Delphi method for evaluating scientific research proposals in a neutrosophic environment

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Abstract. The scientific research proposal is part of the task to be carried out in academic and research institutions around the world. This is a complex decision-making problem, because decision-makers must determine the projects that are appropriate to the subjects addressed by the institution, those projects must be achievable within a reasonable deadline, they must have the financial means and the budget necessary to be carried out, the staff must be sufficiently qualified and an optimum number of personnel must be available to succeed the tasks and not interfere with other research projects. This is a predictive problem, thus, the proposed model is based on Delphi method for evaluating research projects and is supported by neutrosophy. Delphi method is widely applied in the prediction of future events, in this model we introduce the uncertainty and indeterminacy modeled with neutrosophy. As the best of our knowledge, this model is the first one, which applies a neutrosophic Delphi method in the evaluation of scientific research proposals. Finally, a hypothetical case study illustrates the applicability of the method.

Keywords: Research proposal, Delphi method, fuzzy Delphi method, single valued neutrosophic set, single valued triangular neutrosophic number.

1 Introduction

A research proposal is a document that proposes a research project, usually in science or academia, and that usually constitutes a request for sponsorship of such research, see [1-10]. The proposals are evaluated on the cost and potential impact of the research, and on the robustness of the proposed plan to carry it out. Generally, research proposals address several critical points, including the following:

- Which research questions will be addressed and how they will be addressed,
- How much time and expenses will be needed for research,
- What previous research has been done on the subject,
- How research results will be evaluated,
- How research will benefit the sponsoring organization and other parties.

Research proposals could be requested, which means that they are sent in response to a request with specific requirements, such as a request for proposals, or may be unsolicited, which means that they are sent without prior request. Other types of proposals include "pre-proposals", where a letter of intent or documentary summary is sent for review prior to the submission of a full proposal; follow-up proposals, which reiterate an original proposal and its funding requirements to ensure continued funding; and proposals for renewal, which seek the continued sponsorship of a project that would otherwise be terminated.

Academic research proposals are usually written as part of the initial requirements for writing a thesis, research work or dissertation. In general, they follow the same format as a research work, with an introduction, a review of literature, a discussion of the methodology and objectives of research, and a conclusion. This basic structure can vary between projects and between fields, each of which may have its own requirements.

The scientific method is a methodology for obtaining new knowledge, which has historically characterized science, consisting of systematic observation, measurement, experimentation, and the formulation, analysis and modification of hypotheses. Other characteristics of the scientific method are deduction, induction, abduction, prediction, falsifiability, the reproducibility and repeatability of the results, and the peer review. The rules and principles of the scientific method seek to minimize the influence of the subjectivity of the scientist in his\her work, which reinforces the validity of the results, and therefore of the knowledge obtained.

The selection of the most appropriate research topic in the academic or the research institution is not a trivial problem, it needs of the assessment of the topic relevance in the near future, that is, it is a predictive problem. It is also complex, since the decision depends on different factors, some of them depend on the institution's researchers and others are external. This complexity of the problem requires of the experts' opinion on the subject, rather than measuring with objective indicators. The experts are those who can carry out the selection of the most promising projects, which give visibility to the institution and at the same time those projects must be achievable within a reasonable time. Other aspects to be considered are that researchers must have the capacity to attain the selected projects, that there exists the optimal number of scientific personnel working on the project, that the institution must have the necessary financial support to accomplish the research, and the project must be sufficiently relevant such that it can be published in high-impact scientific journals in a relatively short period of time or it results in patents, palpable economic and social results, among others.

Due to the problem complexity and the large number of variables to consider, the proposal selection contains elements of uncertainty and at the also experts could have doubts, ignorance, inconsistencies, among other elements.

This paper aims to propose a model for research proposals selection and evaluation. This model is based on the Delphi method, which is used in predicting future scenarios or events through expert assessment, see [11, 12]. Basically Delphi method is based on the intuitive idea that a group of experts will come to better conclusions than only one of them. The Delphi method consists of applying questionnaires to a group of experts, anonymously, and then each of them gives a response in a first round. The index of agreement between experts is then calculated using a central tendency statistical measure, and if the agreement is not sufficient, a second round is conducted for the experts to reconsider their assessments and so on until sufficient consensus is reached among them. One criticism of the method is that it can converge very slowly and therefore some experts may not continue to collaborate, nevertheless this is a widely used method.

