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COMPARISON OF THREE FUZZY MCDM METHODS FOR SOLVING THE SUPPLIER SELECTION PROBLEM

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Abstract. *The evaluation and selection of an optimal, efficient and reliable supplier is becoming more and more important for companies in today's logistics and supply chain management. Decision-making in the supplier selection domain, as an essential component of the supply chain management, is a complex process since a wide range of diverse criteria, stakeholders and possible solutions are embedded into this process. This paper shows a fuzzy approach in multi – criteria decision-making (MCDM) process. Criteria weights have been determined by fuzzy SWARA (Step-wise Weight Assessment Ratio Analysis) method. Chosen methods, fuzzy TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution), fuzzy WASPAS (Weighted Aggregated Sum Product Assessment) and fuzzy ARAS (Additive Ratio Assessment) have been used for evaluation and selection of suppliers in the case of procurement of THK Linear motion guide components by the group of specialists in the "Lagerton" company in Serbia. Finally, results obtained using different MCDM approaches were compared in order to help managers to identify appropriate method for supplier selection problem solving.*

Key Words: *Supplier Selection, Fuzzy MCDM Methods, Linear Motion Guide, Comparative Analysis*

1. INTRODUCTION

Given that supply chains generate a value added of over 80% of the final product [1], nowadays supplier evaluation and selection have been recognized as one of the most important factors which significantly affect company competitiveness, reputation and success in highly competitive markets. The supplier selection process consists of several tasks [2, 3]: problem definition (identification of the needs and specifications), formulation and selection of evaluation criteria, evaluation and pre-qualification of potential suppliers

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with respect to considered criteria and respective significance and evaluation and final selection of supplier. The quality of the final selection largely depends on the quality of all the steps involved in the selection process [4]. Among these the formulation and selection of evaluation criteria, attending to cover all important aspects in the selection process as well as the choice of methods for generation of decision (selection) rule play a very important role. Starting from the pioneer study of Dickson [5], who identified 23 different criteria for evaluation of suppliers, the list of criteria is continuously changing and upgrading, wherein the relative significance of each particular criteria may vary from one case to another. Generation of a decision rule, aimed at ranking the considered potential suppliers, relies on efficient processing of information related to attribute values, both quantitative and qualitative which may involve a certain degree of uncertainty and vagueness. Given that the supplier selection often involves several decision-makers and requires consideration of a number of conflicting criteria, wherein the entire decision-making process in influenced by uncertainty in practice [6], it can be argued that the supplier selection is a complex task which can be represented as a multi-criteria decision-making (MCDM) problem. The use of MCDM methods has become widely accepted for solving real life supplier selection problems [7]. These methods allow decision-makers to determine compromise solution taking into the account different criteria, type of information (quantitative and qualitative), interest of stakeholders, relative significance of criteria as well as decision-maker preferences [8]. Since decision-makers' judgments are usually imprecise when selecting an alternative with respect to multiple criteria, the fuzzy concept is integrated within the MCDM process [9]. The fuzzy based MCDM methods enable quantification of linguistic attributes and criteria weighting scores which are used by decision-makers thus enable handling of uncertainty, imprecision and vagueness during decision-making process.

This section will briefly review the previous research studies focused on the use of fuzzy MCDM methods for supplier evaluation and selection. Awasthi et al. [10] used fuzzy technique for ordering preferences by similarity to ideal solution (TOPSIS) methods for solving a supplier selection problem considering the environmental criteria. Shaw et al. [11] proposed an integrated fuzzy-AHP and fuzzy multi-objective linear programming for solving a supplier selection problem taking into account greenhouse gas emission, costs, quality, lead time and demand as criteria for evaluating and ranking of suppliers. Kumar et al. [12] used fuzzy TOPSIS method to gain more efficient steal manufacturing throughout the supplier selection for raw materials. Luthra et al. [13] employed AHP and VIKOR methods for analyzing and ranking the sustainable suppliers in a supply chain. Baneian et al. [14] used fuzzy grey relational analysis (GRA), fuzzy TOPSIS and fuzzy VIKOR in order to evaluate and rank sustainable suppliers in the agricultural industry. Senetal [15] employed intuitionistic fuzzy TOPSIS, intuitionistic fuzzy multi-objective optimization by ratio analysis (MOORA) and intuitionistic GRA (IF-GRA) to facilitate supplier selection in the sustainable supply chain. Zeydan et al. [16] combined AHP and fuzzy TOPSIS in a framework which firstly estimated the criteria weights with AHP and then ranked a set of potential suppliers based on fuzzy TOPSIS. Büyüközkan and Göçer [17] presented the phases of the ARAS method based on the intuitive phase of the setting at intervals to support the process of selecting digital vendors.

