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A NEW FUZZY HYBRID MULTI-CRITERIA DECISION-MAKING APPROACH TO SOLVE PERSONNEL ASSESSMENT PROBLEMS. CASE STUDY: DIRECTOR SELECTION FOR ESTATES AND ECONOMY OFFICE

Abstract.*Personal selection is known as one of the most important parts of human resource management. Economic performance of organisations depends on effective and proper management. Hybrid fuzy multi-criteria decision-making approachpresented in the paper take into consideration the quantitative or objective criteria but also the ones appear to be qualitative or subjective. Such methods are mainly designed to evaluate and compare alternatives, are independent of the assessment models that are used (since they are mainly based on expert judgement), and therefore represent a practical tool to assist decision-making in complex projects.*

Keywords*: personnel selection, fuzzy multi-criteria decision-making, MCDM, hybrid, Delphi, AHP, ARAS-F, EDAS-F.*

JEL Classification: C61, M12, M54, D79, D81

1. Introduction

In the era of competitive markets, appropriate selection of personnel determines success of organizations (Keršulienė, Turskis, 2011). Personal selection is known as one of the most important parts of human resource management (Liu et al., 2015). Personnel selection is the process of choosing individuals who match the qualifications required to perform a defined job in the best way. Proper recruitment has influence on organization's climate directly or influence it through mediators (Kosareva et al.,2016).Personnel selection is a typical Multi-Attribute Decision-Making problem (Bogdanovic and Miletic, 2014). It is a branch of a general class of Operations Research (or OR) models which deal with decision problems under the presence of a number of decision criteria. This class of models called multi-criteria decision-making (or MCDM). Multi-attribute decision-making (MADM) concentrates on problems with discrete decisions (Zavadskas et al., 2014). The set of decision alternatives has been predetermined in these problems. Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed finite. They are screened, prioritized and ranked. A MADM problem is associated with multiple attributes. Attributes also referred to as "goals" or "decision criteria". They represent the different dimensions from which the alternatives are viewed. Different attributes of the alternatives may conflict with each other. Different attributes may be associated with different units of measure. Methods to support MCDM should not only take into consideration the quantitative or objective criteria but also the ones that appear to be qualitative or subjective, which is not always simple to perform. Such methods are mainly based on expert judgement, and, therefore, represent a practical tool to assist decision-making in complex problems. MCDM techniques support the decision-makers in evaluating a set of alternatives and deal with a selection process: by finding an optimal solution from a set of available. The curvature of utility functions varies between people. There is a relationship between individual differences in preferred decision mode. If a person habitually prefers a deliberative mode, the utility function should be nearly linear, while it curved when a person prefers the intuitive mode.

The selection of most suitable personnel to perform the defined job, to develop an effective selection model is vital. There are dozens of research papers which investigate personnel selection problem. Hybrid MCDM model was used to select personnel for public relations in Taiwan. ANP (Analytical Network Process) method was used to obtain the weights of criteria. For security guards selection, TOPSIS and SAW methods were used (Dadelo et al., 2013). Algorithm of Maximizing the Set of Common Solutions for Several MCDM was proposed and used in private security personnel selection (Dadelo et al., 2014). Kabak et al. (2012) combined the Fuzzy ANP, Fuzzy TOPSIS, and Fuzzy ELECTRE techniques for sniper selection.

Zavadskas et al. (2012) presented Multiple criteria decision support system, which is based on AHP, ARAS and experts judgement methods, to assess projects managers in construction.Karabasevic et al. (2016) applied hybrid method based on ARAS and SWARA methods to assess personnel under uncertainties.

A hybrid multiple criteria group decision-making (MCGDM) method is based on AHP, entropy, elimination and the choice of expressing the reality III (ELECTRE III), and the linear assignment method to assist the manufacturer in choosing among four polarizer suppliers (Wu et al., 2013).

ANP and DEA methods combination was used for selecting a project manager (Keren et al., 2014). Hybrid DEMATEL and ANP method called DANP was used to address the dependent relationships among the various criteria to better reflect the real-world situation in global market in Taiwan companies (Hsu et al., 2013). DANP was used for of snipers selection (Kabak, 2013). ARAS-F and AHP were used for selecting a chief accounting officer (Keršulienė and Turskis, 2014).

2. Problem solution model

To solve problem is selected hybrid fuzzy multi-criteria decision-making model. The model integrates fuzzy sets, nominal group technique Delphi, expert judegement, Analytic Hierarchy Process (AHP), ARAS-F, and EDAS-F methods.

2.1. Basic concepts and definitions

In most cases, the classes of objects encountered in the real physical world do not have precisely defined criteria of membership. A fuzzy set is a class of objects with a continuum of membership grades. Such a set characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one (Zadeh 1965). Some of the definitions related to fuzzy sets and fuzzy numbers, which used in this research, stated as follows:

Definition 1. A fuzzy subset $\tilde{A}$ of a universal set X defined by its membership function $\mu_{\tilde{A}}(x)$ as:

$$\tilde{A} = \{(x,\ \mu_{\tilde{A}}(x)) |\ x \in X\}, \tag{1}$$

where $x \in X$ denotes the elements belonging to the universal set, and $\mu_{\tilde{A}}(x): X \to [0, 1]$.

Definition 2. A fuzzy number is a special case of a convex, normalized fuzzy subset ($\sup\ \mu_{\tilde{A}}(x) = 1$) of the real line $\mathbb{R}$ ($\mu_{\tilde{A}}(x): \mathbb{R} \to [0, 1]$). The membership function $\mu_A : X \to [0;1]$associates with each element $x \in X$, a real number $\mu_{\tilde{A}}(x) \in [0;1]$. The value $\mu_{\tilde{A}}(x)$ at x represents the grade of membership of $x$in $\tilde{A}$and is interpreted as the membership degree to which $x$belongs to $\tilde{A}$. So the closer the value $\mu_A(x)$ is to 1, the more $x$belongs to $\tilde{A}$.

