This method supports the academic staff selection according to a group of experts' criteria. The experts' consensus on the significance of selected criteria is ensured by the Delphi method. The advantage of the neutrosophic framework is that it includes both uncertainty and indeterminacy in decision-making. Another benefit is that experts use linguistic scales to conduct evaluations, which brings the final results closer to human rationality. Finally, this method approves its usefulness in a real multi-criteria decision-making problem as presented in [11]. To the best of our knowledge, this is the first time that a conceptual model like ours has been proposed in the literature. It combines the Delphi method with AHP in a neutrosophic framework, introducing a new measurement: the veto threshold. This threshold reflects the minimum requirements of the decision-makers in each criterion and is loosely based on the MAXMIN approach used in decision analysis. A fundamental criticism of the previous method is that it does not consider any information about the potential outcomes of different states of nature. When probability evaluations for natural states are available, the expected value technique may be utilized to determine the best decision option or decision strategy [43]. Sensitivity analysis might be performed in this context to examine the impact of changes in the probabilities for the states of nature and changes in the values of the payoffs on the proposed decision option.

According to the experimental results, the proposed method proves its capability in obtaining the expected results when compared to the existing multi-criteria decision-making method proposed in [11] for simplified neutrosophic sets. Therefore, it is concluded that the achievement of this paper could produce a significant prospect and potential in solving multi-criteria decision-making problems. For the time being, our method is limited to selecting the appropriate candidate for academic position in neutrosophic environment with the specific techniques (Delphi and AHP).

By proposing and applying our conceptual methodological framework, we demonstrate practical utility and relevance in addressing real-world problems beyond academia. The integration of the suggested methodology to other MCDMA methods to handle various issues in other domains, such as project assessment, supplier selection, manufacturing systems, and many other areas of management systems, might be a future step towards our research.

Other possible and interesting future research work would involve applying our conceptual framework and attempting to adapt it to the concept of neutrosophic cognitive map (NCM), an extension of fuzzy cognitive map (FCM) that includes indeterminacy. Furthermore, our method could be integrated with simplified neutrosophic projection measure (SNPM) methods that address multiple attribute decision-making (MADM) problems, as they demonstrate the ability to consider not only the distance, but also the included angle between evaluated objects.

A novel approach would be to solve the problem of academic staff selection utilizing the Brown-Gibson model. This concept, which is related to the characteristics of the preference theory and used to evaluate subjective factors, is a multi-attribute decision analysis model that has been applied in various engineering and science fields. It uses a combination of factors, namely, critical, subjective, and objective factors, with the aim to provide with the suitable solution of the under examination problem. However, although different versions of the model have been established, still, no research study related to the implementation of this model has been published proposing a method of extending it and applying it in a neutrosophic environment.

Table 9 Comparison matrix for relative importance of DMs

	Academic level	**Experience**	**Studies**	W_K
DM 1	(0.35, 0.6, 0.7)	(0.8, 0.2, 0.15)	(0.35, 0.6, 0.7)	***0.25***
DM 2	(0.5, 0.4, 0.45)	(0.8, 0.2, 0.15)	(0.5, 0.4, 0.45)	***0.32***
DM 3	(0.8, 0.2, 0.15)	(0.8, 0.2, 0.15)	(0.8, 0.2, 0.15)	***0.42***

