World Academy of Science, Engineering and Technology
International Journal of Electrical and Information Engineering
Vol:18, No:10, 2024

A Multi-Criteria Decision Method for the Recruitment of Academic Personnel Based on the Analytical Hierarchy Process and the Delphi Method in a Neutrosophic Environment

Antonios Paraskevas, Michael Madas

***Abstract*—**For a university to maintain its international competitiveness in education, it is essential to recruit qualitative academic staff as it constitutes its most valuable asset. This selection demonstrates a significant role in achieving strategic objectives, particularly by emphasizing a firm commitment to exceptional student experience and innovative teaching and learning practices of high quality. In this vein, the appropriate selection of academic staff establishes a very important factor of competitiveness, efficiency and reputation of an academic institute. Within this framework, our work demonstrates a comprehensive methodological concept that emphasizes on the multi-criteria nature of the problem and on how decision makers could utilize our approach in order to proceed to the appropriate judgment. The conceptual framework introduced in this paper is built upon a hybrid neutrosophic method based on the Neutrosophic Analytical Hierarchy Process (N-AHP), which uses the theory of neutrosophy sets and is considered suitable in terms of significant degree of ambiguity and indeterminacy observed in decision-making process. To this end, our framework extends the N-AHP by incorporating the Neutrosophic Delphi Method (N-DM). By applying the N-DM, we can take into consideration the importance of each decision-maker and their preferences per evaluation criterion. To the best of our knowledge, the proposed model stands out within the realm of related literature as one of the few studies to employ N-DM in the context of academic staff selection. As a case study, it was decided to use our method to a real problem of academic personnel selection, having as main goal to enhance the algorithm proposed in previous scholars' work, and thus taking care of the inherit ineffectiveness which becomes apparent in traditional multi-criteria decision-making methods when dealing with situations alike. As a further result, we prove that our method demonstrates greater applicability and reliability when compared to other decision models.

***Keywords*—**Analytical Hierarchy Process, Delphi Method, Multi-criteria decision making methods, neutrosophic set theory, personnel recruitment.

I. Introduction

HUMAN resources are regarded as one of the most significant, if not the most important, asset for any organization seeking long-term development and success. The goal of the personnel selection process is to suggest the best applicant for the suitable position inside an organization [1].

Multiple-criteria decision making (MCDM) issues with quantitative or qualitative attribute values are employed in a variety of scientific domains, such as operation research, management science, economics, and so on. Because of the ambiguity and complexity of the criteria involved, the attribute values of MCDM issues cannot always be described properly using crisp numbers, hence leading to misconceptions. In this sense, the decision-makers' preference value for assessing alternatives has a high likelihood of being ambiguous, imprecise, or incomplete.

Professor Smarandache proposed neutrosophic logic, as a first attempt to unify many logics in a single field, because fuzzy logic is thought to be incapable of showing indeterminacy on its own [2]. According to [3], 'Neutrosophic logic is a logic variant that extends fuzzy logic, paraconsistent logic, intuitionistic logic, and so on.' 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. Wang et al. [4], [5] suggested interval neutrosophic sets (INSs) and single-valued neutrosophic sets (SVNSs) as NS subclasses. SVNSs and INSs are exceptionally powerful tools for studying imprecise, incomplete, and uncertain data, which are common in many engineering and technological problems.

There is a plethora of MCDM approaches in the literature that attempt to deal with academic staff selection, but most of these studies, e.g. [6]-[8], show limitations due to the fact that these types of problems rely primarily and heavily on human judgement and intuition, resulting in a high degree of uncertainty and incomplete and/or inconsistent information. As a result, "intelligent" inference approaches that analyse vague input and knowledge are required. In this context, current paper suggests a hybrid MCDM methodology in a neutrosophic framework that takes into consideration the problems encountered in decision-making regarding human judgement and proposes a coherent and robust "algorithm" that proves its efficiency in real world problems.

The rest of this paper is organized as follows: Section II presents brief prior relevant research dealing with the personnel/academic staff selection problem from a MCDM perspective. Section III describes the stages involved in developing our method's algorithm. Following that, in section IV, we demonstrate how our methodology works in a real case study based on academic personnel selection. Finally, Section V highlights conclusions and potential future work.

Antonios Paraskevas and Michael Madas are with the Department of Applied Informatics, University of Macedonia, Egnatias Str. 156, 54636, Thessaloniki, Greece (e-mail: aparaskevas@uom.edu.gr, mmadas@uom.edu.gr).