Other authors have extended this method into uncertainty environments, for example fuzzy Delphi includes uncertainty and represents it in form of fuzzy sets, in particular fuzzy numbers are used, see [13-17]. Ishikawa et al. in [18] propose a fuzzy Delphi method where a survey is designed in such a way that a single round is sufficient to perform the calculations. In general, the fuzzy Delphi method has application in several real problems, see [13-17].

Other approaches are based on neutrosophy, which generalizes fuzzy sets, fuzzy intuitionist sets, among others. In the context of neutrosophy Delphi method takes into account the neutrality given by contradictions, ignorance, inconsistencies, among other ones, typical of decision-making. Some papers model fuzzy Delphi method into a neutrosophic framework, see [19, 20]. Abdel-Basset et al. use Delphi method combined with AHP, in a neutrosorphic environment, see [21].

The model proposed in this paper is based on the Delphi method, which helps to select a set of scientific research proposals in a neutrosophic environment. We have not found in the consulted literature the use of Delphi method applied in this topic in a neutrosophic environment. This neutrosophic Delphi method uses single value triangular neutrosophic number, see [22]. The method takes advantage of the possibility of evaluating research proposals in form of linguistic terms, in addition to considering the uncertainty and indeterminacy inherent to neutrosophy frameworks. It is a decision-making model because it allows the evaluation of project alternatives by criteria. In addition, we explicitly set out the minimum criteria that should be considered in conducting evaluations.

The paper consists of the following structure; after this introduction follows Section 2 which contains the concepts necessary to design the model, such as the basic concepts of neutrosophy, its aggregation operators, among others, as well as a brief explanation of the Delphi method. Section 3 describes the proposed model and provides an illustrative case study of the application of the model in a real-life problem. The paper finishes with the conclusions.

2 Basic concepts

This section discusses the concepts and methods to be used throughout this article. Section 2.1. contains a brief explanation of the classic Delphi method, whereas Section 2.2. contains the main concepts of neutrosophy, among them we can find, neutrosophic sets, single valued neutrosophic sets, single valued triangular neutrosophic numbers, aggregation operators for single valued triangular neutrosophic numbers, among other concepts of interest.

2.1 The Delphi method

The Delphi method is a structured communication technique, which is developed as an interactive systematic prediction method, based on a panel of experts, see [11, 12]. It aims to achieve a consensus based on discussion among experts. It is a repetitive process, where its operation is based on the elaboration of a questionnaire to be answered by the experts. Once the information is received, another questionnaire based on the previous one is re-performed to be answered again.

Finally, the study will draw its conclusions from the statistical analysis of the obtained data.

The Delphi as a methodology of forecasting uses expert judgments in technology or social processes considering the responses to a questionnaire to examine the likely guidelines for the development of specific technologies, meta-types of technologies or different processes of social change. The summary of expert judgments (in the forms of quantitative assessments and written comments) are provided as feedback to the experts themselves as parts of a next round of questionnaire. Experts then reassess their views in the light of this information, and a group consensus tends to emerge. The Delphi technique is based on firm concepts to draw conclusions with supported arguments.

Delphi is based on:

- Anonymity of participants.
- Repeatability and controlled feedback.
- Group response in statistical form.

Before starting Delphi, a number of previous tasks are performed, such as:

- Define the context and time horizon in which the forecast on the subject under study is to be made.
- Select the panel of experts and get the commitment to collaboration. People who are elected should not only be very knowledgeable about the subject on which the study is being conducted, but should present a plurality in their approaches. This plurality should avoid the appearance of biases in the information available in the panel.
- Explain to experts what the method is. This is intended to get obtaining reliable forecasts, because the experts are going to know at all times what is the objective of each of the processes required by the methodology.

The core of Delphi technique is a series of questionnaires. The first questionnaire may include general questions. At each later stage, the questions become more specific because they are formed with the answers to the previous questionnaire.

The Delphi technique comprises at least three phases:

1. A questionnaire is sent to a group of experts.
2. A summary of the first phase is prepared.
3. A summary of the second phase is prepared.

Three phases are usually recommended, but more phases can be used, as in the safety management Delphi study.