Table 10 Weighted aggregate of criteria

Criteria	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	*Aggregated SVNN*	**Score function**	**Selected or rejected (*S* or *R*)**
				Weightage of DMs					
				0.25	**0.32**	**0.42**			
1	(0.9, 0.1, 0.1)	(0.6, 0.35, 0.4)	(0.8, 0.15, 0.2)				(0.79, 0.39, 0.64)	0.80	*S*
2	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.6, 0.35, 0.4)				(0.54, 0.43, 0.46)	0.55	*R*
3	(0.6, 0.35, 0.4)	(0.5, 0.5, 0.5)	(0.6, 0.35, 0.4)				(0.57, 0.40, 0.43)	0.58	*R*
4	(0.9, 0.1, 0.1)	(0.8, 0.15, 0.2)	(0.8, 0.15, 0.2)				(0.83, 0.14, 0.17)	0.85	*S*
5	(0.5, 0.5, 0.5)	(0.8, 0.15, 0.2)	(0.8, 0.15, 0.2)				(0.74, 0.21, 0.26)	0.77	*S*
6	(0.5, 0.5, 0.5)	(0.6, 0.35, 0.4)	(0.6, 0.35, 0.4)				(0.57, 0.39, 0.43)	0.59	*R*
7	(0.6, 0.35, 0.4)	(0.6, 0.35, 0.4)	(0.8, 0.15, 0.2)				(0.7, 0.25, 0.3)	0.73	*S*
8	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.8, 0.15, 0.2)				(0.66, 0.30, 0.34)	0.68	*R*
9	(0.8, 0.15, 0.2)	(0.5, 0.5, 0.5)	(0.8, 0.15, 0.2)				(0.73, 0.22, 0.27)	0.75	*S*
10	(0.5, 0.5, 0.5)	(0.6, 0.35, 0.4)	(0.6, 0.35, 0.4)				(0.57, 0.39, 0.43)	0.59	*R*

Table 11 Aggregated comparison matrix for relative importance of criteria

	Criterion 1	**Criterion 4**	**Criterion 5**	**Criterion 7**	**Criterion 9**	W_κ
Criterion 1	1.00	0.38	0.74	0.84	0.56	***0.13***
Criterion 4	2.64	1.00	0.64	0.87	0.64	***0.19***
Criterion 5	1.34	1.56	1.00	0.70	0.28	***0.16***
Criterion 7	1.19	1.14	1.44	1.00	0.54	***0.18***
Criterion 9	1.80	1.56	3.60	1.85	1.00	***0.33***

Table 12 Aggregated weightage of candidates under criterion 1

Criterion 1	**Candidate A**	**Candidate B**	**Candidate C**	$\mathbf{W\kappa_1}$
Candidate A	(0.5, 0.5, 0.5)	(0.72, 0.29, 0.28)	(0.7, 0.3, 0.3)	**0.32**
Candidate B	(0.3, 0.65, 0.7)	(0.5, 0.5, 0.5)	(0.6, 0.35, 0.4)	**0.35**
Candidate C	(0.32, 0.62, 0.69)	(0.4, 0.45, 0.69)	(0.5, 0.5, 0.5)	**0.33**

Table 13 Aggregated weightage of candidates under criterion 4

Criterion 4	**Candidate A**	**Candidate B**	**Candidate C**	$\mathbf{W\kappa_4}$
Candidate A	(0.5, 0.5, 0.5)	(0.76, 0.24, 0.28)	(0.73, 0.29, 0.27)	**0.27**
Candidate B	(0.29, 0.66, 0.75)	(0.5, 0.5, 0.5)	(0.63, 0.34, 0.37)	**0.31**
Candidate C	(0.28, 0.72, 0.73)	(0.37, 0.52, 0.63)	(0.5, 0.5, 0.5)	**0.42**

Table 14 Aggregated weightage of candidates under criterion 5

Criterion 5	**Candidate A**	**Candidate B**	**Candidate C**	$\mathbf{W\kappa_5}$
Candidate A	(0.5, 0.5, 0.5)	(0.39, 0.54, 0.61)	(0.37, 0.52, 0.63)	**0.18**
Candidate B	(0.61, 0.37, 0.39)	(0.5, 0.5, 0.5)	(0.68, 0.32, 0.32)	**0.36**
Candidate C	(0.63, 0.34, 0.37)	(0.38, 0.6, 0.64)	(0.5, 0.5, 0.5)	**0.46**

Table 15 Aggregated weightage of candidates under criterion 7

Criterion 7	**Candidate A**	**Candidate B**	**Candidate C**	$\mathbf{W\kappa_7}$
Candidate A	(0.5, 0.5, 0.5)	(0.32, 0.63, 0.68)	(0.26, 0.74, 0.78)	**0.13**
Candidate B	(0.67, 0.32, 0.33)	(0.5, 0.5, 0.5)	(0.29, 0.66, 0.66)	**0.27**
Candidate C	(0.78, 0.27, 0.22)	(0.76, 0.28, 0.24)	(0.5, 0.5, 0.5)	**0.60**