II. Literature Review

The personnel selection procedure is suggested by many researchers to be utilized by decision support system tools in order to improve the judgments of decision makers [9], [10]. An aggregating function, or “closeness to the ideal” solution, is used in [11]. The AHP approach divides the problem into a top-down hierarchical framework to improve decision makers' judgements [12]. Fuzzy approaches are presented to improve decision makers' judgements throughout the personnel selection process due to vague and inaccurate information [13]. Fuzzy AHP is a method used to rate applications and select the best candidate [14]. The AHP and TOPSIS approaches, along with neutrosophic logic, are employed in a range of domains, including supplier selection and risk, and decision support, resulting in the best judgements under ambiguity and inconsistency [15], [16].

In order to select the best learning management system, researchers in [17] proposed a neutrosophic AHP technique. They claimed that neutrosophic set theory makes expert assessments more flexible, whereas the traditional AHP technique considers decision makers' definitive judgements. Another neutrosophic AHP-related research paper is published in [18]. In order to deal with experts' non-deterministic assessment values, they created a neutrosophic AHP Delphi group decision-making model based on trapezoidal neutrosophic numbers. In [19], the researchers introduced a system for group decision making based on N-AHP that used triangular neutrosophic numbers and addressed a real-world problem created by the experts.

The Delphi method is a well-known method used in many different research fields, including program planning, resource allocation, policy evaluation, requirements assessment and economics. In [20], researchers combined AHP with Delphi to address conflict resolution in recruitment choices. Recently, in [21], researchers developed a model that incorporates fuzzy AHP and fuzzy Delphi and used it in real case study, i.e. to select an academic at Neapolis University Pafos in Cyprus.

There are very few studies in the literature that use the Delphi technique in a neutrosophy context. For example, in [22], the N-Delphi technique for evaluating academic research projects is presented, which is supported by neutrosophy logic. Their concept is based on the Delphi technique, which supports the consensus index to avoid Delphi's sluggish convergence, albeit this may need numerous rounds to obtain agreement between experts, and is used to anticipate future scenarios or occurrences through expert evaluation. The neutrosophic paradigm benefits decision-making by including both uncertainty and indeterminacy. Another benefit is that specialists perform evaluations using language scales, which boosts the validity of the results.

III. Materials and Methods

In this section we present essential definitions involving SVNSs and outline the steps of the proposed methodology.

Definition 1 [23]. Let X be a space of points (objects), with a generic element in X denoted by x. An SNS N in X is characterized by a truth-membership function $T_N(x)$, an indeterminacy-membership function $I_N(x)$ and a falsity-membership function $F_N(x)$. Then, an SNS N can be expressed as $N = \{<x, T_N(x), I_N(x), F_N(x)>|x \in X\}$, where the sum of $T_N(x), I_N(x), F_N(x) \in [0, 1]$ satisfies the condition $0 \leq \sup T_N(x) + \sup I_N(x) + \sup F_N(x) \leq 3$ for each point x in X. Then, SNS is a subclass of the neutrosophic set and includes the concepts of SVNS. Then, a simplification of the neutrosophic set A, which is a subclass of neutrosophic sets, is denoted by

$$A = \{\langle x, T(x), I(x), F(x)\rangle \mid x \in X\} \quad (1)$$

Definition 2 [24]. If A is a single valued neutrosophic number, a score function S(A) is mapped into the single crisp output S(A’) as follows:

$$S(A) = (3+T_A-2I_A-F_A)/4 \quad (2)$$

$$S(A') = 1 / S(A) \quad (3)$$

A. Neutrosophic Logic to Assign Weights to the Decision-Makers

The DMs weights have been assigned based on the fact that their opinions represent different importance due to their different experience, position, and academic qualification. Let $D^{(k)} = (d_{ij}^{(k)})_m \times_n$ be the single-valued neutrosophic decision matrix of the k-*th* decision maker and $\mathbf{\Psi} = (\psi_1,\psi_2,..\psi_p)^T$ be the weight vector of decision maker such that each $\psi_\kappa \in [0,1]$. The aggregated matrix could be created by applying the single valued neutrosophic weighted averaging (SVNWA) aggregation operator, as suggested by Ye [25] for SVNSs as shown: $\mathcal{D} = (d_{ij}^{(k)})_m \times_n$ where

$$d_{ij} = \text{SVNSWA}_\psi (d_{ij}^{(1)}, d_{ij}^{(2)}, ... d_{ij}^{(p)}) = \psi_1 d_{ij}^{(1)} \oplus \psi_1 d_{ij}^{(2)}, \oplus ......\oplus \psi_p d_{ij}^{(p)} = \left\langle 1-\prod_{\kappa=1}^{p}(1-T_{ij}^{(p)})^{\psi_\kappa}, \prod_{\kappa=1}^{\pi}(I_{ij}^{p})^{\psi_\kappa}, \prod_{\kappa=1}^{\pi}(F_{ij}^{p})^{\psi_\kappa}\right\rangle \quad (4)$$

B. Neutrosophic Delphi (N-Delphi)

In order to maintain only the most critical characteristics for academic staff selection, a neutrosophic Delphi technique is used. Using this approach, unimportant criteria may be recognized and hence removed.