In order to cope with vagueness and uncertainty this study employs fuzzy SWARA (Step-wise Weight Assessment Ratio Analysis) method for the determination of the considered criteria weights and fuzzy TOPSIS, fuzzy WASPAS (Weighted Aggregated Sum Product Assessment) and fuzzy ARAS (Additive Ratio Assessment) methods for the evaluation and selection of suppliers in the case of procurement of THK Linear motion guide components. The data from company management was used so as to determine criteria importance as well as to setup the decision-making matrix.

The remainder of this study is structured as follows. In the next section, a theoretical framework of the fuzzy logic, fuzzy decision-making and selected fuzzy MCDM methods are presented. The case study, i.e. THK linear motion guide supplier selection and implementation of the selected fuzzy MCDM methods are then presented in Section 3. This section also provides a comparative analysis of the obtained results. Concluding remarks and future research directions are given in the last, concluding Section 4.

2. THE FUZZY LOGIC IN MCDM METHODS

Today fuzzy logic and fuzzy set theory have numerous applications in artificial intelligence, computer science, medicine, decision theory, expert systems, management science and operations research. Fuzzy set theory has been proposed by Zadeh [18] with intention to generalize the classical notion of a set. The idea was to accommodate fuzziness as a computational framework for dealing with systems which contain human language, human judgment, their behavior, emotions and decisions. The theory of fuzzy logic provides a mathematical tool to capture the uncertainties associated with linguistic and vague variables such as "not very clear", "probably so", "very likely", etc. A linguistic variable is a variable whose values are sentences in a natural or artificial language.

In ordinary set theory, the membership of an element belonging to that set is based upon two valued Boolean logic (a member is either in or out of a subset). Unlike that fuzzy set theory is based upon multi-valued fuzzy logic which deals with degree of membership. The membership of an element is described in a real unit interval [0,1].

2.1. Fuzzy numbers

Fuzzy numbers are fuzzy subset of real numbers most often presented in form of Triangular Fuzzy Number (TFN), trapezoidal and Gaussian fuzzy numbers [19]. According to numerous definitions[20, 21, 22] TFN is represented as $\tilde{A}(l,m,u)$ where its membership function $x \in \tilde{A}, \mu_{\tilde{A}}(x)\colon \mathbb{R} \to [0,1]$ is given by Eq. (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l; \\ \frac{x-l}{m-l} & l \le x \le m; \\ \frac{u-x}{u-m} & m \le x \le u; \\ 0 & x > u. \end{cases} \tag{1}$$

Values l and u represent **l**ower and **u**pper bounds of the fuzzy number $\tilde{A}$ and b is **m**odal value (see Fig. 1). According to [18, 21] the basic algebraic operations with two TFNs,$\tilde{A}_1(l_1,m_1,u_1)$ and $\tilde{A}_2(l_2,m_2,u_2)$, are put forward:

- *Addition of triangular fuzzy numbers*(+):

$$\tilde{A}_1(+)\tilde{A}_2 = (l_1,m_1,u_1)(+)(l_2,m_2,u_2) = (l_1+l_2, m_1+m_2, u_1+u_2) \tag{2}$$

- *Multiplication of fuzzy numbers* $(*)$:

$$\tilde{A}_1(*)\tilde{A}_2 = (l_1, m_1, u_1)(*)(l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \quad for\ l_1, l_2 > 0 \tag{3}$$

- *Multiplication of a real number k and fuzzy number*$(*)$:

$$k(*)\tilde{A}_1 = (k, k, k)(*)(l_1, m_1, u_1) = (k \cdot l_1, k \cdot m_1, k \cdot u_1) \quad for\ l_1, k > 0 \tag{4}$$

- *Subtraction of fuzzy numbers* $(-)$:

$$\tilde{A}_1(-)\tilde{A}_2 = (l_1, m_1, u_1)(-)(l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{5}$$

- *Division of fuzzy numbers* (/):

$$\tilde{A}_1(/)\tilde{A}_2 = (l_1, m_1, u_1)(/)(l_2, m_2, u_2) = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right) \quad for\ l_1, l_2 > 0 \tag{6}$$

- *Reciprocal of a fuzzy number:*

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad for\ l_1 > 0 \tag{7}$$

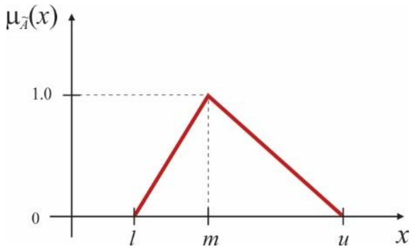

Fig. 1 The membership function of the triangular fuzzy number

2.2. Fuzzy multi criteria decision-making

Decision-making in solving the supplier selection problem involves the consideration of a number of opposite criteria and possible solutions. A decision-maker has to choose the best alternative among several candidates while considering a set of conflicting criteria. In the case where some ratings of alternatives *versus* criteria as well as the importance weights of all criteria are assessed in linguistic values represented by fuzzy numbers, such selection can be considered as a fuzzy multi-criteria decision-making (FMCDM) problem. In order to evaluate the overall effectiveness of the candidate alternatives, rank and select the most appropriate (the best) supplier, the primary objective of a FMCDM methodology is to identify the relevant supplier selection problem criteria, assess the alternatives information relating to those criteria and develop methodologies for evaluating the significance of criteria.