The number of experts involved can range from just a few to more than 100, depending on the scope of the issue. A range of 15-30 is recommended for a focal issue. As long as experts participate, the costs as well as the coordination required for the technique will also be raised.

2.2 Basic concepts of neutrosophy

Neutrosophy is a branch of philosophy that studies the origin, nature and scope of neutralities, as well as their interactions with different ideological spectra. In mathematics and logic, the most important concept is the neutrosorphic set that generalizes the fuzzy sets of Zadeh and the fuzzy intuitionist sets of Atanassov, in the following these definitions are formally defined.

Definition 1: ([22]) The *Neutrosophic set* N is characterized by three membership functions, which are the truth-membership function T_A, indeterminacy-membership function I_A, and falsity-membership function F_A, where U is the Universe of Discourse and $\forall x \in U, TA(x), IA(x), FA(x) \subseteq]-0, 1+[, and\ -0 \leq inf\ TA(x) + inf\ IA\ (x)\ +\ inf\ FA\ (x) \leq sup\ TA(x) +\ sup\ IA\ (x)\ +\ sup\ FA\ (x) \leq 3+$.

See that according to Definition 3, $T_A(x)$, $I_A(x)$, and $F_A(x)$ are real standard or non-standard subsets of $]-0, 1+[\ and\ hence, TA(x), IA(x)\ and\ FA(x)\ can\ be\ subintervals\ of\ [0, 1]$.

Definition 2: ([22]) The *Single-Valued Neutrosophic Set* (SVNS) N over U is $A = \{< x;\ TA(x), IA(x), FA(x) >: x \in U\}, where\ TA: U \to [0, 1], IA: U \to [0, 1], and\ FA: U \to [0, 1], 0 \leq TA(x)\ + IA(x)\ + FA(x) \leq 3$.

The *Single-Valued Neutrosophic number* (SVNN) is symbolized by $N\ =\ (t, i, f\ )$, such that $0 \leq t, i, f\ \leq 1$ and $0 \leq t\ +\ i\ +\ f \leq 3$.

Definition 3: ([22]) The *single-valued triangular neutrosophic number* $\tilde{a} = \langle (a_1, a_2. a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$, is a neutrosophic set on $\mathbb{R}$, whose truth, indeterminacy and falsity membership functions are defined as follows, respectively:

$$T_{\tilde{a}}(x)=\begin{cases}\alpha_{\tilde{a}}\left(\frac{x-a_1}{a_2-a_1}\right), & a_1\le x\le a_2\\ \alpha_{\tilde{a}}, & x=a_2\\ \alpha_{\tilde{a}}\left(\frac{a_3-x}{a_3-a_2}\right), & a_2<x\le a_3\\ 0, & \text{otherwise}\end{cases} \quad (1)$$

$$I_{\tilde{a}}(x)=\begin{cases}\frac{\left(a_2-x+\beta_{\tilde{a}}(x-a_1)\right)}{a_2-a_1}, & a_1\le x\le a_2\\ \beta_{\tilde{a}}, & x=a_2\\ \frac{\left(x-a_2+\beta_{\tilde{a}}(a_3-x)\right)}{a_3-a_2}, & a_2<x\le a_3\\ 1, & \text{otherwise}\end{cases} \quad (2)$$

$$F_{\tilde{a}}(x)=\begin{cases}\frac{\left(a_2-x+\gamma_{\tilde{a}}(x-a_1)\right)}{a_2-a_1}, & a_1\le x\le a_2\\ \gamma_{\tilde{a}}, & x=a_2\\ \frac{\left(x-a_2+\gamma_{\tilde{a}}(a_3-x)\right)}{a_3-a_2}, & a_2<x\le a_3\\ 1, & \text{otherwise}\end{cases} \quad (3)$$

Where $\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\in[0,1]$, $a_1, a_2, a_3 \in \mathbb{R}$ and $a_1\le a_2\le a_3$.

