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APPLICATION OF MULTI-CRITERIA DECISION-MAKING UNDER UNCERTAINTY IN PERSONNEL SELECTION OF ACADEMIC STAFF

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Abstract:

Selecting the best personnel among several applicants is an important and complex multi-criteria decision-making problem for human resources management. In recent years, a growing interest in university academic staff selection has been noted since the quality of staff has a direct influence on the organization's effectiveness. The process of selecting a suitable academic staff contains various types of uncertainty. The uncertainty arises especially when the qualitative criteria are considered and the candidates are evaluated verbally, or when the importance of criteria is not described precisely. A suitable tool for describing and dealing with the uncertainty brings fuzzy sets theory that was introduced in 1965 by Lotfi A. Zadeh and that has been subsequently applied to many fields in engineering and science. In this paper, the fuzzy multi-criteria decision-making model based on the fuzzy weighted average will be developed to solve the academic staff selection problem. The model will contain 6 criteria (specified according to the suggestions of experts from the HR college and university managements) and their importance will be described by triangular normalized fuzzy weights. The final evaluations of the candidates will be obtained by the fuzzy weighted averages of fuzzy evaluations with respect to the criteria. The ordering of candidates will be based on the centres of gravity and visual examination of the graphs of membership functions of their fuzzy evaluations.

Key words:

Personnel selection, academic staff, multi-criteria decision-making model, fuzzy numbers, fuzzy weighted average

JEL: C02, C6, C63, D81

1 Introduction

Personnel selection is one of the important parts of human resources management not only at universities but also in private companies. High-quality evaluating of the candidates play an important role in the success of the organization and it is quite difficult to correct the consequences following from incorrect decisions. Therefore, one of the targets of human resources management is searching for powerful ways of evaluating and ranking the applicants.

There are many studies in the literature for making appropriate personnel selection decisions in organizations. These studies are mostly based on interviews, work sample tests, assessment centres, job knowledge tests, or personality tests (see, e.g., Chien & Chen, 2008, or Robertson & Smith 2001).

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The results following from the tests and interviews together with the data from questionnaires must be summarized together. One of the standard methods that is widely used for this "summarization" in the personnel selection process is a multi-criteria decision-making strategy. In the multi-criteria decision-making models, it is necessary at first to determine which criteria become the basis of the evaluation. Subsequently, the importance of the criteria, i.e. the weights of the criteria, must be determined. Usually, the decision makers have difficulties in assigning the crisp real values as the weights of the criteria, since the decision makers are not sure about the exact importance. This leads to the fact that one of the main characteristics of personnel selection problem is the fuzziness. The fuzziness or the uncertainty follows also from the fact that the criteria are often qualitative and not quantitative ones, which makes also the partial evaluations uncertain.

The uncertainty appearing in the personnel selection problems can be managed and covered into the models when the crisp multi-criteria decision-making process is replaced by the fuzzy model since fuzzy sets theory is a suitable tool for handling and describing the uncertainty. In the most sophisticated fuzzy multi-criteria decision-making models, the weights of the criteria as well as the partial evaluations are described by suitable fuzzy numbers.

The different types of fuzzy multi-criteria decision-making models have been applied for the personnel selection's problems up to now. In Chen, 2009, Pant et al., 2014 and Kelemenis & Askounis, 2010, the extensions of the crisp Analytical Hierarchical Process (AHP) and TOPSIS to the fuzzy environment were described and used for the personnel selection. Lin, 2010, combined Analytical Network Process (ANP) with Fuzzy Data Envelopment Analysis (DEA) for solving personnel selection problem in group decision-making environment. The comprehensive literature review of applying fuzzy decision-making techniques in personnel selection problems up to 2014 can be found in Afshari et al., 2014. Recently, the fuzzy decision-making methods were used e.g. by Samanlioglu et al., 2018, for the IT personnel selection or by Santiago et al., 2020, for the personnel selection.

In this paper, the fuzzy multi-criteria decision-making model based on the fuzzy weighted average will be developed to solve the academic staff selection problem. The weighted average model is a well-known method for solving decision-making problems and its fuzzy extension enables the decision makers to implement the uncertainty in the model. In the proposed model, the weights of the criteria as well as the partial evaluations will be characterized by suitable fuzzy numbers which will enable the usage of qualitative criteria, linguistic partial evaluations as well as the application of uncertain weights describing the vague importance of the criteria.