Here, a brief description of the applied FMCDM methods is given. In order to calculate criteria weights, fuzzy SWARA method is used, while fuzzy TOPSIS, fuzzy WASPAS and fuzzy ARAS methods are used for evaluation of alternatives.

The first step in all FMCDM methods for evaluation of alternatives (TOPSIS, WASPAS, ARAS…) is structuring the fuzzy decision matrix $\tilde{X}$ with fuzzy membership function as shown by Eq. (8):

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} = \begin{bmatrix} (x_{11}^l, x_{11}^m, x_{11}^u) & (x_{12}^l, x_{12}^m, x_{12}^u) & \cdots & (x_{1n}^l, x_{1n}^m, x_{1n}^u) \\ (x_{21}^l, x_{21}^m, x_{21}^u) & (x_{22}^l, x_{22}^m, x_{22}^u) & \cdots & (x_{2n}^l, x_{2n}^m, x_{2n}^u) \\ \vdots & \vdots & \cdots & \vdots \\ (x_{m1}^l, x_{m1}^m, x_{m1}^u) & (x_{m2}^l, x_{m2}^m, x_{m2}^u) & \cdots & (x_{mn}^l, x_{mn}^m, x_{mn}^u) \end{bmatrix} \quad (8)$$

In this expression *m* is the number of alternative solutions, *n* is the number of evaluation criteria and $\tilde{x}_{ij}$ represents aggregated performance of alternative *i* regarding criteria *j*. For qualitative criteria boundaries $\left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right)$ are aggregated values obtained using singular judgments of decision-makers in form $\tilde{x}_{ijk} = \left(x_{ijk}^l, x_{ijk}^m, x_{ijk}^u\right), (k = 1 \div K)$. Here, values $\left(x_{ijk}^l, x_{ijk}^m, x_{ijk}^u\right)$ are assigned to each alternative based on suggestions given in Table 1.

Table 1 The fuzzy scale for the alternative assessment [23]

Rank	Triangular fuzzy number	Attribute grade
Very Low (VL)	(0, 0, 0.25)	$\tilde{1}$
Low (L)	(0, 0.25, 0.5)	$\tilde{2}$
Medium (M)	(0.25, 0.5, 0.75)	$\tilde{3}$
High (H)	(0.5, 0.75, 1.0)	$\tilde{4}$
Very High (VH)	(0.75, 1.0, 1.0)	$\tilde{5}$

The aggregated values $\left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right)$ for each alternative can be obtained using the minimal, arithmetic mean and maximal value of the corresponding scores (see Eq. (9)).

$$\left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right) = \left(\min_k\left(x_{ij}^l\right), \frac{\sum_{k=1}^{K} x_{ijk}^m}{K}, \max_k\left(x_{ij}^u\right)\right) \quad (9)$$

If the specific criterion is quantitative, according to [21, 24] two approaches can be applied:

a) If no historical (statistical) data are known, triangular fuzzy numbers can be used directly by subjectively expression. For example, if transportation costs are 390 [EUR], decision-maker can subjectively estimate lower and upper boundary in triangular fuzzy number as (380, 390, 420).

(b) If there are statistical data for some past period, for example, let $x_{ij1}, x_{ij2}, \ldots, x_{ijK}$ represent transportation costs of past *K* periods, the triangular fuzzy number can be obtained using the minimal, geometric mean and maximal value of the corresponding scores:

$$\left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right) = \left(\min_k\left(x_{ij}\right), \left(\prod_{k=1}^{K} x_{ijk}\right)^{\frac{1}{k}}, \max_k\left(x_{ij}\right)\right) \quad (10)$$

In this paper the second approach is applied. The further steps of the applied FMCDM methods are different and because of that are briefly described in the following sub-sections 2.2.2 – 2.2.4.

2.2.1. *Fuzzy SWARA Method*

The Step-wise Weight Assessment Ratio Analysis (SWARA) method was originally introduced by Kersuliene et al. [25] in 2010, as a tool for the estimation of criteria weights in MCDM problems considering decision-makers' preferences. The process of determining the relative weights of criteria using the fuzzy SWARA method is the same as in the ordinary SWARA method, such as the following steps [26, 27]:

Step 1: The criteria should be sorted in descending order based on their expected significances, i.e. the most significant criterion is assigned as rank first, and the least significant criterion is assigned as rank last.

