MULTI-CRITERIA DECISION-MAKING METHODS AND THEIR APPLICATIONS FOR HUMAN RESOURCES

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ABSTRACT:

Both within the formation field and the labor market Multi-Criteria Decision Methods (MCDM) provide a significant support to the management of human resources in which the best choice among several alternatives can be very complex. This contribution addresses fuzzy logic in multi-criteria decision techniques since they have several applications in the management of human resources with the advantage of ruling out mistakes due to the subjectivity of the person in charge of making a choice. Evaluating educational achievements as well as the professional profile of a technician more suitable for a job in a firm, industry or a professional office are valuable examples of fuzzy logic. For all of the previous issues subjectivity is a fundamental aspect so that fuzzy logic, due to the very meaning of the word fuzzy, should be the preferred choice. However, this is not sufficient to justify its use; fuzzy technique has to make the system of evaluation and choice more effective and objective. The methodological structure of the multi-criteria fuzzy criterion is hierarchic and allows one to select the best alternatives in all those cases in which several alternatives are possible; thus, the optimal choice can be achieved by analyzing the different scopes of each criterion and sub-criterion as well as the relevant weights.

1. INTRODUCTION

The development of new technologies and the unstoppable growth within the education world of more and more flexible and effective models of teaching-learning are producing the birth of a new kind of society that could be defined as "cognitive". It is a society that requires a deep renovation of the educational institutions and of the way in which knowledge is transmitted. In particular, Universities have to be able to cope with a more and more open and flexible labor market.

Within this context, teachers involved within the educational process and persons in charge of human resources management in the labor market are forced to learn new and complex skills mainly in the evaluation processes. This new tendency prompts for collaborative teams of teachers, working groups, departments around disciplinary areas, transverse projects, often yielding plurality and sharing of decisions.

The human resources for science and technology are the crucial survival and growth factor for economics competitiveness. The human resources represent the most important factor in achieving economic success. Therefore evaluating the performance of the human resources for science and technology in each country is a critical research topic.

This work intends to use a combination of Analytical Hierarchy Process (AHP) and fuzzy decision-making method in human resources for science and technology. Specifically, this study uses AHP first to evaluate the weighting for each selected criterion and, subsequently, uses fuzzy logic to establish contextual relationships among the selected criteria. In this way one sets up a dominance hierarchy, i.e. a reticular structure made at least of two levels that encompass all the elements of the problem under examination. Thus, the problem is initially complex and unstructured; subsequently, it is decomposed and synthetized in a more rational manner.

The first level contains the general objective while the second one is related to the criteria that include and detail contents and subjects of the general objective. In turn each of them can be further decomposed in more specific sub-criteria by defining a possible third level and so on.

Switching from the upper levels to the lower ones the method forecasts a series of pairwise comparisons for each element beginning at a specified level with respect to the element placed at an immediately upper level. Accordingly, criteria are mutually compared with respect to the global objective while the alternatives are compared as function of the criterion that they are referred to. As outcome of this operative sequence a set of comparison matrices is derived and a vector of priorities which measures the relative priority of the alternatives existing at the lower level with respect to the achievement of the main objective.

This paper is organized as follow. Section 2 presents the basic aspects of decision making multi-criteria; section 3 shows how the fuzzy AHP methodology has been adopted;

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section 4 illustrates our empirical results along with some discussions relating to managerial implications associated with the evaluation of a profile for choosing a technical Director of a Geomatics Laboratory within an international corporation. Conclusions and remarks are given in section 5.

2. MULTI-CRITERIA DECISION MAKING

Each decision-making problem implies consequences that the decision maker estimates to be more reasonable than others; conversely, no choice would be possible. Particularly important is the dominance principle according to which all alternatives that involve worst consequences are excluded; if a dominant alternative does exist the dominance principle allows us to choose this alternative, thus solving the decision-making problem optimally; unfortunately, such cases occur very rarely in real situations.

Another interesting question concerns the distinction between a “right” decision and a “rational” decision. In most cases, it is impossible to take a right decision so that it is mandatory to take a rational decision by evaluating the partially available information in the best way. Thus, solving a problem by a scientific approach culminates with the definition of a model that can be both quantitative, aiming at logic rigor and precision, and qualitative, without using formulas or numerical techniques. In both cases, analysis, synthesis, evaluation and capacity to research and to generate alternatives are required.