Definition 4: ([22]) Given $\tilde{a}=\langle(a_1,a_2,a_3);\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\rangle$ and $\tilde{b}=\langle(b_1,b_2,b_3);\alpha_{\tilde{b}},\beta_{\tilde{b}},\gamma_{\tilde{b}}\rangle$ two single-valued triangular neutrosophic numbers and λ any non null number in the real line. Then, the following operations are defined:

19. Addition: $\tilde{a}+\tilde{b}=\langle(a_1+b_1,a_2+b_2,a_3+b_3);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle$
20. Subtraction: $\tilde{a}-\tilde{b}=\langle(a_1-b_3,a_2-b_2,a_3-b_1);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle$
21. Inversion: $\tilde{a}^{-1}=\langle(a_3^{-1},a_2^{-1},a_1^{-1});\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\rangle$, where $a_1,a_2,a_3\neq 0$.
22. Multiplication by a scalar number:
$$\lambda\tilde{a}=\begin{cases}\langle(\lambda a_1,\lambda a_2,\lambda a_3);\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\rangle, & \lambda>0\\ \langle(\lambda a_3,\lambda a_2,\lambda a_1);\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\rangle, & \lambda<0\end{cases}$$
23. Division of two triangular neutrosophic numbers:
$$\frac{\tilde{a}}{\tilde{b}}=\begin{cases}\langle\left(\frac{a_1}{b_3},\frac{a_2}{b_2},\frac{a_3}{b_1}\right);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, a_3>0\ and\ b_3>0\\ \langle\left(\frac{a_3}{b_3},\frac{a_2}{b_2},\frac{a_1}{b_1}\right);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, a_3<0\ and\ b_3>0\\ \langle\left(\frac{a_3}{b_1},\frac{a_2}{b_2},\frac{a_1}{b_3}\right);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, a_3<0\ and\ b_3<0\end{cases}$$
24. Multiplication of two triangular neutrosophic numbers:
$$\tilde{a}\tilde{b}=\begin{cases}\langle(a_1b_1,a_2b_2,a_3b_3);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, & a_3>0\ and\ b_3>0\\ \langle(a_1b_3,a_2b_2,a_3b_1);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, & a_3<0\ and\ b_3>0\\ \langle(a_3b_3,a_2b_2,a_1b_1);\alpha_{\tilde{a}}\wedge\alpha_{\tilde{b}},\beta_{\tilde{a}}\vee\beta_{\tilde{b}},\gamma_{\tilde{a}}\vee\gamma_{\tilde{b}}\rangle, & a_3<0\ and\ b_3<0\end{cases}$$

Where, ∧ is a t-norm and ∨ is a t-conorm.

Let $\tilde{a}=\langle(a_1,a_2,a_3);\alpha_{\tilde{a}},\beta_{\tilde{a}},\gamma_{\tilde{a}}\rangle$ be a single valued triangular neutrosophic number, then,

$$S(\tilde{a})=\frac{1}{8}[a_1+a_2+a_3](2+\alpha_{\tilde{a}}-\beta_{\tilde{a}}-\gamma_{\tilde{a}}) \quad (4)$$

$$\mathbf{A}(\tilde{a}) = \frac{1}{8}[a_1 + a_2 + a_3](2 + \alpha_{\tilde{a}} - \beta_{\tilde{a}} + \gamma_{\tilde{a}}) \quad (5)$$

They are called the score and accuracy degrees of ã, respectively.

Let $\{\widetilde{A}_1, \widetilde{A}_2, \cdots, \widetilde{A}_n\}$ be a set of n SVTNNs, where $\widetilde{A}_j = \langle (a_j, b_j, c_j); \alpha_{\tilde{a}_j}, \beta_{\tilde{a}_j}, \gamma_{\tilde{a}_j} \rangle$ (j = 1, 2, …, n), then the *weighted mean of the SVTNNs* is calculated with the following Equation:

$$\widetilde{A} = \sum_{j=1}^{n} \lambda_j \widetilde{A}_j \quad (6)$$

Where λ_j is the weight of A_j, $\lambda_j \in [0, 1]$ and $\sum_{j=1}^{n} \lambda_j = 1$.

3 The Delphi model in the neutrosophic environment

This section is dedicated to describe the model proposed in this paper. Let us start with two tables, Tables 1 and 2. Table 1 contains the scale for measuring the weights of the criteria and Table 2 summarizes the scale of evaluations associated with the single-valued triangular neutrosophic numbers (SVNTN). We finish with a hypothetical case study.