Step 2: Starting from the second criterion, each decision-maker (in total K experts) expresses the relative importance of criterion j in relation to the previous $j-1$, for all considered criteria. This ratio is called the *Comparative importance of average value* s_j[25]. The fuzzy comparison scale presented in Table 2 should be applied.

Table 2 The fuzzy comparison scale for the assessment of evaluation criteria [23]

Linguistic variable	Response scale
Equally important	(1, 1, 1)
Moderately less important	(2/3, 1, 3/2)
Less important	(2/5, 1/2, 2/3)
Very less important	(2/7, 1/3, 2/5)
Much less important	(2/9, 1/4, 2/7)

The aggregated average values of experts' judgments for evaluation criteria can be obtained, similarly as previously described, using minimal, arithmetic mean and maximal value of the corresponding scores (see Eq. (11)).

$$\tilde{s}_j = (\tilde{s}_{jl}, \tilde{s}_{jm}, \tilde{s}_{ju}) = \left(\min(\tilde{s}_{jlk}), \frac{\sum_{k=1}^{K} \tilde{s}_{jmk}}{K}, \max(\tilde{s}_{juk})\right) \tag{11}$$

Step 3: Obtain coefficient $\tilde{k}_j$values, fuzzy weights $\tilde{q}_j$and final weights of criteria.

Coefficient $\tilde{k}_j$value is computed as:

$$\tilde{k}_j = \begin{cases} \tilde{1} & j = 1 \\ \tilde{s}_j(+)\tilde{1} & j > 1 \end{cases} \tag{12}$$

Fuzzy recalculated weights $\tilde{q}_j$ as:

$$\tilde{q}_j = \begin{cases} \tilde{1} & j = 1 \\ \frac{\tilde{x}_{j-1}}{\tilde{k}_j} & j > 1 \end{cases} \tag{13}$$

Final relative weights of criteria $\widetilde{w}_j$ as:

$$\widetilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k} \tag{14}$$

where $\widetilde{w}_j = (\widetilde{w}_{jl}, \widetilde{w}_{jm}, \widetilde{w}_{ju})$ denotes relative importance fuzzy weight of the jth criterion.

2.2.2. *Fuzzy TOPSIS Method*

The Technique for the Order Preference by Similarity to Ideal Solution (TOPSIS) method was introduced by Hwang and Yoon [28] in 1981. The ordinary TOPSIS method is based on the concept that the best alternative should have the shortest Euclidian distance from the ideal solution (positive ideal solution – PIS) and at the same time the farthest from the anti-ideal solution (negative ideal solution – NIS). It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion. The method was popularized by many researchers from different fields and adapted to deal with fuzzy numbers [22, 29, 30].

In the Fuzzy TOPSIS approach an alternative that is nearest to the Fuzzy Positive Ideal Solution (FPIS) and farthest from the Fuzzy Negative Ideal Solution (FNIS) is chosen as optimal. An FPIS is composed of the best performance values for each alternative whereas the FNIS consists of the worst performance values.

Here, the relevant steps of fuzzy TOPSIS method are given as:

Step 1: The first step is the same as described in section 2.2 (Eq. (8)).

Step 2: Normalizing fuzzy decision matrix $\tilde{X}^N = \left[\tilde{x}_{ij}^N\right], i = 1 \div m,\ j = 1 \div n$:

$$\tilde{x}_{ij}^N = \begin{cases} \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}^u} & C_j^+ - \text{benefit criteria} \\ \frac{\min_i \tilde{x}_{ij}^l}{\tilde{x}_{ij}} & C_j^- - \text{cost criteria} \end{cases} \tag{15}$$

Step 3: Constructing weighted normalized decision matrix $\tilde{V}^N = \left[\tilde{V}_{ij}^N\right]$ as below:

$$\tilde{V}_{ij}^N = \tilde{x}_{ij}^N (*) \tilde{w}_j \tag{16}$$

Step 4: Determining the FPIS ($\tilde{V}^+$) and FNIS($\tilde{V}^-$) as below:

$$\begin{gathered} \tilde{V}^+ = \left(\tilde{V}_1^+, \tilde{V}_2^+, \cdots \tilde{V}_n^+\right) = (\max_i \tilde{V}_{i1}^N, \max_i \tilde{V}_{i2}^N, \cdots \max_i \tilde{V}_{in}^N) \\ \tilde{V}^- = \left(\tilde{V}_1^-, \tilde{V}_2^-, \cdots \tilde{V}_n^-\right) = (\min_i \tilde{V}_{i1}^N, \min_i \tilde{V}_{i2}^N, \cdots \min_i \tilde{V}_{in}^N) \end{gathered} \tag{17}$$

Step5: Calculating the Euclidean distance between each alternative and FPIS and FNIS as below:

$$\begin{matrix} d_i^+ = \sum_{j=1}^n d_v(\tilde{V}_{ij}^N, \tilde{V}_j^+) \\ d_i^- = \sum_{j=1}^n d_v(\tilde{V}_{ij}^N, \tilde{V}_j^-) \end{matrix}, i = 1 \div m \tag{18}$$

where, $d_v(\tilde{A}_1, \tilde{A}_2) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]}$ is the distance measurement between two fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$.