The paper will be divided into 4 sections. After the Introduction, the basic facts concerning fuzzy sets theory will be described together with the weighted average and its fuzzy extension. Subsequently, the multi-criteria decision-making model for the selection of academic staff will be constructed and the computations will be carried out for the concrete academic staff selection problem. Finally, the conclusions and possible future studies will be discussed.

2 Preliminaries

As was written in the Introduction, a suitable tool for implementing the uncertainty into the decision-making models is fuzzy sets theory that was introduced in 1965 by Lotfi A. Zadeh (see Zadeh, 1965). Therefore, the basic facts concerning fuzzy sets and fuzzy numbers will be mentioned now. Also, the fuzzy weighted average that will be used afterwards as the principal instrument for the construction of the multi-criteria decision-making model will be described here.

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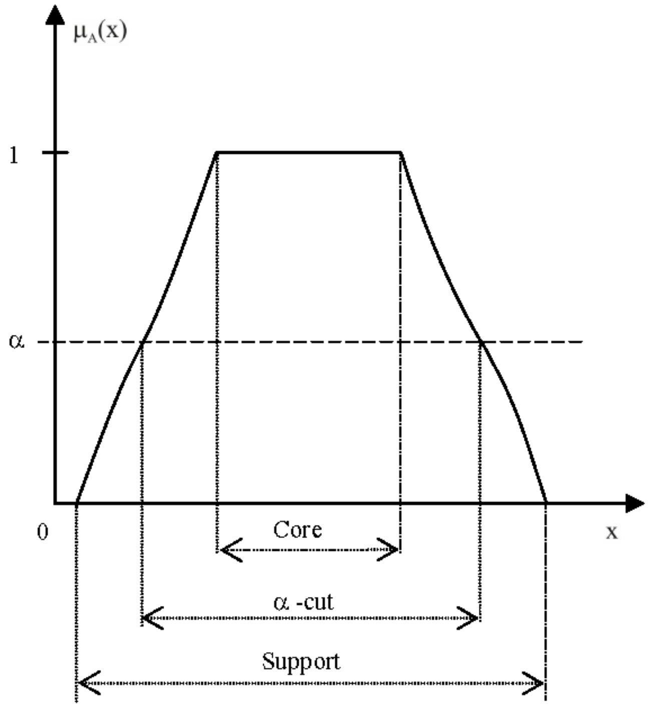
2.1 Fuzzy Sets and Fuzzy Numbers

In this section, basic notions of fuzzy sets theory will be briefly introduced. A *fuzzy set A* on a non-empty set *X* is characterized by its membership function μ_A: X ⟶ [0,1]. By *Core A* and *Supp A*, a *core of A* and a *support of A* will be denoted, i.e.

$$Core\ A := \{x \in X \mid \mu_A(x)=1\} \quad \text{and} \quad Supp\ A := \{x \in X \mid \mu_A(x)>0\}.$$

For any $\alpha \in (0, 1]$, $A(\alpha)$ will mean *an α-cut of A*, i.e. $A(\alpha) = \{x \in X \mid \mu_A(x) \geq \alpha\}$.

Figure 1: The core, the support, and the *α*-cut of the fuzzy set *A*



Any crisp set $A \subseteq X$ can be viewed as a fuzzy set of a special kind, where $A(\alpha) = A$ holds, for all $\alpha \in (0, 1]$.

A special type of fuzzy sets are fuzzy numbers. A *fuzzy number* is a fuzzy set *A* on the real axis **R** that fulfils the following conditions: 1) $Core\ A \neq \emptyset$, 2) for all $\alpha \in (0, 1]$, the *α*-cuts $A(\alpha)$ are closed intervals, 3) *Supp A* is bounded.

Any fuzzy number *A* can be uniquely determined (see e.g. Dubois & Prade, 1988) by a couple of functions $\underline{a}$: [0; 1] ⟶ **R** and $\bar{a}$: [0; 1] ⟶ **R** that describe the minimal and maximal values of the *α*-cuts of *A* and of the closure of the support of *A*.