Table 16 Aggregated weightage of candidates under criterion 9

Criterion 9	**Candidate A**	**Candidate B**	**Candidate C**	$\mathbf{W\kappa_9}$
Candidate A	(0.5, 0.5, 0.5)	(0.76, 0.28, 0.24)	(0.67, 0.32, 0.33)	**0.26**
Candidate B	(0.29, 0.66, 0.75)	(0.5, 0.5, 0.5)	(0.63, 0.34, 0.34)	**0.31**
Candidate C	(0.32, 0.63, 0.68)	(0.37, 0.52, 0.63)	(0.5, 0.5, 0.5)	**0.42**

Appendix B

Table 17 Academic profile of candidate A [5]

Candidate A			
Academic education	• PhD in Computer Science, Aristotle University of Thessaloniki, Greece • Bachelor Degree in Computer Science, Technological Institute of Thessaloniki, Greece		
Foreign languages	• Proficiency in English Language		
Experience	2011–2015	Position: senior researcher Employer: EKETA Thessal., Greece	
	2016–2020	Position: adjunct lecturer Employer: University of Patras, Greece	
Research articles	20 research papers and 5 book chapters in the field of AI		
Research projects	2013–2017	SmartCLIDE: Smart Cloud Integrated Development Environment	Senior researcher
Awards/honors	2016	Personal Research Grant “Support for PostDoc Researchers”	National Scholarships Association

Table 18 Academic profile of candidate B [5]

Candidate B			
Academic education	• PhD in Computer Science, Aristotle University of Thessaloniki, Greece • Bachelor Degree in Physics, Aristotle University of Thessaloniki, Greece		
Foreign languages	• Proficiency in English language • Very good knowledge of German language		
Experience	2015–2017	Position: adjunct lecturer Employer: University of Cyprus	
	2018–2021	Position: visiting lecturer Employer: Univ. Of Essex, UK	
Research articles	14 research article and 9 book chapters in Software Engineering field		
Research projects	2015–2017	EXA2PRO: Enhancing Programmability and boosting Performance Portability for Exascale Computing Systems	Senior researcher
Awards/honors	2016	Acknowledged as the 3rd most active Early Stage Researcher in terms of publishing in high-quality Software Engineering journals	Journal of Systems and Software
	2018	Acknowledged as part of the top-7 reviewers	Journal of Systems and Software
	2020	Seal of Excellence from the European Commission awarded to Proposals of Excellent Quality (> 85%) submitted in the Individual Fellowship call of Marie Curie Research Actions	Marie Curie Research Actions

Table 19 Academic profile of candidate C [5]

Candidate C			
Academic education	• PhD in Computer Science, Aristotle University of Thessaloniki, Greece • MBA, National Kapodistrian University of Athens, Greece • Master of Science in Comp. Science, National Kapodistrian University of Athens, Greece • Bachelor Degree in Mathematics, National Kapodistrian University of Athens, Greece		
Foreign languages	• Proficiency in English language • Very good knowledge of German language • Very good knowledge of French language		
Experience	2018–2021	Position: adjunct lecturer Employer: Univ. of York, UK	
Research articles	9 research articles and 3 book chapters in Software Engineering field		
Research projects	2018	SDK4ED: Software Development Kit for Energy and Technical Debt Management	Senior researcher
	2019	GraDAna: Improving Innovation and Entrepreneurship Competences of Iranian Higher Education Graduates through Data Analytics	Project and technical manager
	2020	WJETSS: Whole-Journey Experience through Sen-Sourcing	Senior researcher

Appendix B

Author Contribution Antonios Paraskevas: Conceptualization, Investigation, Data Curation, Formal Analysis, Methodology, Validation, Writing—Original Draft. Michael Madas: Conceptualization, Validation, Writing—Review & Editing, Supervision, Project administration.

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Declarations

Conflict of Interest The authors declare no competing interests.

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