Definition 3.A fuzzy number is defined to be a fuzzy triangular number (TFN)(α, β, γ) if its membership function (Fig.1) is fully described by three parameters (α< β<γ).

$$\mu_A(x) = \begin{cases} \dfrac{1}{\beta-\alpha}x - \dfrac{\alpha}{\beta-\alpha}, & if\ \ x \in [\alpha, \beta]; \\ \dfrac{1}{\beta-\gamma}x - \dfrac{\alpha}{\beta-\gamma} & ,if\ \ x \in [\beta, \gamma]; \\ 0 & ,otherwise. \end{cases} \tag{2}$$

Definition 4. A crisp number k represented by a TFN $\tilde{k} = (k, k, k)$.

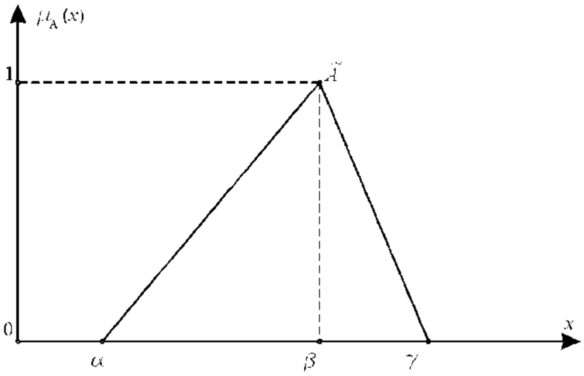

Figure 1.Triangular membership function

Definition 5. Suppose that $\tilde{n}_1 = (n_{1\alpha}, n_{1\beta}, n_{2\gamma})$ and $\tilde{n}_2 = (n_{2\alpha}, n_{2\beta}, n_{2\gamma})$ be two positive TFN and k is a crisp number. The arithmetic operations with these fuzzy numbers (van Laarhoven and Pedrycz 1983) are defined as follows:

$$\tilde{n}_1 \oplus \tilde{n}_2 = (n_{1\alpha} + n_{2\alpha}, n_{1\beta} + n_{2\beta}, n_{1\gamma} + n_{2\gamma}) \quad \text{addition} \quad (3)$$

$$\tilde{n} + k = (n_\alpha + k, n_\beta + k, n_\gamma + k) \quad (4)$$

$$\tilde{n}_1 \ominus \tilde{n}_2 = (n_{1\alpha} - n_{2\gamma}, n_{1\beta} - n_{2\beta}, n_{1\gamma} - n_{2\alpha} \quad \text{substraction} \quad (5)$$

$$\tilde{n}_1 \otimes \tilde{n}_2 = (n_{1\alpha} \times n_{2\alpha}, n_{1\beta} \times n_{2\beta}, n_{1\gamma} \times n_{2\gamma})$$
$$\tilde{n}_1 \times \mathrm{k} = (n_{1\alpha} \times \mathrm{k}, n_{1\beta} \times \mathrm{k}, n_{1\gamma} \times \mathrm{k}) \quad \text{multiplication} \quad (6)$$

$$\tilde{n}_1 \oslash \tilde{n}_2 = (n_{1\alpha}/n_{2\gamma}, n_{1\beta}/n_{2\beta}, n_{1\gamma}/n_{2\alpha})$$
$$\tilde{n}_1/\mathrm{k} = (n_{1\alpha}/\mathrm{k}, n_{1\beta}/\mathrm{k}, n_{1\gamma}/\mathrm{k}) \quad \text{division} \quad (7)$$

$$(\tilde{n}_1)^{-1} = (1/n_{1\gamma}, 1/n_{1\beta}, 1/n_{1\alpha}) \quad \text{inversion} \quad (8)$$

In order to obtain a crisp output, a defuzzification process needed. The output of the defuzzification process is a single number. Many defuzzification techniques been proposed in the literature. Various types of membership functions are used. The most commonly used membership functions are the following: triangular, trapezoid, linear, sigmoidal, π-type, and Gaussian. The most typical fuzzy set membership function is triangular membership function (Fig. 1).

Definition 6. Then, the defuzzified (crisp) value of this fuzzy number defined as follows: $c(\tilde{n}) = \frac{1}{3}(n_{1\alpha} + n_{1\beta} + n_{1\gamma})$ (9)

2.2. Criteria weights determination applying expert judgement method

A fundamental problem of decision theory is how to derive weights for a set of activities according to importance. Importance usually judged according to several criteria (Saaty 1980). A variety of methods proposed for eliciting weights(Zavadskas *et al* 2010), e.g., the eigenvector method, SWARA (Keršuliene *et al* 2010),Entropy method, fuzzy AHP (Kurilov et al. 2016), etc. To determine criteria weights is selected Improved AHP method. There is no "best" method for choosing weights. The review of past works has shown that Analytic Hierarchy Process (AHP) seems to be the most common MCDM method used in civil engineering decision problems.

Saaty recommends a nine level dominance scale(Table 1) (Saaty 1980). There are $n(n-1)/2$ judgments required to develop a $n \times n$judgment matrix, since reciprocals automatically assigned in each pair-wise comparison.

Table 1. Initial data for for pairwise comparison

Saaty's classical nine-point scale of relative importance	
a_{ij}=1	Diagonal elements *i=j*, C_i and C_j are equally important
a_{ij}=3	C_i is weakly more important than C_j
a_{ij}=5	$C_i$is strongly more important thanC_j
a_{ij}=7	C_i is demonstatively more important than C_j
a_{ij}=9	$C_i$is absolutely more important than C_j
a_{ij}=2, 4, 6, 8	Compromise between two judgments
$a_{ij} = 1/a_{ij}$	If element C_j dominates over element C_i

Random Consistency Indices *(IR)* for different number of criteria (*n*).								
n	1	2	3	4	5	6	7	*8*
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

The AHP method is a step-wise procedure.