3.1 The method

Linguistic terms	SVTNN
Extremely unimportant (EU)	$\langle (0,0,1); 0.00, 1.00, 1.00 \rangle$
Not very important (NVI)	$\langle (0,1,3); 0.17, 0.85, 0.83 \rangle$
Not important (NI)	$\langle (1,3,5); 0.33, 0.75, 0.67 \rangle$
Medium (M)	$\langle (3,5,7); 0.50, 0.50, 0.50 \rangle$
Important (I)	$\langle (5,7,9); 0.67, 0.25, 0.33 \rangle$
Very important (VI)	$\langle (7,9,10); 0.83, 0.15, 0.17 \rangle$
Extremely important (EI)	$\langle (9,10,10); 1.00, 0.00, 0.00 \rangle$

Table 1. Importance weight as linguistic variables and their associated SVTNN.

Linguistic term	SVTNN
Very low (VL)	$\langle (0,0,1); 0.00, 1.00, 1.00 \rangle$
Medium low (ML)	$\langle (0,1,3); 0.17, 0.85, 0.83 \rangle$
Low (L)	$\langle (1,3,5); 0.33, 0.75, 0.67 \rangle$
Medium(M)	$\langle (3,5,7); 0.50, 0.50, 0.50 \rangle$
High (H)	$\langle (5,7,9); 0.67, 0.25, 0.33 \rangle$
Medium high (MH)	$\langle (7,9,10); 0.83, 0.15, 0.17 \rangle$
Very high (VH)	$\langle (9,10,10); 0.00, 1.00, 1.00 \rangle$

Table 2: Linguistic terms for evaluations associated with SVTNN.

Let us observe two important aspects, which are the following:

1. The scales shown in Tables 1 and 2 are inspired by the linguistic scales in [16]. SVTNNs are obtained by rescaling the original 0-1 scale to a 0-10 scale. The values $\alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}}$ are adapted from another scale appeared in [16].
2. The scale shown in Table 2 was linguistically taken in such a way, because the survey questions asked to experts will be done in the form of probability of events occurrence, which will be evaluated linguistically as Low, Medium low, etc.

Let us observe that the values obtained above are more accurate than fuzzy numbers, because they contain more elements; not only the belongingness, but also the non-belongingness and the indeterminacy.

The algorithm for evaluating research proposals that we offer is as follows:

1. Starts from a subject or group of subjects that are usually investigated in the institution.
2. Experts on the proposed subject or subjects are selected to evaluate the projects and at least one moderator. The experts will be denoted by $E_1, E_2, \ldots, E_n$.
   Usually each academic or research institution has a group of specialists who are part of the scientific council that is where the scientific projects of the institution are discussed. This group of people could be used to carry out the evaluations, although external experts are also useful. Experts need not to be in touch with each other, so the moderator must design, implement and process the surveys.
3. The n experts are asked to propose projects that can serve as a research proposal on the basis of the topic identified in the previous point. Each of them proposes at least one, they are called $p_1, p_2, \ldots, p_m$.
4. Experts could be asked to identify the criteria they consider for evaluating projects. However we suggest the following criteria:
   C_1: The project is a sufficiently relevant scientific contribution to the subject being investigated over a sufficiently long period of time.
   C_2: The project is scientifically achievable in a sufficiently short time.
   C_3: The institution has sufficient qualified staff to carry out the project.
   C_4: Sufficient personnel are available to conduct the investigation.
   C_5: There are the means and the budget necessary to carry out the research.
   C_6: The desired results will be obtained (publications in high-impact journals, patents, discussion of Master's or doctoral theses, solution of a real-life problem, etc.) in a reasonable time.
   C_7: The project serves as a basis or starting point for another project.
   C_8: The project gives scientific visibility, economic income, prestige, etc. to the institution.
   The survey can contain questions as follows:
   4.1. What do you think is the probability that project *P* will become a sufficiently relevant scientific contribution to the subject under investigation over a sufficiently long period of time?
   4.2. What do you think is the probability that project *P* will be scientifically achievable in a sufficiently short time?
   4.3. What do you think is the probability that the institution will have sufficiently qualified staff to carry out project *P*?
   4.4. What do you think is the probability that the institution will have sufficient available staff to carry out project *P*?
   4.5. What do you think is the probability that the institution will have the means and the budget to carry out project *P*?
   4.6. What do you think is the probability that the desired results of project *P* will be achieved in a reasonable time?
   4.7. What do you think is the probability that project *P* will serve as a basis for another project?
   4.8. What do you think is the probability that project *P* will provide scientific visibility, economic income, prestige, etc. to the institution?
   The answers will be given on the basis of the linguistic scale shown in Table 2.
   Each of the experts assesses the importance of each of the criteria. $\widetilde{w}_{ij}$ shall denote the linguistic value according to Table 1, which expert E_i associates with the criterion C_j (i = 1, 2,..., n; j = 1, 2, ..., 8).