Each DM is asked to assess the importance of each evaluation criterion using a questionnaire. The goal is to incorporate all DMs' perspectives in order to eliminate irrelevant criteria. Table I lists the language words that can be used in the questionnaire.

TABLE I
List of Linguistic Terms (Adopted and Modified From [17])

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)*

In order to decide the weight of each criterion from corresponding neutrosophic pairwise comparison matrix, we first transform neutrosophic pairwise comparison matrix to deterministic pairwise comparison matrix, using (4) so as to determine the aggregated neutrosophic decision matrix that can be obtained by fusing all the decision makers' opinion. To calculate the weight of each criterion from corresponding aggregated neutrosophic pairwise comparison matrix, we transform it to deterministic pairwise comparison matrix, by applying (2) & (3).

With compensation by the score value of each neutrosophic number in the neutrosophic pairwise comparison matrix, we get the deterministic (crisp) matrix shown as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

From the previous matrix we can easily find ranking of priorities, namely the Eigen Vector X as follows [26]:

1. Normalize the column entries by dividing each entry by the sum of the column.
2. Take the totality row averages.

The selection process becomes more demanding and time-consuming as the number of criteria increases. Therefore, only critical criteria are taken into consideration for the subsequent evaluation, while unimportant criteria are rejected. Thus, by combining the judgements of the all of the analysts using (3), we define a minimum acceptable weight for all of the criteria, defined as a threshold value.

A consistency index (CI) is provided by AHP approach to quantify inconsistency within the judgements in each comparison matrix and for the overall hierarchy [27]. The AHP approach uses the CI and consistency ratio to detect if the neutrosophic judgement matrix (CR) has any contradictions. If the CR is more than 0.1, the decisions are deemed untrustworthy because they are too near to randomness, and the procedure is either invalid or must be redone. To compute CI and CR, we use the method presented in [28].

C. Neutrosophic AHP (N-AHP)

Experts may consider that not all attributes are equally important during the decision-making process. To acquire the grouped opinion of the chosen attribute, the judgements of all decision makers on the importance of each attribute must be aggregated. Let $w_k^j = (w_1^{(j)}, w_2^{(j)} \ldots, w_p^{(j)})$ be the neutrosophic number (NN) assigned to the attribute C_j by the *k*th decision maker. Then the combined weight $\mathcal{W} = \{w_1, w_2 \ldots, w_n\}$ of the attribute can be determined by using *SVNWA* aggregation operator using (4) where $w_j = \langle T_{ij}, I_{ij}, F_{ij} \rangle$ 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 per Table II.

To determine the aggregated attribute weight vector using the N-Delphi method, we follow the described procedure. This process helps in obtaining the calculated weightage of criteria selected in this phase.

TABLE II
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)*

We calculate overall weightage of each alternative (score) and determine final ranking of all alternatives.

IV. APPLICATION

We investigate a real-world situation in [17] to test the suggested methodology. As a result, we will evaluate our proposed approach in a neutrosophic setting and compare the findings to the previous work. It should be noted that in [17], researchers used the Fuzzy Delphi and Fuzzy AHP approaches as their recommended framework to select the best candidate from the last three applications. Because DMs have varying levels of expertise, credentials, and designations, their perspectives are weighted differently in decision-making. The decision team consists of three academics from the same academic institution that have the authority to make the ultimate decision and are referred to as DM 1, DM 2, and DM 3. The experience, educational level, and academic credentials of the decision-makers are used to calculate their weights. For example, Decision maker 1 is a lecturer who holds a Ph.D. and current experience of two years in the academic field, which means in the educational level corresponds to the neutrosophic number (0.35, 0.6, 0.7); in the studies level, the number (0.8, 0.2, 0.15) and finally, in experience the number (0.35, 0.6, 0.7). The same procedure is followed with the two other DMs and then we formulate a 3x3 neutrosophic matrix and with the help of (3) and by normalization of the matrix we get the eigenvalue vector of DMs weight given by $\mathcal{W}$ = {0.25, 0.32, 0.42}.

On the basis of the decision makers' weights and judgement, the processes indicated in the N-Delphi method subsection were applied to establish each criterion's weighted aggregated value and crisp value.

In order to remove unimportant criteria for the next phase of our method, it was decided to select all the criteria with score function more than 0.70 (SF ≥ 0.70) and eliminate the rest. The notion of the threshold value adopted in our study follows a unique approach that was motivated from the MAXIMIN criterion often credited to Wald [25], treating the criteria under consideration as the decision alternatives and their score functions as their payoff values (or outcomes).