Step 6: Calculating the relative closeness coefficient as:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{19}$$

Step 7: Ranking the alternatives. The alternative with the smallest value of CC_i is considered as the best alternative.

2.2.3. *Fuzzy WASPAS Method*

The Weighted Aggregated Sum Product ASsessment (WASPAS) method was proposed by Zavadskaset al. [31] in 2012. It consists of two aggregated parts:

1. The Weighted Sum Model (WSM);
2. The Weighted Product Model (WPM).

A joint criterion of optimality, upon which final complete ranking of the alternatives is obtained, is derived based on two optimality criteria which are linearly combined using the λ coefficient [32]. The popularity of the method has resulted in the development of WASPAS-G [33], WASPAS-F [34], and WASPAS-IVIF [35, 36] methods that are intended to work with grey numbers, fuzzy numbers and interval valued intuitionistic fuzzy numbers. Also, there are a number of applications of the WASPAS method, including a number of real cases of solving the supplier selection problems [37].

The WSM determines the overall score of an alternative as a weighted sum of the attribute values, while WPM is developed in order to avoid alternatives with poor attribute values. It determines score of each alternative as a product of the scale rating of each attribute to a power equal to the importance weight of the attribute. The relevant steps of the fuzzy WASPAS method are as follows [34]:

Step 1: Forming of a fuzzy decision matrix as previously described (see Eq. (8)).

Step 2: The second step (normalization of the fuzzy decision matrix) is the same as in the previous method (see Eq. (15)).

Step 3a: Calculating the weighted normalized fuzzy decision matrix for WSM $\tilde{X}^S = [\tilde{x}_{ij}^S]$:

$$\tilde{x}_{ij}^S = \tilde{x}_{ij}^N (*) \tilde{w}_j \tag{20}$$

Step 3b: Calculating the weighted normalized fuzzy decision matrix for WPM $\tilde{X}^P = [\tilde{x}_{ij}^P]$:

$$\tilde{x}_{ij}^P = \left(\tilde{x}_{ij}^N\right)^{\tilde{w}_j} \tag{21}$$

Step 4: Calculating values of the optimality function:

a) according to the WSM for each alternative:

$$\tilde{Q}_i = \sum_{i=1}^{n} \tilde{x}_{ij}^S, i = 1 \div m \tag{22}$$

b) according to the WPM for each alternative:

$$\tilde{P}_i = \prod_{i=1}^{n} \tilde{x}_{ij}^P, i = 1 \div m \tag{23}$$

Step 5: Calculating crisps values of fuzzy numbers $\tilde{Q}_i$ and $\tilde{P}_i$. To derive the crisp value of a fuzzy number few defuzzification methods can be performed (center of gravity, center of area, mean of maxima etc.). Here the center-of-area method was used as the simplest approach to apply for defuzzification:

$$\begin{aligned} Q_i &= \frac{1}{3}\left(\tilde{Q}_{il} + \tilde{Q}_{im} + \tilde{Q}_{iu}\right) \\ P_i &= \frac{1}{3}\left(\tilde{P}_{il} + \tilde{P}_{im} + \tilde{P}_{iu}\right) \end{aligned} \tag{24}$$

Step 6: Calculating the integrated utility function value:

a) Firstly, based on the assumption that total of all alternatives WSM scores must be equal to the total of WPM scores,λ coefficient should be calculated:

$$\lambda = \frac{\sum_{i=1}^{m} P_i}{\sum_{i=1}^{m} Q_i + \sum_{i=1}^{m} P_i} \quad (25)$$

b) Finally, the integrated utility function value is:

$$K_i = \lambda \sum_{i=1}^{m} Q_i + (1-\lambda) \sum_{i=1}^{m} P_i \quad (26)$$

Alternative with maximal K_i value should be chosen as the best alternative.

2.2.4. *Fuzzy ARAS Method*

The Additive Ratio ASsessment (ARAS) method was conceptualized and proposed by Zavadskas and Turskis [38] in 2010. The specificity of this method is that an alternative's performances are determined with respect to the ideal (optimal) alternative. They argue that the ratio of the sum of normalized and weighted criteria scores, which describe alternative under consideration, to the sum of the values of normalized and weighted criteria, which describes the optimal alternative, is a degree of optimality, which is reached by the alternative under comparison.