***Step* 1.** Establishment of pair-wise comparison matrix

$$A = [c_{ij}] = \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}. \qquad (10)$$

***Step* 2.** Normalising of pair-wise comparison matrix as follows:

$$\bar{A} = [\bar{c}_{ij}] = \begin{bmatrix} c_{11}/\sum_{i=1}^{n} c_{i1} & c_{12}/\sum_{i=1}^{n} c_{i2} & \cdots & c_{1n}/\sum_{i=1}^{n} c_{in} \\ c_{21}/\sum_{i=1}^{n} c_{i1} & c_{22}/\sum_{i=1}^{n} c_{i2} & \cdots & c_{2n}/\sum_{i=1}^{n} c_{in} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1}/\sum_{i=1}^{n} c_{i1} & c_{n2}/\sum_{i=1}^{n} c_{i2} & \cdots & c_{nn}/\sum_{i=1}^{n} c_{in} \end{bmatrix}. \qquad (11)$$

***Step* 3.** Computing criteria weights:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1 = \left(\prod_{j=1}^{n} \bar{c}_{1j}\right)^{1/n} / \sum_{i=1}^{n} \left(\prod_{j=1}^{n} \bar{c}_{ij}\right)^{1/n} \\ w_2 = \left(\prod_{j=1}^{n} \bar{c}_{1j}\right)^{1/n} / \sum_{i=1}^{n} \left(\prod_{j=1}^{n} \bar{c}_{ij}\right)^{1/n} \\ \vdots \\ w_n = \left(\prod_{j=1}^{n} \bar{c}_{1j}\right)^{1/n} / \sum_{i=1}^{n} \left(\prod_{j=1}^{n} \bar{c}_{ij}\right)^{1/n} \end{bmatrix} \quad (12)$$

***Step* 4.** Determining the largest eigenvalue:

$$\lambda_{max} = \sum_{j=1}^{n} c_{ij} w_j \quad (13)$$

***Step* 5.** Determining Consistency Index (*CI*):

$$CI = \frac{\lambda_{max} - 1}{n - 1} \quad (14)$$

***Step*6.** Determining Consistency Ratio (*CR*):

$$CR = \frac{CI}{RI} \quad (15)$$

Here, the *RI* (Table 1) represents the average consistency index over numerous random elements of same order reciprocal matrices.

***Step* 7.** If $CR \leq 0.1$ indicated that the matrix reached consistency. Otherwise, go to the first step.

S*tep 8*. Group criteria weightsare determined as follows:

$$w_j = \frac{\left(\prod_{p=1}^{k} w_{jp}\right)^{\frac{1}{k}}}{\sum_{j=1}^{n}\left(\prod_{p=1}^{k} w_{jp}\right)^{\frac{1}{k}}}, j = \overline{1,n}, k = \overline{1,p}, \quad (16)$$

where w_{jp} denotes the importance (weight) of *j*-th criterion ($1 \leq j \leq n$) assigned by the p −th decision-maker ($1 \leq p \leq k$).

2.3. The fuzzy *Additive Ratio Assessment* (ARAS) method ARAS-F

The MCDM approach ARAS with fuzzy criteria values method was selected to solve the problem. ARAS method was developed in 2010 by Zavadskas and Turskis (2010). Later, modifications of ARAS method: ARAS-G (grey relations are applied) and ARAS-F were published ((Turskis and Zavadskas 2010a, b). There are only few applications of ARAS method (Zavadskas et al.,2010).

The main ideas of the ARAS method are taken from the AHP and the TOPSIS methods:

***Step* 1:**The first stage is forming fuzzy decision-making matrix (FDMM).The following DMM of preferences for *m* reasonable alternatives (rows) rated on *n* criteria (columns) is as follws:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{01} & \tilde{x}_{02} & \cdots & \tilde{x}_{0j} & \cdots & \tilde{x}_{0n} \\ \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1j} & \cdots & \tilde{x}_{1n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \tilde{x}_{i2} & \cdots & \tilde{x}_{ij} & \cdots & \tilde{x}_{in} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix}; i = \overline{0,m}; j = \overline{1,n}, \tag{17}$$

where *m* – number of alternatives, *n* – number of criteria describing each alternative, $\tilde{x}_{ij}$ – fuzzy value representing the performance value of the *i* alternative in terms of the *j* criterion, $\tilde{x}_{0j}$ – optimal value of *j* criterion. A tilde "~" will placed above a symbol if the symbol represents a fuzzy set.

***Step* 2**: Definition of optimum alternative.All values criteria of optimal alternative are the best, and can't be improved (idea of optimal alternative construction comes to the ARAS from the TOPSIS method's positive ideal solution). If optimal value of *j* criterion is unknown, then

$$x_{0j} = \max_i \tilde{x}_{ij}\text{ , if} \max_i \tilde{x}_{ij} \text{ is preferable, and } x_{0j} = \min_i \tilde{x}_{ij}^*, \text{ if} \min_i \tilde{x}_{ij}^* \text{is preferable.} \tag{18}$$

***Step* 3**: Determining the weights of criteria. Usually, the performance values $\tilde{\boldsymbol{x}}_{\boldsymbol{ij}}$of alternatives and the criteria weights $\tilde{\boldsymbol{w}}_{\boldsymbol{j}}$are the entries of a DMM. The criteria set as well as the values, and initial weights of criteria determine decision-makers (experts).