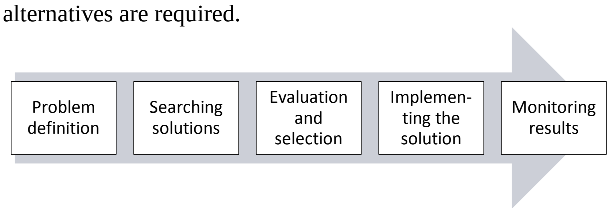

Figure 1. Decision-making process phases

For several years the approach adopted for decision-making problems has been provided by linear optimization with single criterion, i.e. a mathematical method to find the optimal solution of a problem, where the objective is unique but subject to several linear constraints. The use of this technique allows one to make explicit the objective by an accurate definition of each element of the problem; thus, it yields a rational model of reality with the goal of providing the best possible solution of the function to minimize or to maximize.

When decision-making complex problems have to be solved with a lot of alternatives or constraints, often not explicit, the linear optimization approach with single criterion turns out to be too rigid and hardly referable to an adequate model of the problem. In fact, many interesting aspects and point of views of the single decision makers can characterize a complex decision-making problem. In these cases, it is obvious to adopt multi-criteria models analysis since this permits to compare and ordinate the problem alternatives on the basis of related data and often mutually contrasting objectives.

All problems, independently from their different nature, have common characteristics, multiple attributes that the decision maker must focus, conflicts between criteria that hampers the selection of more satisfactory alternatives. The multi-criteria decision-making method has been elaborated for solving situations in which the number of alternatives and variables is high and each of them leads to a result not necessarily coincident with those produced from the others, making extremely difficult to choose the best one in relation to any considered criterion.

In sharp contrast with the classic techniques of operative research and single criterion optimization, there isn’t the “research of objectively optimal solutions” but, rather, the support to a choice of activities by a rationalization of the decision-making process and an optimization of a vector of many criteria, each one weighted according to the assumed priorities.

The innovative element introduced by this decision-making model abandons the paradigm of “optimality” in favour of the “optimal compromise” since one does not look for a unique result but for a selection of elements which clarify the priorities to be adopted in making the choices.

All multi-criteria evaluation problems are analyzed by investigating and inserting, within a making decision structure, a general objective and a decision maker or a decision makers team involved in the choice. Generally, the preferences of decision makers are expressed in terms of assigned weights both to evaluation criteria and to alternatives.

The elements of a decision structure are classified in:

- **Objectives**: declarations concerning the goals to achieve; they are made operative by assigning one or more attributes which make a criterion qualitatively and quantitatively measurable;
- **Criteria**: basic judgements or rules to test the soundness of the decision alternatives, including both objectives and attributes;
- **Alternatives**: objects of the evaluation and of the choices to be ordered on the basis of scores expressing the value of i-th alternative relative to j-th attribute; they represent the entries of the so called decision matrix.

The alternatives are evaluated and ordered on the basis of their performances associated with the assumed criteria and the relevant weights, these last ones ordered in a vector that the decision maker assigns to the criteria.

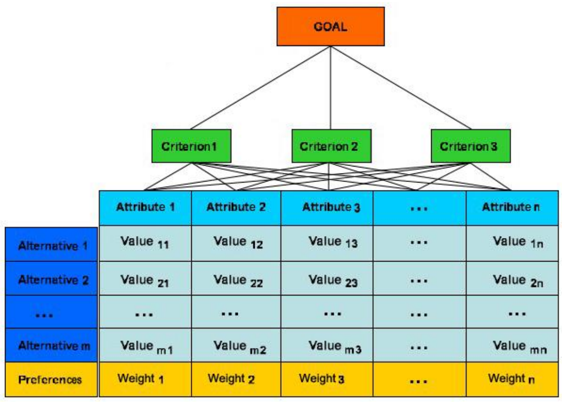

Figure 2. The hierarchy of dominance

Fig. 2 represents a dominance hierarchy, a reticular structure made up of a first level, which embodies the general objective, a second level that embodies the criteria, i.e. the objectives that specify contents and meanings of the general objective, a third level that represents the sub-criteria relative to more specific objectives; this could generally yield a further level.

As the level lowers the importance of the objectives decreases till arriving to the hierarchy basis, where the alternatives to be evaluated are defined. Criteria are mutually compared with respect to the global objective, while the alternatives are compared as function of the criterion that they are referred to.

These comparative judgements define the matrix of paired comparisons, which represents the basic structure for data examination, while the true analysis of the problem foresees the conversion of the dominance coefficients in relative scores denominated weights w.

3. FUZZY HIERARCHICAL METHOD

Human logic is particularly efficient for qualitative judgments; conversely, the uncertainty in the preferences generates doubts in classifying a series of alternatives on the basis of their dominance as well as difficulties in assessing the coherence of the preference judgments.