In the constructed multi-criteria decision-making model, the triangular and the trapezoidal fuzzy numbers will be applied. A *trapezoidal fuzzy number A* is described by the quartet $(a_1; a_2; a_3; a_4)$, where a_1 represents the smallest possible value, the interval $[a_2, a_3]$ the most possible values, and a_4 the largest possible value of the considered fuzzy variable. Its membership function's graph forms a trapezoid with the *x*-axis. A trapezoidal fuzzy number is called a *triangular fuzzy number* if $a_2 = a_3$, i.e. if it is described by a triplet $(a_1; a_2; a_3)$.

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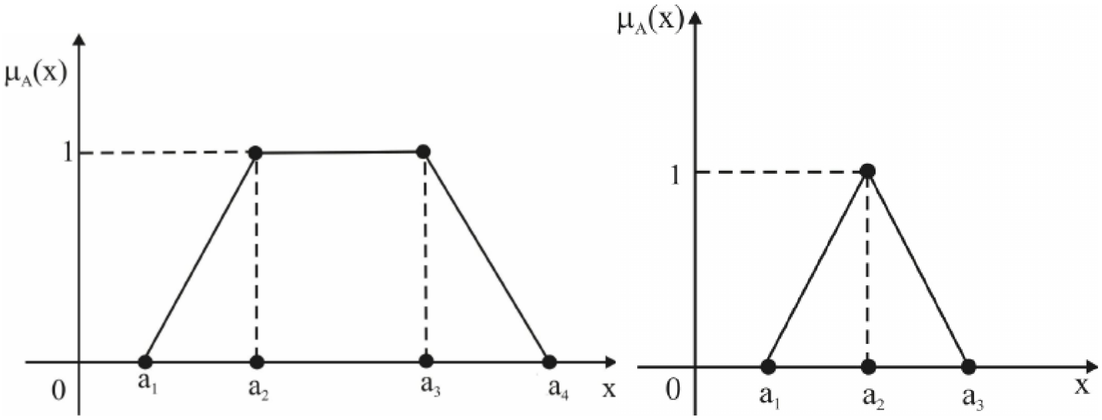
Figure 2: Trapezoidal and triangular fuzzy numbers



In fuzzy models, it is sometimes necessary to transform a fuzzy number into a crisp real number. Such a process is called *defuzzification* and there exist several approaches for it depending on the decision makers and on the concrete situation (see, e.g. Dubois & Prade, 2000). One of the often used techniques (that will be also used in our model) is the method COG – Centre of Gravity by which the fuzzy number *A* is de-fuzzified into its *centre of gravity* COG(*A*), i.e. into the real number given by the formula

$$\mathrm{COG}(A) = \begin{cases} \dfrac{\int_{-\infty}^{\infty} A(x)x\,dx}{\int_{-\infty}^{\infty} A(x)\,dx}, & if \int_{-\infty}^{\infty} A(x)\,dx \neq 0, \\ a, & if\ A\ represents\ a \in \mathbf{R}. \end{cases}$$

2.2 Normalized Fuzzy Weights and Fuzzy Weighted Average of Fuzzy Numbers

In decision-making models, weights of criteria are usually set subjectively, i.e. they are uncertain. Therefore, the models are more realistic if the weights of criteria are expressed by means of the tools of fuzzy sets theory. In this section, a special structure of fuzzy numbers, so called normalized fuzzy weights which are suitable for the modelling of uncertain weights of criteria, will be introduced.

Normalized fuzzy weights represent a fuzzification of the structure of normalized weights; *m*-tuple of real numbers $v_1, v_2, \dots v_m$ forms *normalized weights* if

$$v_i \geq 0, \text{ for all } i \in \{1, 2, ..., m\}, \text{ and } \sum_{i=1}^{m} v_i = 1. \quad (1)$$

Fuzzy numbers $V_1, V_2, \dots V_m$ defined on the interval [0,1] are called *normalized fuzzy weights* (see, e.g. Pavlačka & Talašová, 2006) if, for all $\alpha \in (0, 1]$, and all $i \in \{1, 2, ..., m\}$, the following holds:

$$\text{for any } v_i \in V_i(\alpha) \text{ there exist } v_j \in V_j(\alpha),\ j = 1,2,\dots,m,\ j \neq i, \text{ such that } v_i + \sum_{j=1, j\neq i}^{m} v_j = 1. \quad (2)$$

An example of the triple of the normalized fuzzy weights V_1, V_2, and V_3 is shown in Fig. 3, together with the illustration of the fact that for a certain weight from a given α-cut of V_1 there exist two other weights from α-cuts of V_2 and V_3, such that the sum of all three weights is equal to 1.