***Step* 4:**The initial values of all the criteria are normalized – defining values $\tilde{\tilde{x}}_{ij}$ of normalised DMM $\tilde{\tilde{X}}$ (the normalization is identical to the AHP method):

$$\tilde{\tilde{X}} = \begin{bmatrix} \tilde{\tilde{x}}_{01} & \tilde{\tilde{x}}_{02} & \cdots & \tilde{\tilde{x}}_{0j} & \cdots & \tilde{\tilde{x}}_{0n} \\ \tilde{\tilde{x}}_{11} & \tilde{\tilde{x}}_{12} & \cdots & \tilde{\tilde{x}}_{1j} & \cdots & \tilde{\tilde{x}}_{1n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{i1} & \tilde{\tilde{x}}_{i2} & \cdots & \tilde{\tilde{x}}_{ij} & \cdots & \tilde{\tilde{x}}_{in} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \tilde{\tilde{x}}_{m1} & \tilde{\tilde{x}}_{m2} & \cdots & \tilde{\tilde{x}}_{mj} & \cdots & \tilde{\tilde{x}}_{mn} \end{bmatrix}; i = \overline{0,m}; j = \overline{1,n}. \tag{19}$$

The criteria, whose preferable values are maxima, normalized as follows:

$$\tilde{\tilde{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=1}^{m} \tilde{x}_{ij}}. \tag{20}$$

The criteria, whose preferable values are minima, normalized by applying two-stage procedure:

$$\tilde{x}_{ij} = \frac{1}{\tilde{x}_{ij}^*};\ \tilde{\tilde{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=1}^{m} \tilde{x}_{ij}}. \tag{21}$$

***Step* 5:** Defining normalized-weighted matrix - $\tilde{\bar{X}}$.

$$\tilde{\bar{X}} = \begin{bmatrix} \tilde{\bar{x}}_{01} & \tilde{\bar{x}}_{02} & \cdots & \tilde{\bar{x}}_{0j} & \cdots & \tilde{\bar{x}}_{0n} \\ \tilde{\bar{x}}_{11} & \tilde{\bar{x}}_{12} & \cdots & \tilde{\bar{x}}_{1j} & \cdots & \tilde{\bar{x}}_{1n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\bar{x}}_{i1} & \tilde{\bar{x}}_{i2} & \cdots & \tilde{\bar{x}}_{ij} & \cdots & \tilde{\bar{x}}_{in} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \tilde{\bar{x}}_{m1} & \tilde{\bar{x}}_{m2} & \cdots & \tilde{\bar{x}}_{mj} & \cdots & \tilde{\bar{x}}_{mn} \end{bmatrix}; i = \overline{0,m}; j = \overline{1,n}. \quad (22)$$

Normalized-weighted values of all the criteria calculated as follows:

$$\tilde{\bar{x}}_{ij} = \bar{\tilde{x}}_{ij}\widetilde{w}_j;\ i = \overline{0,m}; j = \overline{1,n}, \quad (23)$$

where $\widetilde{w}_j$ is the weight (importance) of the j criterion and $\bar{\tilde{x}}_{ij}$ is the normalized rating of the *j* criterion.

***Step* 6:** Determining values of multi-criteria optimality function (the values calculated identical to the additive AHP method):

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{\bar{x}}_{ij}\,; i = \overline{0,m}, \quad (24)$$

where $\tilde{S}_i$ is the value of optimality function of *i*-th alternative.

The greater the value of the optimality function $\tilde{S}_i$, the more effective the alternative.

***Step* 7:** Defuzzyfication of results. The result of fuzzy decision making for each alternative is fuzzy number. The centre-of-area is the most practical and simple to apply to defuzzyfication:

$$S_i = \frac{1}{3}\left(S_{i\alpha} + S_{i\beta} + S_{i\gamma}\right). \quad (25)$$

***Step* 8:** Determining of utility degree. The degree of the alternative utility K_i determines a ratio of the analysed alternative utility function value with the optimalone S_0:

$$K_i = \frac{S_i}{S_0}; i = \overline{0,m}, \quad (26)$$

where S_i and S_0 are the optimal criterion values, obtained from Eq. (25).

2.4. An extended Method of Evaluation Based on Distance from Average Solution (EDAS) in fuzzy environment (EDAS-F)

Ghorabaee et al. (2015) proposed a new multi-criteria decision-making method namely Evaluation based on Distance from Average Solution (EDAS). Later, this method was extended for fuzzy environment (Ghorabaee M. Keshavarz et al.(2016). 2-tuple fuzzy numbers determines criteria values in this method. The triangular fuzzy numbers describes criteria values in the case study.

The evaluation a set of m alternatives ($A = \{A_1, A_2, \ldots, A_m\}$) in this method based on distances of each alternative from the average solution with respect to each criterion.

The set of alternatives is rated on a set of n criteria

($C = \{c_1, c_2, \ldots, c_n\}$) by$k$ decision-makers ($D = \{D_1, D_2, \ldots, D_k\}$). The steps of the fuzzy EDAS method are as follows:

***Step* 1:** Select the most important criteria that describe alternatives.

***Step* 2:** A problem is representing by the decision-making matrix $\tilde{X}$ of preferences for *m* reasonable alternatives A_i (rows) rated on *n* criteria (columns):

$$\tilde{X} = \left[\tilde{x}_{ij}\right]_{m\times n} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \tag{27}$$

where$\tilde{x}_{ij}$ – value representing the performance value of the *i* alternative in terms of the *j* criterion.

$$\tilde{x}_{ij} = \frac{1}{k}\sum\nolimits_{p=1}^{k} \tilde{x}_{ij}^{p} \tag{28}$$

where$\tilde{x}_{ij}^{p}$ denotes the performance value of alternative A_i ($1 \le i \le m$) with respect to criterion x_j ($1 \le j \le n$) assigned by the $p-$th decision-maker ($1 \le p \le k$).