Although the application of the traditional analytic hierarchy process can deal with these problems adequately, many researchers have decided to implement new fuzzy-based techniques that could work with the traditional methods in order to overcome their weak points.

This work illustrates an application of Fuzzy Analytical Hierarchy Method to support a decision activity for strategic management of human resources. The proposed approach can be interpreted as an advanced method consistently derived from the traditional method, but aiming at improving some issues associated with the uncertainty and the vagueness of specific decisions in very complex and multi-criteria frameworks. Actually, these are characterized by experiences and judgments of the decision makers that are expressed by linguistic models, thus being vague and un-precise.

Accordingly, an improved representation can justify a more refined approach based on the combination of analytical hierarchical methods and fuzzy logic. On the other hand, the traditional method has been used basically in the so called *quasi-clear* decision applications for which this method uses a sharp and well defined judgment scale. This scale takes into account the uncertainly and the subjectivity of the judgments more poorly than the fuzzy method. Being impossible to precisely simulate the style of human mind, it provides a rather stiff schematic interpretation that unavoidably reflects on the validity and on the performances of the choices.

In the proposed fuzzy model for supporting the decision-making activity pairwise comparisons of criteria, sub-criteria and alternatives are carried out by defining linguistic variables that can be represented by membership functions with different shapes, differently from the traditional method in which the linguistic variables are associated with absolute numbers of the Saaty's semantic scale.

An example of this scale is represented in Figure 3; it establishes a relation between the first nine integer numbers with similar judgments and linguistic variables that qualitatively express the results of the comparisons. This is a scale of absolute numbers used to express subjective and qualitative judgments by means of a numerical objective value; it includes three values for each judgment, a minimum, a medium and a maximum one.

Conversely, in the "fuzzification" phase of the method, triangulated membership functions are arbitrarily chosen to adequately cover the whole space of the term set of variables, by taking into account uncertainty.

Intensity of dominance	Opinion
1; 1; 1	Equal importance
2; 3; 4	Weak predominance
4; 5; 6	Strong predominance
6; 7; 8	Evident predominance
9; 9; 9	Absolute predominance
1; 2; 3 3; 4; 5 5; 6; 7 7; 8; 9	Values of compromise

Figure 3. Saaty's semantic scale

On a parallel side an accurate and straightforward inference process, such as the one proposed by Buckley (1985) is carried out. The decision-maker involved in the decision-making process compares criteria and alternatives through the assignment of the linguistic variables shown in the Saaty's semantic scale that, in turn, is built from the values of the triangular membership functions.

In particular, due to the triangular shape of the membership function, the "de-fuzzification" method used to transform the fuzzy values in "crisp" outputs is the center of gravity method. The choice of the membership function, of the scale values and of the judgment according to predefined linguistic variables are discretionary of the single decision-maker or of a group of decision-makers.

The pairwise comparisons matrix $\tilde{A}^k$ is square and reciprocal; thus, it is referred to a triangular fuzzy number with two extreme values and a third one as mean value:

$$(lw_i; mw_i; uw_i)$$

this is represented in the Figure 4 that shows the triangular fuzzy function membership for different qualitative judgments.

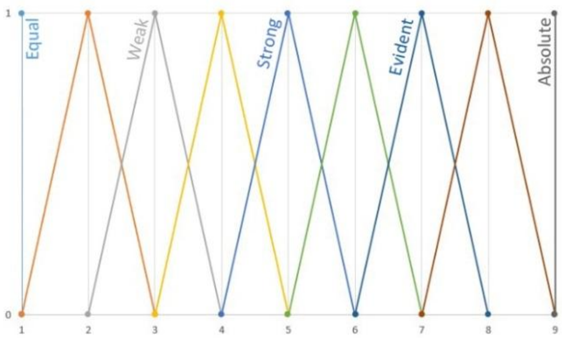

Figure 4. Triangular membership function term set

The matrix of pairwise comparisons, $\tilde{A}^k$, built by a single decision-maker, has the following form:

$$\tilde{A}^k = \begin{vmatrix} \tilde{a}_{11}^k & \tilde{a}_{12}^k & \dots & \tilde{a}_{1n}^k \\ \tilde{a}_{21}^k & \tilde{a}_{22}^k & \dots & \tilde{a}_{2n}^k \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1}^k & \tilde{a}_{n2}^k & \dots & \tilde{a}_{nn}^k \end{vmatrix} \quad (1)$$

where $\tilde{a}^k_{ij}$ denotes the k-th preference of the single decision-maker with respect to the i-th criterion in relation to the j-th criterion, expressed by a triangular fuzzy number.