Although it has been developed relatively recently, its application field has been extended by the development of ARAS-F [39] and ARAS-G methods [40] for solving MCDM problems involving fuzzy and grey numbers.

The relevant steps of fuzzy ARAS method are as follows [39]:

Step 1: Forming of fuzzy decision matrix as previously described (Eq. (8)).

Step 2: Forming of expanded fuzzy decision matrix by adding one row with optimal values of each criterion in the form as:

$$\tilde{X}^O = \begin{bmatrix} \tilde{x}_{01} & \tilde{x}_{02} & \cdots & \tilde{x}_{0n} \\ \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, i = 0 \div m, j = 1 \div n \quad (27)$$

Here, the optimal value of j criterion is counted as:

$$\tilde{x}_{0j} = \max_i \tilde{x}_{ij}\text{, if } \max_i \tilde{x}_{ij} \text{ is preferable} - \text{benefit criteria}$$
$$\tilde{x}_{0j} = \min_i \tilde{x}_{ij}\text{, if } \min_i \tilde{x}_{ij} \text{ is preferable} - \text{cost criteria} \quad (28)$$

Step 3: Normalizing the expanded fuzzy decision matrix $\tilde{X}^N = [\tilde{x}_{ij}^N], i = 0 \div m,\ j = 1 \div n$:

a) The criteria, whose preferable values are maximal, are normalized as follows:

$$\tilde{x}_{ij}^N = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}} \quad (29)$$

b) The criteria, whose preferable values are minimal, are normalized by applying two-stage procedure:

$$\tilde{x}_{ij}^N = \frac{1}{\tilde{x}_{ij}} \text{ then } \tilde{x}_{ij}^N = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}} \quad (30)$$

Step 4: Constructing weighted normalized decision matrix $\tilde{X}^S = \left[\tilde{x}_{ij}^S\right]$ as below:

$$\tilde{x}_{ij}^S = \tilde{x}_{ij}^N (*) \tilde{w}_j \tag{31}$$

Step 5: Calculating values of optimality function:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{x}_{ij}^S \tag{32}$$

where $\tilde{S}_i$ represents the value of optimality function of i-th alternative. Taking into account the calculation process, the optimality function $\tilde{S}_i$ has a direct and proportional relationship with the values $\tilde{x}_{ij}$ and weights $\tilde{w}_j$ of the considered criteria. Therefore, the highest value of the optimality function $\tilde{S}_i$ matches the most effective alternative (in this case it is optimal alternative A_0). The center-of-area defuzzification method can be applied here too:

$$S_i = \frac{1}{3}\left(\tilde{S}_{il} + \tilde{S}_{im} + \tilde{S}_{iu}\right) \tag{33}$$

Step 5: Calculating value of the alternative utility degree. The priority orders of considered alternatives ($i = 1 \div m$) can be determined according to the values K_i (the degree of the alternative utility). The equation used for the calculation of the utility degree of an alternative A_i is given as:

$$K_i = \frac{S_i}{S_0} \tag{34}$$

where S_i and S_0 are values of optimality function. Alternative with maximal K_i value should be chosen as the best alternative.

3. Case Study – THK Linear Motion Guide Supplier Selection

The proposed fuzzy MCDM methods for supplier evaluation and selection have been implemented in the company "Lagerton" (Limited Liability Company) from Serbia, which is an authorized distributor of a number of mechanical components. In order to illustrate and validate the applicability of proposed fuzzy MCDM methods a real-life problem, considering evaluation and selection of linear motion guide technologies supplier, is solved here.

Linear motion guide is a product of THK Company from Japan. It provides a component that enables linear rolling motion for practical usage in high-precision, high-rigidity, and energy-saving, high-speed machines.

For a known buyer the company "Lagerton" procures components (Fig. 2):

- Slide blocks SRS 12 GM UU;
- Rail SRS 12/570 – 10 – 10.

The company acquires components through a selection of the best supplier from European market qualified suppliers. Four companies (S_1, S_2, S_3 and S_4) have been evaluated and the main criteria for evaluation and selection that were used are: product price (C_1), transportation costs (C_2), delivery time (C_3), company rating (C_4) and established cooperation (C_5). The first three criteria (quantitative) are minimization criteria where lower attribute values are preferred. The last two criteria (qualitative) are maximization criteria where higher attribute values are preferable.

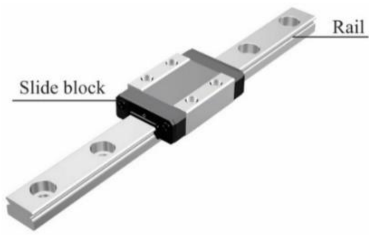

Fig. 2 THK Linear motion guide components

A graphical illustration of decision-making model for THK Linear motion guide components supplier selection is shown in Fig. 3.