***Step* 3**: Construct the vector of criteria weights, shown as follows:

$$\widetilde{W} = \left[\widetilde{w}_j\right]_{1\times \mathrm{n}} \tag{29}$$

$$\widetilde{w}_j = \frac{1}{k}\sum\nolimits_{p=1}^{k} \widetilde{w}_{ij}^{p} \tag{30}$$

where$\widetilde{w}_j^{p}$ denotes the weight of criterion c_j ($1 \le j \le n$) assigned by the pth decision-maker ($1 \le p \le k$).

***Step* 4:** Determine the average value x_{aj} to all criteria:

$$\tilde{x}_{aj} = \frac{\sum_{i=1}^{m} \tilde{x}_{ij}}{m}. \tag{31}$$

The elements of this matrix ($\tilde{x}_{aj}$) represents the average solutions with respect to each criterion. Therefore, the dimension of the matrix is equal to the dimension of criteria weights matrix.

***Step* 5:** Construct the average $\tilde{A}_a$solution based on average values of all criteria$\tilde{x}_{aj}$:

$$\tilde{A}_a = \left[\tilde{x}_{aj}\right] = [\tilde{x}_{a1}, \tilde{x}_{a2}, \cdots, \tilde{x}_{an}]. \tag{32}$$

***Step*6:** Suppose that *B* is the set of beneficial criteria and *N* is the set of non-beneficial criteria. Construct a matrix $\widetilde{D}$ of positive $\tilde{p}_{ij}$ and $\tilde{r}_{ij}$ negative distances from average $A_a$solution (from average valuesx_{aj}) for all *n* criteria:

$$D = \left[\tilde{p}_{ij};\ \tilde{r}_{ij}\right] = \begin{bmatrix} \tilde{p}_{11}; \tilde{r}_{11} & \tilde{p}_{12}; \tilde{r}_{12} & \cdots & \tilde{p}_{1n}; \tilde{r}_{1n} \\ \tilde{p}_{21}; \tilde{r}_{21} & \tilde{p}_{22}; \tilde{r}_{22} & \cdots & \tilde{p}_{2n}; \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{p}_{m1}; \tilde{r}_{m1} & \tilde{p}_{m2}; \tilde{r}_{m2} & \cdots & \tilde{p}_{mn}; \tilde{r}_{mn} \end{bmatrix}. \tag{33}$$

For beneficial criteria the values p_{ij} and r_{ij} are calculated as follows:

$$\tilde{p}_{ij} = \frac{\tilde{x}_{ij} - \tilde{x}_{aj}}{\tilde{x}_{aj}}, if j \in B, \quad (34)$$

$$\tilde{r}_{ij} = \frac{\tilde{x}_{aj} - \tilde{x}_{ij}}{\tilde{x}_{aj}}, if j \in N. \quad (35)$$

For non-beneficial criteria the values p_{ij} and r_{ij} are calculated as follows:

$$\tilde{p}_{ij} = \frac{\tilde{x}_{aj} - \tilde{x}_{ij}}{\tilde{x}_{aj}}, if j \in N \quad (36)$$

$$\tilde{r}_{ij} = \frac{\tilde{x}_{ij} - \tilde{x}_{aj}}{\tilde{x}_{aj}}, if j \in B. \quad (37)$$

***Step* 7:** Determine weighted sum of positive S_{ip} and negative S_{ir} distances from average $A_a$solution for all alternatives A_i (from average valuesx_{aj}) for all *n* criteria:

$$\tilde{S}_{ip} = \sum_{j=1}^{n} \tilde{w}_j \tilde{p}_{ij}, \text{ and} \quad (38)$$

$$\tilde{S}_{ir} = \sum_{j=1}^{n} \tilde{w}_j \tilde{r}_{ij}, \quad (39)$$

wherew_j is the weight of *j* criterion.

***Step* 8:** Normalise the values of S_{ip} and S_{ir} for all alternatives as follows:

$$\tilde{P}_i = \frac{\tilde{S}_{ip}}{\max_i \tilde{S}_{ip}}, \quad (40)$$

$$\tilde{R}_i = 1 - \frac{\tilde{S}_{ir}}{\max_i \tilde{S}_{ir}}, \quad (41)$$

***Step* 9:** Calculate apraisailscores values for all *m* alternatives as follows:

$$U_i = \frac{1}{2}(\tilde{P}_i + \tilde{R}_i). \quad (42)$$

***Step* 10:** Rank the alternatives according to the decreasing values of U_i. The alternative with the highest $U_i$is the best choice among the candidate alternatives. The alternatives could be classifying with respect to this ranking.

3. Case study:Director selection for Estates and Economy Office

The competence and the expirience of staff managing of the Director causes thesuccess of office work. Many projects are based on fundamental principles and knowledge of scope, time, cost, quality, human resource, communications, as well as effective scheduling and control. A Director should have many different responsibilities in different industries and disciplines. Hewould usually be responsible for managing construction projects and ensuring completing tasks on schedule at low risk. Qualifications for a leader include an academic degree in engineering, an engineering license, certification in project managemen, and an appropriate work experience. Director, applying technical regulation of work, should mean a person who, representing the interests of an organisation, organises the preparation of work and coordinates solutions of parts of the project documentation and the activities of project participants. He supervises and is responsible for the implementation of law requirements, other legislative acts, normative technical documents and normative documents pertaining the safety and purpose of work as well as mandatory documents related to the preparation of the design documentation of work. He breaks the boundaries between engineering and project management, leading the technical workers, who contribute to the designing, constructing and maintenance of structures. In some cases, it is the same as a project manager. Technical skills implies an understanding of a specific kind of activity, particularly one that involves methods, processes, procedures or techniques. They involve specialized knowledge and analytical ability in the use of the tools and techniques of the specific discipline, e.g., construction, engineering or information systems. State Public Organization announced a tender for a Director‘s position. It was a team formed of ten experts from a leading group of the organization's staff. They, based on the Delphi technique (three rounds were applied) selected the main seven criteria to evaluate pretenders. Later, AHP, expert judgement, ARAS-F, and EDAS-F methods were consolidated. The problem’s solution model based on MCDM methods is shown in Fig 2.