As an example, the fuzzy value $\tilde{a}^1_{13}$ could represent the preference of the single decision-maker relative to the first criterion with respect to the third criterion with a judgment defined as:

$$\tilde{a}^1_{13} = (2, 3, 4) \quad (2)$$

If several decision-makers are involved, the individual preferences $\tilde{a}^k_{ij}$ are averaged and computed as follows:

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{K} \tilde{a}^k_{ij}}{K} \quad (3)$$

where K denotes the number of decision-makers.

According to the averaged preferences a new general matrix of pairwise comparisons, $\tilde{A}$ is assembled; it will show the averaged triangular coefficients of dominance and it will assume the following form:

$$\tilde{A} = \begin{vmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & \tilde{a}_{nn} \end{vmatrix} \quad (4)$$

According to the Buckley's method, it is computed as the geometric average of the values obtained from the fuzzy comparisons of each criterion, $\tilde{u}_i$. The values $\tilde{u}_i$, are triangular numbers and are defined by the following formula:

$$\tilde{u}_i = \left(\prod_{j=1}^{n} \tilde{a}_{ij}\right)^{\frac{1}{n}} \quad i = 1, \dots, n \quad (5)$$

Then, the vector sum of each fuzzy element $\tilde{u}_i$ is computed and it is elevated to exponential value (-1) by the following relation in which the symbol ⊕ denotes the fuzzy sum:

$$\tilde{u} = (\tilde{u}_1 \oplus \tilde{u}_2 \oplus \tilde{u}_3 \oplus \dots \oplus \tilde{u}_n)^{-1} \quad (6)$$

The subsequent step amounts to computing the fuzzy weight relative to the i-th criterion expressed by the following relation:

$$\tilde{o}_i = \tilde{u}_i \otimes (\tilde{u}_1 \oplus \tilde{u}_2 \oplus \tilde{u}_3 \oplus \dots \oplus \tilde{u}_n)^{-1} = (lw_i; mw_i; uw_i) \quad (7)$$

where the symbol ⊗ denotes the fuzzy product and the vector containing fuzzy weight in ascending order.

Since the term $\tilde{o}_i$ is a triangular number as well, it needs to be "de-fuzzified", by using the "center of gravity" method, i.e. by applying the following equation:

$$M_i = \frac{(lw_i + mw_i + uw_i)}{3} \quad (8)$$

Notice that M_i is not a fuzzy number and it has to be normalized as:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (9)$$

These phases need to be executed in sequential steps in order to compute the normalized weights both of the criteria and of the alternatives. Subsequently, multiplying each weight of the alternative by the relative criterion, the scores relative to each alternative are computed. On the basis of these results, the alternative with higher score represents the choice of the decision-maker or of the decision-makers in team.

4. CASE STUDY

The decision-making activity, due to the large number of factors that influence it, is structured on an ordered sequence of phases, necessary to bring the complex problem to a simplified structure that can be easily decomposed in hierarchical levels.

The proposed hierarchy of dominance identifies four levels: the first level contains the overall objective (O); the second level contains four criteria (C_i) that specify contents and meanings; the third level contains twenty one sub-criteria (S_i) that further characterize the higher level criteria. At the base of the hierarchy there is the fourth level where the three alternatives (A_i) to be evaluated are located:

Choosing the ideal profile for the Director of a Laboratory of Geomatics (O)

- Education (C_1)
    - MSc in Engineering (S_1)
    - Management of a Research Center (S_2)
    - MSc in Earth Science (S_3)
    - MSc in Physics (S_4)
- Achievements (C_2)
    - Cultural background (S_5)
    - Exam score average (S_6)
    - Bachelor Science grade (S_7)
    - MSc grade (S_8)
- Curriculum (C_3)
    - Age (S_9)
    - Publications (S_{10})
    - Peer -reviewed Journals (S_{11})
    - National job experiences (S_{12})
    - Job experiences abroad (S_{13})
    - Projects leader (S_{14})
- Skills (C_4)
    - Leadership (S_{15})
    - Problem solving ability (S_{16})
    - Ability in team working (S_{17})
    - Knowledge of languages (S_{18})
    - Computer skills (S_{19})
    - Experiences in international cooperation (S_{20})
    - Mobility attitude (S_{21})
- Profile 1 (A_1)
- Profile 2 (A_2)
- Profile 3 (A_3)

The first phase of the decision-making process is the composition of the group of expert decision-makers involved in the strategic solution of the problem. They are in charge to give a personal opinion based on their own experiences in the context of human resources.