$w_{ij} = \boldsymbol{A}(\widetilde{w}_{ij})$ (i = 1, 2,..., n; j = 1, 2, ..., 8) is calculated using formula 5. Then they are normalized with respect to each expert, let us use the notation $W_{ij} = \frac{w_{ij}}{\sum_{i=1}^{n} w_{ij}}$.

5. Each expert E_i (i = 1, 2,..., n) evaluates each project p_k (k = 1, 2,..., m) with respect to criteria C_j (j = 1,2,..,8).
6. For each expert E_i (i = 1, 2,..., n), the evaluation of each project p_k (k = 1, 2,..., m) is obtained by aggregating their values by criterion using the W_{ij} weights in Formula 6. So we have an evaluation of each expert for each project. Let us denote by P_{ik} the evaluation of the k^{th} project by the i^{th} expert in form of the SVTNN associated with the linguistic term in Table 2.
7. It is calculated $\overline{P}_k = \frac{\sum_{i=1}^{n} P_{ik}}{n}$ which is the mean of the evaluation of each project for all experts.
8. The *Consensus Indexes* for each project p_k are calculated with formula $CI_k = \frac{\sum_{i=1}^{n} |\boldsymbol{A}(P_{ik}) - \boldsymbol{A}(\overline{P}_k))|}{n}$.
9. If $CI_k \leq 0.2$, see [16], then there exists sufficient expert consensus for all projects and go to Step 11, otherwise there is no consensus and go to point 10.

10. The moderator anonymously informs each of the experts about the results. He\she asks for explanations for each of them, including the weights assigned by them to the criteria and go to a next round. Emphasis is placed on those projects that reached a consensus index of $\mathrm{CI_k} > 0.2$, which reduces the algorithm complexity when concentrating recalculation only on those projects where there was not satisfactory consensus. Next go to point 5.
11. $\widetilde{\mathrm{P}}_k = \boldsymbol{A}(\overline{\mathrm{P}}_k)$ are calculated according to Equation 5. $\widetilde{\mathrm{P}}_k$ is ordered, where projects with higher values are preferred over those with lower values.
    Finish.

3.2 Case Study of case: Comparative analysis

A research group of an academic institution has as its research topic artificial intelligence applied to digital image processing. The institution wishes to work on new projects on the subject so that they become doctoral theses of some members. Supervisors wish to determine which projects could be approved to obtain doctoral theses from a group of members within a maximum of five years. To this end, they decide to apply the method we propose in this article as follows:

1. They decided that the general theses themes should be “artificial intelligence applied to digital image processing”.
2. They select one moderator within the institution. The moderator selects the panel of experts on the subject to carry out evaluations. Five experts were selected; let us denote them by E_1, E_2, E_3, E_4, E_5. None of them knows the identity of the others, which is why the moderator keeps in touch with each one via email. Any queries that experts have to make about the institution's data are directly asked to the moderator.
3. The moderator consults them to ask for proposed projects on the subject. These were four; let us call them p_1, p_2, p_3, p_4. This consultation process remains anonymous.
4. The moderator distributes the survey with the questions in Step 4 of the algorithm and asks them to evaluate the importance of each of the given criteria on the linguistic scale in Table 1.
   The results were as follows as in Table 3 for linguistic evaluations and Table 4 for the crisp values of the normalized weights of evaluations in Table 3:

Criteria\Weight given by:	E_1	E_2	E_3	E_4	E_5
C_1	I	VI	I	M	I
C_2	VI	I	I	VI	I
C_3	VI	VI	M	I	VI
C_4	I	VI	I	I	VI
C_5	VI	I	VI	I	I
C_6	M	I	M	I	M
C_7	M	M	M	I	I
C_8	I	I	M	EI	I

Table 3: Importance given by experts to the criteria in form of linguistic terms.