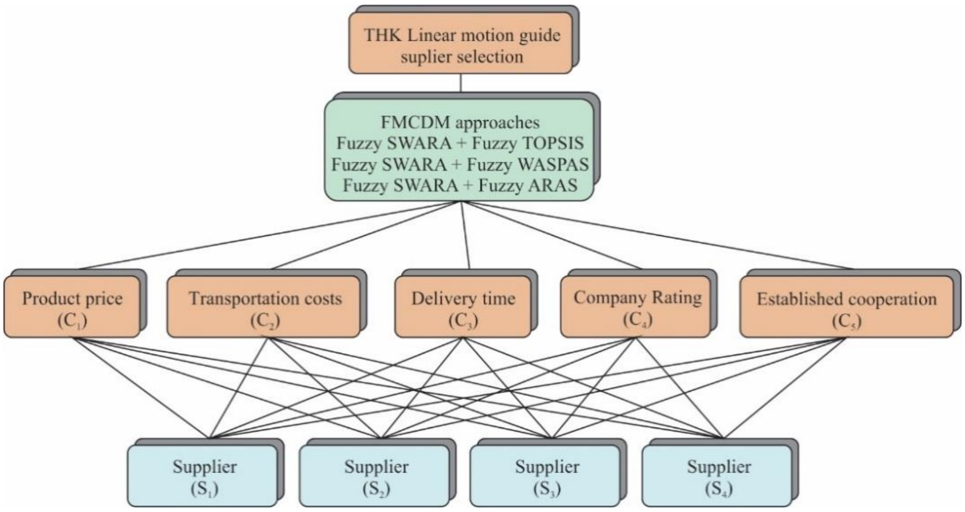

Fig. 3 A model for supplier selection of THK Linear motion guide components

In an interview, the management team of the company "Lagerton", responsible for evaluation and selection of suppliers, estimated performance ratings of four suppliers and results are shown in Table 3. Quantitative criteria are evaluated using statistical data for last two years while criteria C_4 and C_5 (qualitative) are evaluated by five experts of the company management team.

Table 3 Supplier's performance ratings-decision matrix

Criteria	C_1[EUR]			C_2[EUR]			C_3[days]			C_4[-]			C_5[-]		
Alternatives	min			min			min			max			max		
S_1	320	343.22	380	45	51.75	60	10	14.01	20	0.5	0.9	1	0.5	0.9	1.0
S_2	380	391.73	420	50	59.73	65	12	18.09	25	0.5	0.85	1	0	0.1	0.5
S_3	385	402.83	420	55	62.56	75	10	14.25	18	0.25	0.65	1	0	0.1	0.5
S_4	350	372.61	400	50	61.60	70	5	7.02	9	0.25	0.55	1	0	0.05	0.5

The processing of the obtained data was performed in accordance with the previously defined procedure (section 2.2). In the case of quantitative criteria alternatives are evaluated using Eq.10 (data from earlier similar purchases are used) and in the case of qualitative criteria using Eq. (9).

Fuzzy SWARA method is applied in order to calculate fuzzy criteria weights. According to step 1 the criteria are sorted in descending order based on their expected significances $C_5 \rightarrow C_1 \rightarrow C_2 \rightarrow C_3 \rightarrow C_4$. In second step, the relative importance of each criterion in relation to the previous one is expressed by five experts of the company management team. Results are shown in Table 4.

Table 4 Comparison of criteria relative importance by "Lagerton" experts

Expert	C_1 to C_5			C_2 to C_1			C_3 to C_2			C_4 to C_3		
E_1	0.667	1.000	1.500	0.400	0.500	0.667	0.400	0.500	0.667	0.400	0.500	0.667
E_2	0.400	0.500	0.667	0.400	0.500	0.667	0.400	0.500	0.667	0.286	0.333	0.400
E_3	0.400	0.500	0.667	0.286	0.333	0.400	0.286	0.333	0.400	0.400	0.500	0.667
E_4	0.400	0.500	0.667	0.400	0.500	0.667	0.400	0.500	0.667	0.286	0.333	0.400
E_5	0.667	1.000	1.500	0.667	1.000	1.500	0.400	0.500	0.667	0.400	0.500	0.667

All further calculations (step 3) and results are shown in Table 5. Data in column s_j are calculated according to Eq. 11.