Based on the Saaty semantic fuzzy scale, the decision-makers give their opinions individually, by assigning an intensity of dominance at each pairwise comparison between elements of the same hierarchical level. Individual results are averaged to take account of the multidisciplinary nature of the problem.

A first matrix of pairwise comparisons is created: the second level criteria Education (C_1), Achievements (C_2), Curriculum (C_3), Skills (C_4) are mutually compared with respect to the first level overall objective.

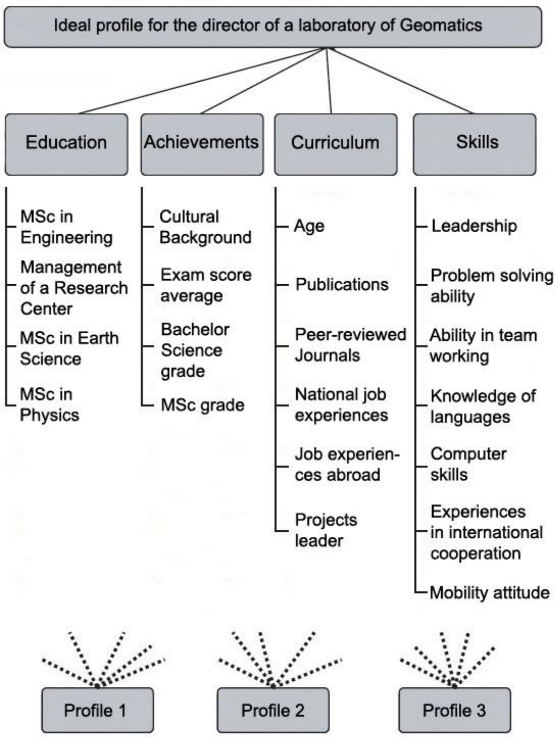

Figure 5. Case study hierarchy of dominance

The following example represents the simulation for selecting the ideal profile for the Director of a Laboratory of Geomatics (O). Table 1 shows the matrix of pairwise comparison between the previous criteria.

O	*C₁*	*C₂*	*C₃*	*C₄*
C₁	1;1;1	3;4;5	1/3;1/2;1	3;4;5
C₂	1/5;1/4;1/3	1;1;1	1/4;1/3;1/2	1;2;3
C₃	1;2;3	2;3;4	1;1;1	2;3;4
C₄	1/5;1/4;1/3	1/3;1/2;1	1/4;1/3;1/2	1;1;1

Table 1. Matrix of pairwise comparisons of the criteria in relation to the overall objective

The values $\tilde{u}_i$ are first calculated as geometric mean of the fuzzy relations:

$$\tilde{u}_1 = \left(\prod_{j=1}^{4} \tilde{a}_{1j}\right)^{\frac{1}{4}} = \left(1 \cdot 3 \cdot \left(\frac{1}{3}\right) \cdot 3\right)^{\frac{1}{4}}; \left(1 \cdot 4 \cdot \left(\frac{1}{2}\right) \cdot 4\right)^{\frac{1}{4}}; (1 \cdot 5 \cdot 1 \cdot 5)^{\frac{1}{4}} = 1{,}316;\ 1{,}682;\ 2{,}236$$

$$\tilde{u}_2 = \left(\prod_{j=1}^{4} \tilde{a}_{1j}\right)^{\frac{1}{4}} = \left(\left(\frac{1}{5}\right) \cdot 1 \cdot \left(\frac{1}{4}\right) \cdot 1\right)^{\frac{1}{4}}; \left(\left(\frac{1}{4}\right) \cdot 1 \cdot \left(\frac{1}{3}\right) \cdot 2\right)^{\frac{1}{4}}; \left(\left(\frac{1}{3}\right) \cdot 1 \cdot \left(\frac{1}{2}\right) \cdot 3\right)^{\frac{1}{4}} = 0{,}473; 0{,}639; 0{,}841$$

$$\tilde{u}_3 = \left(\prod_{j=1}^{4} \tilde{a}_{1j}\right)^{\frac{1}{4}} = (1 \cdot 2 \cdot 1 \cdot 2)^{\frac{1}{4}}; (2 \cdot 3 \cdot 1 \cdot 3)^{\frac{1}{4}}; (3 \cdot 4 \cdot 1 \cdot 4)^{\frac{1}{4}} = 1{,}414; 2{,}060; 2{,}632$$

$$\tilde{u}_4 = \left(\prod_{j=1}^{4} \tilde{a}_{1j}\right)^{\frac{1}{4}} = \left(\left(\frac{1}{5}\right) \cdot \left(\frac{1}{3}\right) \cdot \left(\frac{1}{4}\right) \cdot 1\right)^{\frac{1}{4}}; \left(\left(\frac{1}{4}\right) \cdot \left(\frac{1}{2}\right) \cdot \left(\frac{1}{3}\right) \cdot 1\right)^{\frac{1}{4}}; \left(\left(\frac{1}{3}\right) \cdot 1 \cdot \left(\frac{1}{2}\right) \cdot 1\right)^{\frac{1}{4}} = 0{,}359; 0{,}452; 0{,}639$$