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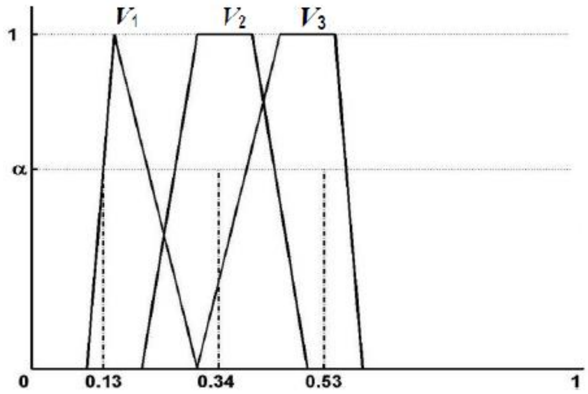
Figure 3: Example of normalized fuzzy weights



The easiest way of setting normalized fuzzy weights is the following: First, an expert sets crisp normalized weights $v_1, v_2, \ldots v_m$ and then he/she fuzzifies them into triangular fuzzy numbers

$V_i = (v_i - s; v_i; v_i + s)$, $i = 1, 2, ..., m$, where $s \geq 0$ satisfies: (3)

$v_i - s \geq 0$ and $v_i + s \leq 1$, for all $i \in \{1, 2, ..., m\}$.

The more sophisticated methods of setting normalized fuzzy weights were introduced e.g. in Pavlačka & Talašová, 2006 and 2007.

A fuzzy weighted average of fuzzy numbers with normalized fuzzy weights is defined as a fuzzification of a weighted average operation $\sum_{i=1}^{m} v_i u_i$, where $\sum_{i=1}^{m} v_i = 1$ and $v_i \geq 0$, for all $i \in \{1, 2, ..., m\}$. The *fuzzy weighted average of fuzzy numbers* $U_1, U_2, \ldots U_m$ *with normalized fuzzy weights* $V_1, V_2, \ldots V_m$ is a fuzzy number U whose membership function is given for each $u \in \mathbf{R}$ by the following formula:

$$U(u) = max\left\{min\{V_1(v_1), \ldots, V_m(v_m), U_1(u_1), \ldots, U_m(u_m)\} | \sum_{i=1}^{m} v_i u_i = u, \sum_{i=1}^{m} v_i = 1\right\}$$

The direct computation of the fuzzy weighted average is not an elementary task. Therefore, the algorithm for computing the fuzzy weighted average of fuzzy numbers with normalized fuzzy weights was developed in Pavlačka & Talašová, 2006.

3 Multi-Criteria Fuzzy Decision-Making Model for Personnel Selection of the Academic Staff

In this section, the fuzzy multi-criteria decision-making model suitable for personnel selection of the academic staff is developed. As the first step, it is necessary to specify the criteria the selection process is based on. For this purpose, a few experts from the HR college and university managements have been addressed and according to their ideas, 6 criteria are taken into the consideration. The importance of criteria is specified by triangular normalized fuzzy weights applying the formulae (3), where the cores are computed as the arithmetic means of experts´ estimations of crisp normalized weights and the value s=0.05 is set according to the differences in experts´ estimations of normalized weights. For the overview of the criteria and the corresponding triangular fuzzy weights see Tab. 1 and Fig. 4.