Table 5 Criteria weights obtained using SWARA method

Criteria	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
C_5	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.329	0.417	0.584
C_1	0.400	0.700	1.500	1.400	1.700	2.500	0.400	0.588	0.714	0.132	0.245	0.417
C_2	0.286	0.567	1.500	1.286	1.567	2.500	0.160	0.375	0.556	0.053	0.157	0.324
C_3	0.286	0.467	0.667	1.286	1.467	1.667	0.096	0.256	0.432	0.032	0.107	0.252
C_4	0.286	0.433	0.667	1.286	1.433	1.667	0.058	0.179	0.336	0.019	0.074	0.196

In order to evaluate suppliers relative to given criteria three FMCDM methods (fuzzy TOPSIS, fuzzy WASPAS and fuzzy ARAS) are used. The application of the proposed FMCDM approaches gives the complete ranking of the suppliers as shown in Table 6.

Table 6 Complete rankings of the suppliers according to different FMCDM approaches

Supplier	S_1	S_2	S_3	S_4
Fuzzy TOPSIS	0.492 **(1)**	0.343 **(3)**	0.339 **(4)**	0.382 **(2)**
Fuzzy WASPAS	0.802 **(1)**	0.452 **(3)**	0.446 **(4)**	0.471 **(2)**
Fuzzy ARAS	0.862 **(1)**	0.506 **(3)**	0.503 **(4)**	0.567 **(2)**

The complete rankings are given according to calculated utility functions for each fuzzy approach. According to this Table, the supplier order preference is given below: Supplier S_1> Supplier S_4> Supplier S_2> Supplier S_3, for all FMCDM methods. The best choice is Supplier S_1. This order is the result of a strict attitude of "Lagerton" company's management team that the most important criterion is "established cooperation" – C_5. Thus, they directly favor the Supplier S_1 with which they have established cooperation through previous purchases of similar components.

It is more interesting to study the case in which there is no established cooperation with any supplier. In that new FMCDM problem criterion C_5 would have weight $\tilde{0}$. For this hypothetical case calculation of fuzzy criteria weights is given in Table 7. Table 8 shows the new suppliers order, obtained by application of three FMCDM methods. It can be noticed that the order of alternative suppliers has not changed significantly except that Supplier S_1 and Supplier S_4 have switch places. The new order is the follows: Supplier S_4> Supplier S_1> Supplier S_2> Supplier S_3, for all FMCDM methods.

Table 7 Criteria weights without C5 - SWARA method

Criteria	s_j			k_j			q_j			w_j		
C_1	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.350	0.421	0.561
C_2	0.286	0.567	1.500	1.286	1.567	2.500	0.400	0.638	0.778	0.140	0.269	0.436
C_3	0.286	0.467	0.667	1.286	1.467	1.667	0.240	0.435	0.605	0.084	0.183	0.339
C_4	0.286	0.433	0.667	1.286	1.433	1.667	0.144	0.304	0.471	0.050	0.128	0.264
C_5	-	-	-	-	-	-	-	-	-	0	0	0

Table 8 Complete rankings of the suppliers according to different FMCDM approaches – special case

Supplier	S_1	S_2	S_3	S_4
Fuzzy TOPSIS	0.441 **(2)**	0.379 **(3)**	0.369 **(4)**	0.452 **(1)**
Fuzzy WASPAS	0.790 **(2)**	0.699 **(3)**	0.679 **(4)**	0.791 **(1)**
Fuzzy ARAS	0.803 **(2)**	0.715 **(3)**	0.706 **(4)**	0.853 **(1)**

5. CONCLUSIONS

The supplier selection problem is of vital importance for operation of every company because the solution of this problem can directly and substantially affect costs and quality. Indeed, for many organizations effective supplier evaluation and purchasing process are critical success factors.

This research has demonstrated the applicability of three fuzzy MCDM approaches (Fuzzy SWARA + Fuzzy TOPSIS, Fuzzy SWARA + Fuzzy WASPAS and Fuzzy SWARA + Fuzzy ARAS) in the selection of suppliers of mechanical components.

In the case of THK linear motion guide components procurement, all considered approaches clearly highlighted Supplier S_1 as the best. Variations in other final ranking scores (Supplier $S_{2\text{-}4}$) are insignificant. In the second considered case (no established cooperation with any supplier) alternatives S_1 and S_4 have switched ranking places. Supplier S_4 would be suggested to Serbian company "Lagerton" as the best selection.

The developed fuzzy MCDM model can be extended to accompany other relevant criteria which belong to three main criteria groups (quality, environmental and social) so as to achieve continuous supplier monitoring and evaluation. Applied fuzzy methods are tools that use data in any form like numerical and linguistic, etc. Collecting and converting data into the fuzzy model, using considered approaches, reduce subjectivity of each decision maker in group decisioning and also reduce chances of errors caused by units of parameters that can make problem in some mathematical calculations. To overcome those challenges, fuzzy MCDM methods are ideal solutions.

The most important future endeavors are directed to the development of an expert and intelligent decision-making system that will be based on fuzzy principles.

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