The vector sum $\tilde{u}$ is calculated and raised to -1:

$$\tilde{u} = (\tilde{u}_1 \oplus \tilde{u}_2 \oplus \tilde{u}_3 \oplus \tilde{u}_4)^{-1} = (1{,}316 + 0{,}473 + 1{,}414 + 0{,}359)^{-1}; (1{,}682 + 0{,}639 + 2{,}060 + 0{,}452)^{-1}; (2{,}236 + 0{,}841 + 2{,}632 + 0{,}639)^{-1} = 0{,}281;\ 0{,}207;\ 0{,}158$$

The fuzzy weight is calculated for each criterion:

$$\tilde{o}_1 = \tilde{u}_1 \otimes \tilde{u}_{ord} = (1{,}316 \cdot 0{,}158); (1{,}682 \cdot 0{,}207); (2{,}236 \cdot 0{,}158) = 0{,}207; 0{,}348; 0{,}628$$

$$\tilde{o}_2 = \tilde{u}_2 \otimes \tilde{u}_{ord} = (0{,}473 \cdot 0{,}158); (0{,}639 \cdot 0{,}207); (0{,}841 \cdot 0{,}158) = 0{,}074; 0{,}132; 0{,}236$$

$$\tilde{o}_3 = \tilde{u}_3 \otimes \tilde{u}_{ord} = (1{,}414 \cdot 0{,}158); (2{,}060 \cdot 0{,}207); (2{,}632 \cdot 0{,}158) = 0{,}223; 0{,}426; 0{,}739$$

$$\tilde{o}_4 = \tilde{u}_4 \otimes \tilde{u}_{ord} = (0{,}359 \cdot 0{,}158); (0{,}452 \cdot 0{,}207); (0{,}639 \cdot 0{,}158) = 0{,}057; 0{,}093; 0{,}179$$

The subsequent step is the calculation of the crisp weights Mi by the center of gravity de-fuzzification method:

$$M_1 = \frac{(lw_1 + mw_1 + uw_1)}{3} = \frac{(0{,}207 + 0{,}348 + 0{,}628)}{3} = 0{,}394$$

$$M_2 = \frac{(lw_2 + mw_2 + uw_2)}{3} = \frac{(0{,}074 + 0{,}132 + 0{,}236)}{3} = 0{,}148$$

$$M_3 = \frac{(lw_3 + mw_3 + uw_3)}{3} = \frac{(0{,}223 + 0{,}426 + 0{,}739)}{3} = 0{,}463$$

$$M_4 = \frac{(lw_4 + mw_4 + uw_4)}{3} = \frac{(0{,}057 + 0{,}093 + 0{,}179)}{3} = 0{,}110$$

Normalized weights N_i are now calculated:

$$N_1 = \frac{M_1}{\sum_{i=1}^{4} M_i} = \frac{0{,}394}{(0{,}394 + 0{,}148 + 0{,}463 + 0{,}110)} = 0{,}354$$

$$N_2 = \frac{M_1}{\sum_{i=1}^{4} M_i} = \frac{0{,}148}{(0{,}394 + 0{,}148 + 0{,}463 + 0{,}110)} = 0{,}132$$

$$N_3 = \frac{M_1}{\sum_{i=1}^{4} M_i} = \frac{0{,}463}{(0{,}394 + 0{,}148 + 0{,}463 + 0{,}110)} = 0{,}415$$

$$N_4 = \frac{M_1}{\sum_{i=1}^{4} M_i} = \frac{0{,}110}{(0{,}394 + 0{,}148 + 0{,}463 + 0{,}110)} = 0{,}099$$

The second matrix of pairwise comparisons is created:third level sub-criteria MSc in Engineering (S_1), Management of a Research Center (S_2), MSc in Earth science (S_3), MSc in Physics (S_4) are mutually compared in relation to the second level criterion: Education (C_1).