Criteria\Weight given by:	E_1	E_2	E_3	E_4	E_5
C_1	0.122729	0.150978	0.145338	0.076947	0.121720
C_2	0.157475	0.117665	0.145338	0.152047	0.121720
C_3	0.157475	0.150978	0.094375	0.118498	0.156181
C_4	0.122729	0.150978	0.145338	0.118498	0.156181
C_5	0.157475	0.117665	0.186485	0.118498	0.121720
C_6	0.079694	0.117665	0.094375	0.118498	0.121720
C_7	0.079694	0.076406	0.094375	0.118498	0.121720
C_8	0.122729	0.117665	0.094375	0.178516	0.121720

Table 4: Importance given by experts to the criteria in form of normalized crisp values.

5. Each expert evaluates each project on the basis of the criteria. The results are given in Tables 5-9.

Criteria\Project:	p_1	p_2	p_3	P_4
C_1	H	M	L	H
C_2	M	M	VH	M

C_3	L	ML	H	L
C_4	L	VL	L	H
C_5	L	M	H	VL
C_6	M	ML	H	L
C_7	L	M	VH	L
C_8	L	ML	VH	VL

Table 5: Projects evaluated per criterion by Expert 1.

Criteria\Project:	**p_1**	**p_2**	**p_3**	**P_4**
C_1	VH	ML	M	MH
C_2	ML	H	H	H
C_3	L	L	MH	ML
C_4	M	ML	M	MH
C_5	L	H	MH	L
C_6	MH	L	H	VL
C_7	M	VL	H	VL
C_8	M	L	VH	L

Table 6: Projects evaluated per criterion by Expert 2

Criteria\Project:	**p_1**	**p_2**	**p_3**	**P_4**
C_1	M	VL	VL	VH
C_2	L	ML	M	H
C_3	M	L	M	M
C_4	VL	ML	ML	MH
C_5	M	H	MH	L
C_6	M	L	MH	VL
C_7	M	MH	H	VL
C_8	M	VL	H	L

Table 7: Projects evaluated per criterion by Expert 3.

Criteria\Project:	**p_1**	**p_2**	**p_3**	**P_4**
C_1	MH	MH	VL	MH
C_2	L	MH	H	MH
C_3	ML	L	MH	VL
C_4	ML	L	ML	MH
C_5	VL	ML	VH	L
C_6	VL	L	MH	VL
C_7	ML	H	H	ML
C_8	ML	L	MH	VL

Table 8: Projects evaluated per criterion by Expert 4.

Criteria\Project:	**p_1**	**p_2**	**p_3**	**P_4**
C_1	M	ML	ML	VH
C_2	H	H	H	VH
C_3	ML	L	VH	VL
C_4	ML	ML	M	M
C_5	VL	L	M	L
C_6	VL	L	MH	VL
C_7	VL	H	H	VL
C_8	L	VL	H	L

Table 9: Projects evaluated per criterion by Expert 5.

6. Table 10 contains the project evaluation by each expert after aggregating the set of projects, using the criteria weights of Table 4 in form of SVTNN.

Expert\Project	p_1	p_2	p_3	P_4
E_1	$\langle(1.97,3.97,5.97);\ 0.33,0.75,0.67\rangle$	$\langle(1.55,2.95,4.82);\ 0.00,1.00,1.00\rangle$	$\langle(5.46,7.10,8.38);\ 0.33,0.75,0.67\rangle$	$\langle(2.02,3.46,5.18);\ 0.00,1.00,1.00\rangle$
E_2	$\langle(3.49,5.22,6.80);\ 0.17,0.85,0.83\rangle$	$\langle(1.56,3.11,5.03);\ 0.00,1.00,1.00\rangle$	$\langle(5.40,7.29,8.78);\ 0.50,0.50,0.50\rangle$	$\langle(2.94,4.40,5.90);\ 0.00,1.00,1.00\rangle$
E_3	$\langle(2.27,3.98,5.84);\ 0.00,1.00,1.00\rangle$	$\langle(1.78,3.01,4.68);\ 0.00,1.00,1.00\rangle$	$\langle(3.63,5.19,6.77);\ 0.00,1.00,1.00\rangle$	$\langle(3.62,5.09,6.47);\ 0.00,1.00,1.00\rangle$
E_4	$\langle(0.69,1.68,3.37);\ 0.00,1.00,1.00\rangle$	$\langle(2.73,4.61,6.38);\ 0.17,0.85,0.83\rangle$	$\langle(5.33,6.94,8.21);\ 0.00,1.00,1.00\rangle$	$\langle(2.55,3.60,4.84);\ 0.00,1.00,1.00\rangle$
E_5	$\langle(1.10,2.14,3.82);\ 0.00,1.00,1.00\rangle$	$\langle(1.57,3.05,4.93);\ 0.00,1.00,1.00\rangle$	$\langle(4.62,6.34,7.95);\ 0.17,0.85,0.83\rangle$	$\langle(2.90,3.95,5.10);\ 0.00,1.00,1.00\rangle$