The main steps of MCDM are as follows:

a) Establishing set of evaluation criteria, that describe set of capabilities to goals;
b) Developing alternative systems for attaining the goals (generating alternatives);
c) Evaluating alternatives in terms of criteria (the values of the criteria functions);
d) Applying a normative multi-criteria analysis method;
e) Accepting one alternative as "optimal" (preferred);
f) If the final solution is not accepted, gather new information and go into the next iteration of multi-attribute optimization.

The Director‘s evaluation criteria are based on the of Lithuania laws in force. These are two main groups of skills: technical and experience (Zavadskas et al., 2008).The chief executive officer of the company formed a group of ten experts from the company’s employees. The members of this group considered as the decision-makers. After a basic assessment performed by this group, five candidates are remained for further evaluation. These candidates are considered as the alternatives of the MCDM problem (A_1 to A_5). Seven criteria with some sub-criteria selected by decision-makers to assess pretenders’ performance.

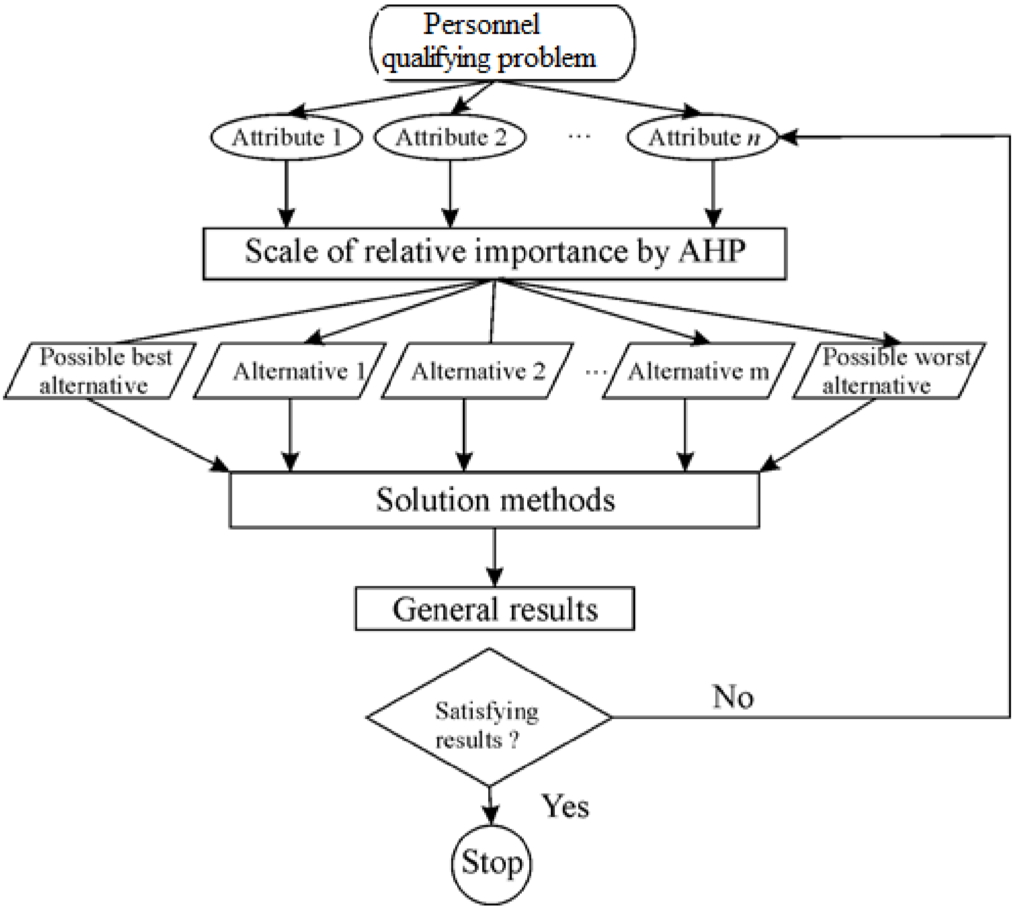

Figure2. Assessment algorithm of personnel selection

Ten experienced experts have expressed their opinion on importance (i.e., weights) of criteria according to the AHP method. Each expert's judgements consistency express *Consistency Index* and *Consistency Ratio (CR).*

The determined main criteria are as follows:

x_1– work experience in a similar position is assessed based on a 10 points scale:

- Lack of experience – 1 point;
- Experience up to a one year – 2 points;
- Experience up to 2 years – 3 points;
- ⋮
- Experience 8 years and more – 10 points.

x_2– qualifications that match job descriptions; it includes the evaluation of education areas on a 10 points scale:

- Civil engineer qualification – 10 points;

– Other qualification in engineering field (energy, environment, mechanics, electronics, transportation, and so on.) – 9 points;
– Qualification of an architect – 8 points;
– Degree in management – 7 points;
– Qualifications of economics – 6 points;
– Natural sciences education – 5 points;
– Qualifications of social sciences, with the exception of management and economics – 4 points;
– Qualifications of agricultural sciences – 3 points;
– Biomedical sciences education – 2 points;
– Humanitarian education – 1 point.