C₁	*S₁*	*S₂*	*S₃*	*S₄*
S₁	1;1;1	2;3;4	2;3;4	1;2;3
S₂	1/4;1/3;1/2	1;1;1	2;3;4	1;2;3
S₃	1/4;1/3;1/2	1/4;1/3;1/2	1;1;1	1/4;1/3;1/2
S₄	1/3;1/2;1	1/3;1/2;1	2;3;4	1;1;1

Table 2. Matrix of pairwise comparisons of the sub-criteria in relation to the criterion C_1

The third matrix of pairwise comparisons is created: third level sub-criteria Cultural background (S_5), Exam score average (S_6), B.Sc. grade (S_7), MSc. grade (S_8) are mutually compared in relation to the second level criterion: Score (C_2).

C_2	S_5	S_6	S_7	S_8
S_5	1;1;1	3;4;5	3;4;5	2;3;4
S_6	1/5;1/4;1/3	1;1;1	1;2;3	1;2;3
S_7	1/5;1/4;1/3	1/3;1/2;1	1;1;1	1/5;1/4;1/3
S_8	1/4;1/3;1/2	1/3;1/2;1	3;4;5	1;1;1

Table 3. Matrix of pairwise comparisons of the sub-criteria in relation to the criterion C_2

The fourth matrix of pairwise comparisons is created: third level sub-criteria Age (S_9), Publications (S_{10}), Peer reviewed journals (S_{11}), National job experiences (S_{12}), Job experiences abroad (S_{13}), Projects leader (S_{14}) are mutually compared in relation to the third level criterion: Curriculum (C_3).

C_3	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}
S_9	1;1;1	1/5;1/4;1/3	1;2;3	2;3;4	1/4;1/3;1/2	1/5;1/4;1/3
S_{10}	3;4;5	1;1;1	2;3;4	2;3;4	1/3;1/2;1	1/4;1/3;1/2
S_{11}	1/3;1/2;1	1/4;1/3;1/2	1;1;1	1/4;1/3;1/2	1/5;1/4;1/3	1/5;1/4;1/3
S_{12}	1/4;1/3;1/2	1/4;1/3;1/2	2;3;4	1;1;1	1/5;1/4;1/3	1/4;1/3;1/2
S_{13}	2;3;4	1;2;3	3;4;5	3;4;5	1;1;1	1;2;3
S_{14}	3;4;5	2;3;4	2;3;4	2;3;4	1/3;1/2;1	1;1;1

Table 4. Matrix of pairwise comparisons of the sub-criteria in relation to the criterion C_3

The fifth matrix of pairwise comparisons is created: third level sub-criteria Leadership (S_{15}), Problem solving ability, (S_{16}), Ability in team working (S_{17}), Knowledge of languages (S_{18}), Computer skills (S_{19}), Experiences in international cooperation (S_{20}), Mobility attitude (S_{21}) are mutually compared in relation to the fourth level criterion: Skills (C_4).

C_4	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}
S_{15}	1;1;1	1/4;1/3;1/2	1;2;3	1;2;3	2;3;4	2;3;4	1/3;1/2;1
S_{16}	2;3;4	1;1;1	1;2;3	2;3;4	2;3;4	2;3;4	1;2;3
S_{17}	1/3;1/2;1	1/3;1/2;1	1;1;1	2;3;4	2;3;4	1;2;3	1/3;1/2;1
S_{18}	1/3;1/2;1	1/4;1/3;1/2	1/4;1/3;1/2	1;1;1	1;2;3	1/3;1/2;1	1;2;3
S_{19}	1/4;1/3;1/2	1/4;1/3;1/2	1/4;1/3;1/2	1/3;1/2;1	1;1;1	1;2;3	1;1;1
S_{20}	1/4;1/3;1/2	1/4;1/3;1/2	1/3;1/2;1	1;2;3	1/3;1/2;1	1;1;1	1;1;1
S_{21}	1;2;3	1/3;1/2;1	1;2;3	1/3;1/2;1	1;1;1	1;1;1	1;1;1

Table 5. Matrix of pairwise comparisons of the sub-criteria in relation to the criterion C_4

Twenty one matrices of pairwise comparisons are now created for the fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) in relation to the twenty one third level sub-criteria (S_i). An example concerning the sub-criterion Engineering (S_1) is addressed in the sequel.

S_1	A_1	A_2	A_3
A_1	1;1;1	3;4;5	1;1;1
A_2	1/5;1/4;1/3	1;1;1	1/5;1/4;1/3
A_3	1;1;1	3;4;5	1;1;1

Table 6. Matrix of pairwise comparisons of the alternatives in relation to the sub-criterion S_1

Once all the weight vectors at each hierarchical level have been obtained, the fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) are weighted against the second level criterion Education (C_1).