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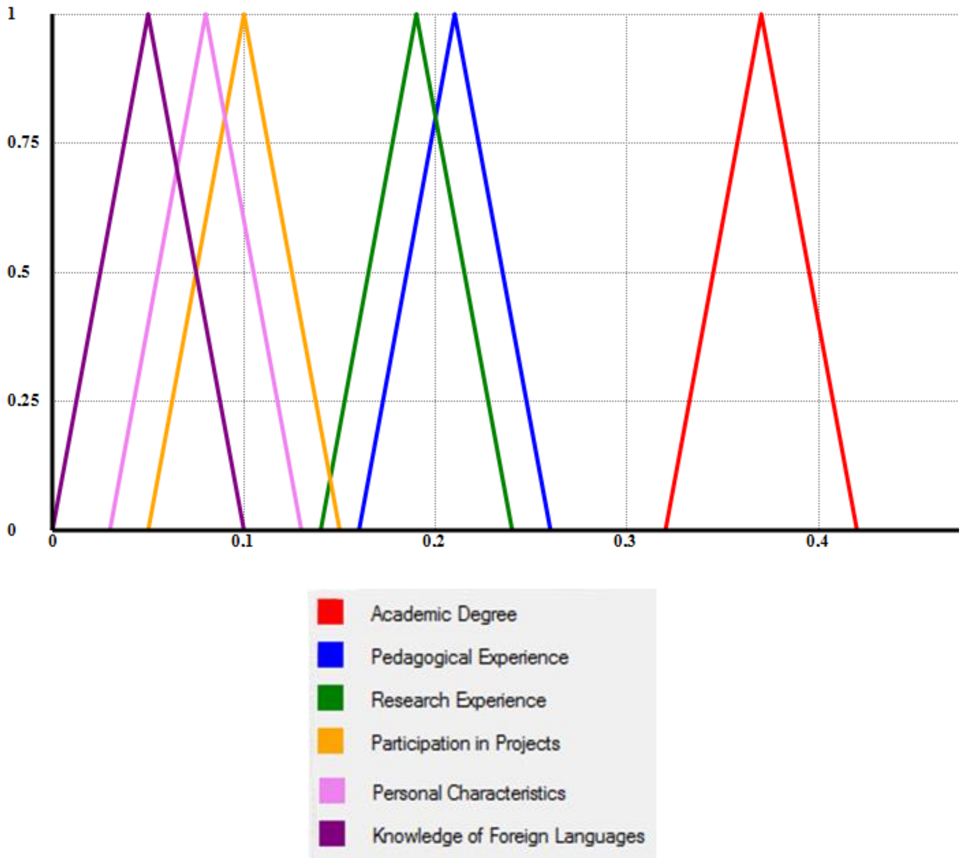
Table 1: The criteria and the normalized fuzzy weights describing their importance

Criteria	Triangular normalized fuzzy weights describing the importance of the criteria
Academic Degree	V_1 = (0.32;0.37; 0.42)
Pedagogical Experience	V_2 = (0.16;0.21; 0.26)
Research Experience	V_3 = (0.14;0.19; 0.24)
Participation in Projects	V_4 = (0.05;0.1; 0.15)
Personal Characteristics	V_5 = (0.03;0.08; 0.13)
Knowledge of Foreign Languages	V_6 = (0;0.05; 0.1)

Figure 4: Triangular normalized fuzzy weights describing the importance of the criteria



Let us note that each of the mentioned criteria includes several items that are considered during the construction of this summary criteria. Particularly:

- The criterion Academic Degree includes: “field of study(ies)”, “degree(s)”, “university/college the degree(s) was (were) obtain”, “the length of doctoral (or other kind of) study”.
- The components of the criterion Pedagogical Experience are: “the length of pedagogical work”, “types of taught subjects”, “guiding of bachelors, master (or doctoral) thesis”, and “guaranteeing of the study programs or subjects”.
- The criterion Research Experience contains: “numbers of published scientific papers together with the average number of papers per year”, “the type of journals the papers are published in”, “the attendance at conferences”, “membership at the editorial board(s)” and “membership at the organizing committee of conferences”.

- Personal Characteristics include "team working", "ability to leadership", "quality of oral and written presentation", "responsibility" and "creativity".

The personnel selection decision-making model we are dealing with contains 5 candidates - A, B, C, D, and E and each of them is characterized in detail with respect to the criteria specified above.
For example, **candidate A** is described by the following characteristics:

Academic Degree: Ph.D. degree, obtained at Masaryk University after 4 years, study program Economics.