Note: If the applicant has acquired several qualifications assessed the qualification, into evaluation is taken the highest evaluation score.

x_3– leadership skills are assessed on a 10 points scale:
– Lack of experience – 1 point;
– Experience up to a year – 2 points;
– Up to 2 years – 3 points; ...
– 8 years and more – 10 points.

x_4– motivation to work in this kind of job position is measured on a 4 points scale:
– Weakly motivated – 1;
– Average motivated – 2;
– Sufficiently motivated – 3;
– Highly motivated – 4.

x_5– possessing of valid construction manager's certificate is assessed on 3 points scale based on the type of certificate:
– Project manager of special structure – 3;
– Manager of project's part of special structure – 2;
– Manager of project supervision of special structure – 3;
– Manager of project's part supervision of special structure – 2;
– Manager of construction of special structure – 3;
– Manager of special construction works of special structure – 2;
– Manager of construction works technical supervising of special structure – 3;
– Manager of special construction works technical supervising of special structure – 2;
– Manager of project's expertise of structure – 2;
– Manager of project's part expertise of structure – 1;
– Manager of structure's construction expertise – 2;
– Manager of part of structure's construction expertise – 1.

Note:*If the applicant has several certificates, then scores for each type of certificate are added up, but the maximum score cannot exceed* 3.

x_6- sociability measured during a direct conversation on a scale 4 point scale:

- Non-communicable – 1;
- Week communicable – 2;
- Average communicable – 3;
- Very communicable – 4.

x_7- ability to work in a team (subdivision very high, about 150 employees) is measured during direct conversation time, depending on the nature of the previous work, and is assessed on 4 point scale:

- No team work experience – 1;
- A small team working experience (1 year) – 2;
- Sufficient experience in teamwork, from 1 to 3 years – 3;
- A great teamwork experience (3 years and up) – 4.

Criteria ranked based on experts' team judgement. Experts rated criteria in order from the most important to the least important. Later, each of experts constructed pair-wise comparison marixes as for the first expert is shown in Table 2.

Table2. Pair-wise comparison matrix constructed by expert E_1

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
x_1	1.00	4.00	2.00	2.00	6.00	4.00	4.00
x_2	0.25	1.00	0.33	0.50	2.00	1.00	1.00
x_3	0.50	3.00	1.00	0.50	4.00	2.00	2.00
x_4	0.50	2.00	2.00	1.00	5.00	3.00	3.00
x_5	0.17	0.50	0.25	0.20	1.00	0.50	0.50
x_6	0.25	1.00	0.50	0.33	2.00	1.00	1.00
x_7	0.25	1.00	0.50	0.33	2.00	1.00	1.00

The determined criteria weights by all 10 experts presented in Table 3.

Based on Delphi and AHP methods the criteria x_1, x_2, x_3, and x_5 are assessed as crisp values, while ten experts as fuzzy values determined x_4, x_6, and x_7. There $\tilde{x}_{ij\alpha}$.means theleast given value by experts to *i*-th pretender's *j*-th criterion, $\tilde{x}_{ij\gamma}$. – thegeometric mean of given values by experts to *i*-th pretender's *j*-th criterion, and $\tilde{x}_{ij\beta}$. – the beast from thegiven values by experts to *i*-th pretender's *j*-th criterion. The initial decision-making matrix for problem solution is constructed (Table 4).

The ARAS-F and EDAS-F methods were applied to solve problem. The normalised-weighted problem‘s solution decision-making matrix for ARAS-F method is shownn in Table 5, and matrix *D* of possitive and negative distances for EDAS-F method is shown in Table 6.

Table 3. The determined criteria weights

	Experts										Geometric mean	Criteria weights
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}		
w_1	0.329	0.328	0.256	0.184	0.312	0.334	0.333	0.174	0.153	0.321	0.262	0.276
w_2	0.081	0.052	0.057	0.106	0.167	0.120	0.062	0.062	0.086	0.080	0.082	0.086
w_3	0.165	0.089	0.156	0.184	0.167	0.178	0.116	0.142	0.194	0.232	0.157	0.166
w_4	0.220	0.233	0.256	0.317	0.167	0.120	0.217	0.278	0.212	0.133	0.206	0.218
w_5	0.043	0.089	0.039	0.062	0.041	0.043	0.040	0.041	0.041	0.040	0.046	0.049
w_6	0.081	0.052	0.085	0.106	0.087	0.132	0.116	0.129	0.258	0.138	0.109	0.115
w_7	0.081	0.157	0.151	0.040	0.058	0.073	0.116	0.174	0.056	0.056	0.085	0.090
CR	0.014	0.013	0.014	0.009	0.007	0.014	0.007	0.035	0.036	0.032		
										Σ	0.948	1.00

Table 4. Initial DMM for problem solution

	$\tilde{x}_1$	$\tilde{x}_2$	$\tilde{x}_3$		$\tilde{x}_4$		$\tilde{x}_5$		$\tilde{x}_6$			$\tilde{x}_7$	
	$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	α	γ	β	$\alpha=\gamma=\beta$	α	γ	β	α	$\gamma\beta$	
	ω_1	ω_2	ω_3		ω_4		ω_5		ω_6			ω_7	
	0.276	0.086	0.166		0.218		0.049		0.115			0.090	
Opt	max	max	max		max		max		max			max	
A_1	3	9	10	3	3.46	4	1	3	3.72	4	3	3.72	4
$_2$	10	9	10	1	2.06	3	3	3	3.22	4	1	1.41	2
A_3	1	10	2	1	2.06	3	1	3	3.46	4	2	2.21	3
A_4	1	4	1	2	2.45	3	1	3	3.22	4	2	2.21	3
A_5	10	10	10	1	1.19	2	3	1	1.41	2	1	1.41	2
A_0	10	10	10	4	4.00	4	3	4	4.00	4	4	4.00	4
Σ	35	52	43	12	15	19	12	17	19.05	22	13	14.98	18
Average	5.83	8.67	7.17		2.57		2.00		3.22			2.55	