Table 10: Projects evaluated by Experts.

7. From Table 10 it is obtained $\overline{P}_1 = \langle(1.904,3.398,5.16); 0.00,1.00,1.00\rangle$, $\overline{P}_2 = \langle(1.838,3.346,5.168); 0.00,1.00,1.00\rangle$, $\overline{P}_3 = \langle(4.888,6.572,8.018); 0.00,1.00,1.00\rangle$, and $\overline{P}_4 = \langle(2.806,4.100,5.498); 0.00,1.00,1.00\rangle$. In addition we have $\widetilde{P}_1 = \boldsymbol{A}(\overline{P}_1) = 2.6155$, $\widetilde{P}_2 = \boldsymbol{A}(\overline{P}_2) = 2.5880$, $\widetilde{P}_3 = \boldsymbol{A}(\overline{P}_3) = 4.8695$, and $\widetilde{P}_4 = \boldsymbol{A}(\overline{P}_4) = 3.1010$.
8. Table 11 contains the crisp values by applying the accuracy function to the values in Table 10.

Expert\Project	p_1	p_2	p_3	P_4
E_1	3.3497	2.3300	5.8894	2.6650
E_2	4.1683	2.4250	6.7094	3.3100
E_3	3.0225	2.3675	3.8975	3.7950
E_4	1.4350	3.6872	5.1200	2.7475
E_5	1.7650	2.3875	5.0821	2.9875

Table 11: Projects evaluated by Experts in form of crisp values.

Therefore, the Consensus Indexes for the projects are the following:
$CI_1 = 0.945$, $CI_2 = 0.38824$, $CI_3 = 0.85898$, and $CI_4 = 0.36120$.

9. Let us observe, all of them are greater than 0.2, which means that another round is necessary. Thus, go to the next point.
10. The moderator informs the experts on the results and requests that each one reconsider the weights given to the criteria and evaluations. The process should be repeated in a second round. We must go to Step 5, but we will not repeat this for simplicity. See that if any of the projects had achieved $CI_k \leq 0.2$ it would not be taken into account for the next round and calculations and effort would simplify. Experts should concentrate more on reaching agreement on projects 1 and 3.
11. We obtain $\widetilde{P}_1 = 2.6155$, $\widetilde{P}_2 = 2.5880$, $\widetilde{P}_3 = 4.8695$, and $\widetilde{P}_4 = 3.1010$.
Thus, so far we have $p_3 \succ p_4 \succ p_1 \succ p_2$ and project p_3 is the preferred. Nevertheless, the moderator has to repeat the round.

Conclusion

This paper was devoted to introduce a method of evaluation and selection of scientific research proposals in academic or research institutions. The model is basically a Delphi method in a neutrosorphic environment. This method supports the research project selection according to a group of experts' criteria. The Delphi method ensures that the opinion is agreed among the experts. The neutrosorphic framework offers the advantage of including not only uncertainty, but also indeterminacy in decision-making. Another advantage is that experts carry out evaluations with the help of linguistic scales, which makes the final results more veridical. In addition, the limitation of the classic Delphi method on slow convergence is attenuated, since with this model the projects that are reevaluated in the next round are only those where there was not sufficient consensus. To our knowledge, this is the first time that a model like this is designed which combines the Delphi method in a neutrosophic framework for the solution of this kind of problem. The paper provides the criteria to be followed for measurement, which does not mean that they are not modifiable. A hypothetical case study illustrates how to use the method and demonstrates its usefulness.

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