Pedagogical Experience: 3 years of pedagogical experience, taught subjects: macro and microeconomics, 3 leading theses, no study program guaranteed

Research Experience: 2 research papers, both in review journals without impact factor, approximately 0,5 papers per year, 1 attended conference, member of organization board of 1 conference

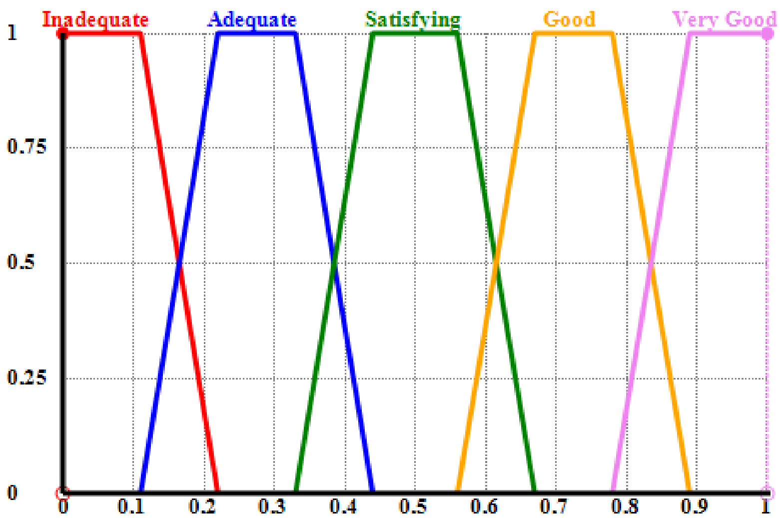
Participation in Projects: Participation in 1 project OP VK, no principal investigator

Personal Characteristics: assumed to be a creative and responsible team-worker, good oral and written presentation, below-average ability to the leadership

Knowledge of Foreign Languages: C1 English

The rest of the candidates are described analogously; the detailed description of all candidates are omitted here and only their expert evaluation by HR managers are shown below.
After defining the criteria of the evaluation and after the detailed description of the candidates, the HR managers expertly rates each of the candidates according to the criteria. For the evaluation, we use the linguistic formulations "Inadequate", "Adequate", "Satisfying", "Good" and "Very Good" together with their combinations "Inadequate-Adequate" (denoted shortly by I, A, S, G, and VG). This linguistic evaluation is then modelled by the trapezoidal fuzzy numbers as is illustrated in Fig. 5.

Figure 5: Trapezoidal fuzzy numbers describing the linguistic evaluations



Inadequate	0, 0, 0.11, 0.22
Adequate	0.11, 0.22, 0.33, 0.44
Satisfying	0.33, 0.44, 0.56, 0.67
Good	0.56, 0.67, 0.78, 0.89
Very Good	0.78, 0.89, 1, 1

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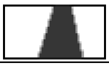
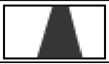
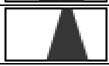
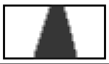
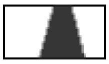
The linguistic evaluations of the candidates with respect to the particular criteria U_{1A}, U_{2A}, …, U_{5E} are shown in Tab. 2 that was constructed according to the HR managers´ assessments based on the detailed descriptions of the candidates.

Table 2: Linguistic evaluation of candidates due to the criteria

Criteria	**Cand. A**	**Cand. B**	**Cand. C**	**Cand. D**	**Cand. E**
Academic Degree	U_{1A} = VG	U_{1B} = G	U_{1C} = G	U_{1D} = S	U_{1E} = VG
Pedagogical Experience	U_{2A} = S	U_{2B} = S-G	U_{2C} = G	U_{2D} = A	U_{2E} = S
Research Experience	U_{3A} = A	U_{3B} = A	U_{3C} = A	U_{3D} = VG	U_{3E} = I-A
Participation in Projects	U_{4A} = I-A	U_{4B} = S	U_{4C} = S	U_{4D} = I-A	U_{4E} = S-G
Personal Characteristics	U_{5A} = A-S	U_{5B} = S	U_{5C} = G	U_{5D} = S	U_{5E} = A
Knowledge of Foreign Languages	U_{6A} = G	U_{6B} = A-S	U_{6C} = S	U_{6D} = VG	U_{6E} = A

After these preliminary steps, the final evaluations of the candidates are computed by the fuzzy weighted averages of fuzzy numbers U_{1i}, U_{2i}, … U_{6i}, where i = A, B, …, E, (see Fig. 5 and Tab. 2) with the normalized fuzzy weights V_1, V_2, …,V_6 (see Tab. 1). The computations can be carried out by the effective algorithm (see Pavlačka & Talašová, 2006) using a suitable mathematical software (Matlab, FuzzME,…). The obtained fuzzy numbers are then de-fuzzified into COGs (see Section 2.1). The final evaluations of the candidates are shown in Tab. 3 below; for the computations, the software FuzzME has been used (see, e.g., Holeček & Talašová, 2010).