Next, we define, for the purpose of our work, an approach for the MAXIMIN criterion which will be used as our threshold value, i.e.

$$\mathcal{T}(f) = \max \left(\min_{s \in \mathcal{S}} u(f(s)) \right) \quad (5)$$

Equation (5) expresses the idea that given the minimum requirements that an applicant should possess under given criteria according to decision-makers' opinion, we select as a veto value the maximum value of the minimum requirements, thus selecting only those criteria that satisfy at least the maximum value in relation to MAXMIN criterion are used in decision analysis.

From a total of 10 initial criteria, the selected main criteria are Knowledge of the subject (C1), Research ability (C4), Communication (C5), Creativity-Innovation (C7), and Orientation to the result (C9). It should be noted that by reducing the minimum acceptable weight (i.e. threshold) for every criterion, additional criteria can be selected for final classification.

The consistency ratio (CR) must be determined since the SVNN utilized is inconsistent. The obtained findings are as follows: 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 discrepancy in the information recorded in the comparison matrix is acceptable [28].

In accordance with the answers, we received from the group of experts (pairwise comparison of each applicant under each criterion) and by using (2) & (3), the neutrosophic pairwise comparison table is transformed to deterministic 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.

Table III is created based on the results previously outlined.

TABLE III
SCORES OF CANDIDATES UNDER 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

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

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

According to the above multiplication of matrices, the AHP ranking of decision alternatives is shown in Table IV.

TABLE IV
RANKING OF CANDIDATES

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

V. CONCLUSIONS AND FUTURE RESEARCH

Based on the results extracted from both our research and scholarly studies, Table V displays the findings. Consequently, we can articulate the following observations based on these results:

TABLE V
COMPARISON OF METHODS

Model	Selected Criteria	Ranking
F-AHP & F-DM [5]	*1,3,4,5 & 9*	*A > B > C*
N-AHP & N-DM	*1,4,5,7 & 9*	*B > C > A*

The best candidate for the intended position in our study is Applicant B while in [21] the position is occupied by Applicant A. It is evident that the difference in the analysed results is related to the fact that in the current study we address uncertainty and indeterminacy to a greater extent, notions that are not addressed satisfactorily in [21]. The neutrosophic logic can manage both incomplete and inconsistent evidence, which is quite likely to occur in a MCDM procedure.

Because of the high precision of the findings, we notice a little variation in the criteria used for the final evaluation of the appropriate candidate. Criterion 7 (Innovation-Creativity) is favoured in our study above criterion 3 (Foreign Languages), which was selected instead in [21] (although with a very tiny variation in weightage, e.g. criterion 3 scored 1.07 vs criterion 7 scored 1.06). Our current work strengthens reality with our findings, as innovation-creativity is considered to be a significantly more important and useful attribute that is much more valued than knowledge of foreign languages when it comes to the selection of academic staff in a real situation [30], [31].

The above result demonstrates the superiority of our proposed threshold value as a method for reducing needless computational cost whilst retaining the most important criteria for the next phase of evaluation of candidates. Our veto 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 values 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 and utilization we refer to the MAXIMIN criterion as seen in in the previous section (see (5)). Instead, in [21] 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.

The neutrosophic framework ensures the benefit of including both uncertainty and indeterminacy in decision-making. As a first remark, we highlighted the capacity of neutrosophic logic to conciliate both qualitative and quantitative aspects of uncertainty. Another advantage is that professionals conduct assessments using language scales, which brings the final conclusions closer to human logic. Finally, as demonstrated in [21], our strategy validates its use in a real-world MCDM situation. To the best of our knowledge, this study is likely one of the few where a conceptual model like ours has been presented in the related literature. It combines the Delphi method with AHP in a neutrosophic framework that presents a measurement. This is the veto threshold that represents the DMs' minimal needs in each criterion and is based on the MAXIMIN decision analysis technique.

For the time being, our strategy is confined to using certain methodologies (Delphi & AHP) to choose the suitable applicant for an academic job in a neutrosophic environment. A possible next step for our article would be to use our conceptual framework and try to adapt it to the idea of Neutrosophic Cognitive Map (NCM), which is an extension of Fuzzy Cognitive Map (FCM) that includes indeterminacy. NCMs model the world as a collection of classes and causal relations between classes. Furthermore, our technique might be combined with Simplified Neutrosophic Projection Measure (SNPM) methods that deal with multiple attribute decision making (MADM) problems since they can incorporate not only the distance but also the included angle between items assessed. Finally, we think it would be interesting to try to solve the problem of academic staff selection using a hybrid Dempster-Shafer/AHP method. The D-S/AHP method addresses the lack of representation of ignorance by allowing opinions on sets of decision alternatives, focusing on belief for subsets of the frame of discernment, and providing solutions to 'classical' AHP concerns such as the requirement to compare each decision alternative with each other decision alternative, thereby increasing the number of comparisons, and the requirement to check for consistency of decision-makers opinions.

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