C_1	S_1	S_2	S_3	S_4	w_{Ai}
w_{Si}	0,43	0,25	0,10	0,22	
A_1	0,44	0,51	0,52	0,17	0,41
A_2	0,12	0,14	0,31	0,52	0,23
A_3	0,44	0,35	0,17	0,31	0,36

Table 7. Table of the weights of the alternatives associated with criterion C_1

$$w_{A1} = (0{,}44 \cdot 0{,}43 + 0{,}51 \cdot 0{,}25 + 0{,}52 \cdot 0{,}10 + 0{,}17 \cdot 0{,}22) = 0{,}41$$

$$w_{A2} = (0{,}12 \cdot 0{,}43 + 0{,}14 \cdot 0{,}25 + 0{,}31 \cdot 0{,}10 + 0{,}52 \cdot 0{,}22) = 0{,}23$$

$$w_{A3} = (0{,}44 \cdot 0{,}43 + 0{,}35 \cdot 0{,}25 + 0{,}17 \cdot 0{,}10 + 0{,}31 \cdot 0{,}22) = 0{,}36$$

The fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) are weighted with respect to the second level criterion Score (C_2).

C_2	S_5	S_6	S_7	S_8	w_{Ai}
w_{Si}	0,52	0,20	0,09	0,19	
A_1	0,21	0,33	0,33	0,33	0,27
A_2	0,47	0,33	0,33	0,33	0,40
A_3	0,32	0,33	0,33	0,33	0,33

Table 8. Table of calculation for the weights of the alternatives against the criterion C_2

The fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) are weighted with respect to the second level criterion Curriculum (C_3).

C_3	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	w_{Ai}
w_{Si}	0,10	0,19	0,06	0,08	0,32	0,27	
A_1	0,11	0,54	0,23	0,51	0,20	0,54	0,37
A_2	0,63	0,12	0,39	0,14	0,60	0,12	0,34
A_3	0,26	0,33	0,39	0,35	0,20	0,33	0,29

Table 9. Table of calculation for the weights of the alternatives against the criterion C_3

The fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) are weighted with respect to the second level criterion Skills (C_4).

C_4	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	w_{Ai}
w_{Si}	0,17	0,28	0,15	0,10	0,08	0,09	0,13	
A_1	0,52	0,14	0,14	0,21	0,20	0,17	0,25	0,23
A_2	0,17	0,35	0,51	0,65	0,20	0,52	0,58	0,41
A_3	0,31	0,51	0,35	0,14	0,60	0,31	0,17	0,36

Table 10. Table of calculation for the weights of the alternatives against the criterion C_4

The fourth level alternatives Profile 1 (A_1), Profile 2 (A_2), Profile 3 (A_3) are weighted with respect to the first level overall objective "Choosing the ideal profile for the Director of a Geomatics Laboratory" (O).

O	C_1	C_2	C_3	C_4	w_{Ai}
w_{Si}	0,35	0,13	0,42	0,10	
A_1	0,41	0,27	0,37	0,23	0,35
A_2	0,23	0,40	0,34	0,41	0,32
A_3	0,36	0,33	0,23	0,36	0,33

Table 11. Table of calculation for the weights of the alternatives against the overall objective O

The alternative Profile 1 (A_1) is finally chosen since it is associated with a greater weight.

5. CONCLUSIONS

This work has applied the fuzzy logic for evaluating the criteria to adopt for selecting human resources in the field of science and technology.

In particular, fuzzy logic has been exploited to define a procedure that could eliminate subjectivity; thus, fuzzy logic has allowed us to consider several criteria such as education and job experiences of the candidates to be selected.

The results obtained in the paper can be improved in order to get the optimal solution in a few time and the system can be further developed.

In fact, as it appears from the case study, the values of the fuzzy set can be improved to increase, as an example, the number of variables of the decision system or modifying criteria and sub-criteria.

Obviously, for improving management of human resources for science and technology, a continuous and wider attention should be devoted to educational infrastructures, particularly to building up specialized educational curricula as well as to financial support to research and development.

It is highly desirable that the framework can be improved by selecting additional factors such as cultural and social skills of the candidates referred to contents of the research. In such a case, the proposed approach can represent an adequate and systematic framework able to provide a useful tool to managers and to experts in the management of human capital.

In particular, this could allow one to exploit more refined solutions in the search for candidates to be employed in the field of science and technology.

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