Table 3: The final evaluations

The candidate	The final evaluations described by the fuzzy numbers		Linguistic form of the final evaluation	The centres of gravity of the final evaluations
A		(*0.333*; *0.495*; *0.667*; *0.787*)	S-G	0.569
B		(*0.329*; *0.472*; *0.664*; *0.787*)	S-G	0.558
C		(*0.395*; *0.55*; *0.661*; *0.816*)	S-G	**0.605**
D		(*0.286*; *0.458*; *0.594*; *0.734*)	S	0.517
E		(*0.344*; *0.494*; *0.671*; *0.802*)	S-G	0.577

The appropriate candidate for the position of academic staff according to 6 criteria specified earlier is the one with the "highest final evaluation". It can be simply the one with the highest COG, but if more candidates have similar COGs, then it is recommended also to visually judge the graphs of the membership functions of their fuzzy evaluations. These graphs are shown in the second column in Tab. 3 and they can be used for the description of the uncertainty connected with the evaluation of particular candidates.

In our case, candidate C with the highest COG would be the most appropriate choice. It is also visible from the resulting fuzzy evaluations, that the fuzzy evaluation of this candidate is described by the relatively narrow fuzzy number, so it is not excessively uncertain. This is caused by the fact that his/her evaluation with respect to partial criteria do not vary too much (see Tab. 2). Therefore, we would recommend this candidate to the HR managers not only from the point of view of the highest centre of gravity but also due to this consistency of the partial evaluations. Let us note that this extended

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approach is suitable mainly in cases when few variants have nearly the same final evaluations and some supplementary information is necessary in order to make the decision.

4 Discussion

The aim of the paper was to show the potential of applying the tools of fuzzy sets theory in the multi-criteria decision-making problem of academic staff selection. The main reasons that lead to the application of fuzzy sets theory in personnel selection of academic staff are the following two:

1. For HR managers that do not necessarily have to had deep mathematical knowledge, it is convenient to evaluate the candidates with respect to each criterion only verbally, by selecting the proper linguistic term from a given linguistic scale. But such verbal description naturally contains uncertainty and vagueness that can be appropriately modelled by fuzzy numbers.

2. Normalized weights expressing the importance of criteria are usually not known precisely and should be therefore described by fuzzy numbers.

In the paper, we have presented a multi-criteria decision-making model for solving academic staff selection problems based on the fuzzy weighted average with normalized fuzzy weights. This approach for computing of final evaluations has been selected since it is the fuzzy extension of the well-known weighted average and is "user-friendly" for the HR managers. More concretely, HR managers only needed to specify the criteria of the evaluation, approximately set their importance, and describe linguistically partial evaluations of the candidates with respect to these criteria. Therefore, nearly no mathematical knowledge was necessary from the side of HR managers which makes this approach widely applicable and understandable.

The significant advantage of the applied approach (in comparison with methods mentioned in the Introduction, like fuzzy AHP, TOPSIS...) lies in the fact that each candidate is evaluated independently. Therefore, it is possible to evaluate the degree of acceptability of only one candidate and it is also not necessary to re-compute all evaluations in the case when a new candidate is added to the set of candidates. The comparison of the proposed method with other methods mentioned in the Introduction is not possible since they are based on pairwise comparison and provide relative types of ratings. The candidate with the overall evaluation 1, i.e. with the best possible evaluation, is "the best from the considered group of candidates" even if he/she is not suitable for the academic staff position at all. On the other hand, the method described in this paper provides absolute type ranking, i.e. evaluation 1 means that the candidate is 100% suitable for the position.

Concerning the possible future studies, instead of the fuzzy weighted average of fuzzy numbers with normalized fuzzy weights, a more generalize operator called fuzzy Choquet integral (see, e.g., Bebčáková, Talašová & Pavlačka, 2010) can be employed. It is a universal and mathematically more complex operator that enables to implement to the model also the synergy and redundancy effects among the criteria. Another possibility is describing the dependency of the final evaluation on the partial ones verbally by a fuzzy rule-based system (this approach is also implemented in the software FuzzME, see, e.g., Holeček & Talašová, 2010).

In conclusion, we would like to note that it would be beneficial in the future to apply the proposed method (or its generalization) to the wider group of applicants and to create the corresponding SW application suitable for HR college and university managements.

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