Table 5. Normalised-weighted DMM (ARAS-F method) DMM

	$\tilde{\tilde{x}}_1$	$\tilde{\tilde{x}}_2$	$\tilde{\tilde{x}}_3$		$\tilde{\tilde{x}}_4$		$\tilde{\tilde{x}}_5$		$\tilde{\tilde{x}}_6$			$\tilde{\tilde{x}}_7$	
	$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	α	γ	β	$\alpha=\gamma=\beta$	α	γ	β	α	γ	β
A_1	0.024	0.015	0.039	0.034	0.050	0.073	0.004	0.016	0.022	0.027	0.015	0.022	0.028
A_2	0.079	0.015	0.039	0.011	0.029	0.055	0.012	0.016	0.019	0.027	0.005	0.008	0.014
A_3	0.008	0.017	0.008	0.011	0.029	0.055	0.004	0.016	0.021	0.027	0.010	0.013	0.021
A_4	0.008	0.007	0.004	0.023	0.035	0.055	0.004	0.016	0.019	0.027	0.010	0.013	0.021
A_5	0.079	0.017	0.039	0.011	0.017	0.036	0.012	0.005	0.009	0.014	0.005	0.008	0.014
A_0	0.079	0.017	0.039	0.046	0.057	0.073	0.012	0.021	0.024	0.027	0.020	0.024	0.028

Table 6. Matrix *D* of possitive and negative distances (EDAS-F method)

$\tilde{p}_1$	$\tilde{p}_2$	$\tilde{p}_3$		$\tilde{p}_4$		$\tilde{p}_5$		$\tilde{p}_6$			$\tilde{p}_7$		$\tilde{S}_{ip}$
$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	$\alpha=\gamma=\beta$	α	γ	β	$\alpha=\gamma=\beta$	α	γ	β	α	γ	β	
-0.49	0.04	0.40	0.17	0.35	0.56	-0.50	-0.07	0.15	0.24	0.17	0.46	0.57	0.04
0.71	0.04	0.40	-0.61	-0.20	0.17	0.50	-0.07	0.00	0.24	-0.61	-0.45	-0.22	0.21
-0.83	0.15	-0.72	-0.61	-0.20	0.17	-0.50	-0.07	0.07	0.24	-0.22	-0.13	0.17	-0.40
-0.83	-0.54	-0.86	-0.22	-0.05	0.17	-0.50	-0.07	0.00	0.24	-0.22	-0.13	0.17	-0.45
0.71	0.15	0.40	-0.61	-0.54	-0.22	0.50	-0.69	-0.56	-0.38	-0.61	-0.45	-0.22	0.10
0.71	0.15	0.40	0.56	0.56	0.56	0.50	0.24	0.24	0.24	0.57	0.57	0.57	0.50
$\tilde{r}_1$	$\tilde{r}_2$	$\tilde{r}_3$		$\tilde{r}_4$		$\tilde{r}_5$		$\tilde{r}_6$			$\tilde{r}_7$		$\tilde{S}_{ir}$
0.49	-0.04	-0.40	-0.17	-0.35	-0.56	0.50	0.07	-0.15	-0.24	-0.17	-0.46	-0.57	-0.04
-0.71	-0.04	-0.40	0.61	0.20	-0.17	-0.50	0.07	0.00	-0.24	0.61	0.45	0.22	-0.21
0.83	-0.15	0.72	0.61	0.20	-0.17	0.50	0.07	-0.07	-0.24	0.22	0.13	-0.17	0.40
0.83	0.54	0.86	0.22	0.05	-0.17	0.50	0.07	0.00	-0.24	0.22	0.13	-0.17	0.45
-0.71	-0.15	-0.40	0.61	0.54	0.22	-0.50	0.69	0.56	0.38	0.61	0.45	0.22	-0.10
-0.71	-0.15	-0.40	-0.56	-0.56	-0.56	-0.50	-0.24	-0.24	-0.24	-0.57	-0.57	-0.57	-0.50

Problems solution results and final ranks of pretenders are shown in Table 7.

Table 7. Solution results

	Method							Final rank
	ARAS-F			EDAS-F				
	S	K	Rank	$\tilde{P}_i$	$\tilde{R}_i$	U_i	Rank	
A_1	0.177	0.700	3	0.07	1.08	0.58	3	3
A_2	0.206	0.816	1	0.42	1.47	0.95	1	1
A_3	0.104	0.411	4	-0.80	0.10	-0.35	4	4
A_4	0.095	0.377	5	-0.90	0.00	-0.45	5	5
A_5	0.186	0.736	2	0.20	1.22	0.71	2	2
A_0	0.253	1.000	0	1.00	2.12	1.56	0	0

According to Table 7, the ranking order of alternatives is $A_2 \succ A_5 \succ A_1 \succ A_3 \succ A_4$. Therefore, A_2 has the best performancwe score in this case study. Meanwhile, the best pretender's A_2score according to ARAS-F method is 81.2 % of the optimal one A_0.

4. Conclusion

Multi-criteria decision-making of personnel selection is the problem of crucial importance for business success. Application of well-defined hybrid MCDM methods and procedures to solve different and complicated problems in personnel selection is powerfull tool. The problems of personnel selection can't be modeled by crisp values due to uncertainty of data. Fuzzy MCDM methods are efficient tools to deal with the uncertain problems. In this research, the Delphi technique, Experts judgement, AHP, ARAS-F, and EDAS-F methodare integrated tosolve personnel selection problem. Real case study of Director for Estates and Economy Officeselection is presented. The set of the main criteria for pretenders' assessment is determined.They are as follows: x_1– work experience in a similar position, x_2– qualifications that match job descriptions, x_3– leadership skills, x_4– motivation to work in this kind of job position, x_5– possessing of valid construction manager's certificate, x_6- sociability, x_7- ability to work in a team. Beside this, scales to determine the criteria values are described. The model could be simply modified to solve different real-world personnel assessment problems.

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