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Newsboy problem with birandom demand

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Abstract: *Estimation of accurate product demand in a single period inventory model (SPIM) is an essential prerequisite for successfully managing the supply chain in large and medium merchandise. Managers/ decision makers (DMs) often find it difficult to forecast the exact inventory level of a product due to complex market situations and its volatility caused by several factors like customers uncertain behavior, natural disasters, and uncertain demand information. In order to make fruitful decisions under such complicated environment, managers seek applicable models that can be implemented in profit maximization problems. Many authors studied SPIM (also known as newsboy problem) considering the demand as a normal random variable with fixed mean and variance. But for more practical situations the mean demand also varies time to time yielding two-folded randomness in demand distribution. Thus, it becomes more difficult for DMs to apprehend the actual demand having two-folded random/birandom distribution. A blend of birandom theory and newsboy model has been employed to propose birandom newsboy model (BNM) in this research to find out the optimal order quantity as well as maximize the expected profit. The practicality of the projected BNM is illustrated by a numerical example followed by a real case study of SPIM. The results will help DMs to know how much they should order in order to maximize the expected profit and avoid potential loss from excess ordering. Finally, the BNM will enhance the ability of the managers to keep parity of product demand and supply satisfying customers' needs effectively under uncertain environment.*

Key words: *Newsboy problem, Uncertain variable, Birandom variable, Expectation.*

1. Introduction

The classical newsboy problem (CNP) aims at determining the optimal order quantity of products, which minimize the expected total cost and / or maximize the

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expected profit in a SPIM. Thus, the characteristics of a SPIM become more complicated due to complex market situations and its volatility caused by several factors like customers uncertain behavior. In response to handle such problems, the CNP is extended in many directions and several researchers have proposed modified versions of CNP. Some of them made proper and thoughtful use of probability theory to solve newsboy problems where product demands follow Poisson and Normal distribution (Hadley and Whitin, 1963), Weibull distribution (Tadikamalla, 1978), Erlang distribution (Mahoney and Sivazlian, 1980), compound Poisson distribution (Dominey and Hill, 2004). Gallego and Moon (1993, 1994) analyzed distribution-free newsboy problems where DMs have no idea about the demand distribution. The only information they have are mean and variance of demand. Their newsboy models can be used as strategic tools in deciding the stock of products that have a limited selling period.

This paragraph is dedicated to articulate the recent developments of SPIM and find the literature gap. Agarwal and Seshadri (2000) worked in CNP where they assumed the demand distribution as a function of selling price and the objective of the risk-averse retailers. To maximize DMs expected utility they presented two models for comparing the risk-neutral retailers (who charge a higher price for less order) with a risk-averse retailer (who charge a low price). The distribution-free newsboy problem under the worst-case and best-case scenario was revealed by Kamburowski (2014). Further, Kamburowski (2015) studied a newsboy problem where the distribution of the random variable is only known when to be non-skewed with given support, mean and variance. For the distribution-free newsboy problem, Gler (2014) extended the model developed by Lee and Hsu (2011). Here, the authors showed the expected profit increases with a proper advertisement policy while an unorganized advertising policy can have its backfire effect or make a very small improvement of the optimal profit value. Ding (2013) proposed a chance constraint multi-product newsboy problem with uncertain demand and uncertain storage capacity. Abdel-Aal et al. (2017) studied a multi-product newsboy problem assuming the service level as a constraint to offer the DMs to select the market to serve. Watt and Vzquez (2017) considered newsboy problem under two new assumptions. First, they assumed that the wholesaler is an expert who sets the wholesale price optimally and a newsboy can return the unsold item with some salvage value. In the second one, the salvage value acts as a standard insurance demand. Sun and Guo (2017) built a newsboy model with fuzzy random demand based on fuzzy random expected value model. Vipin and Amit (2017) proposed a loss aversion SPIM under alternative option and proved the rationality of the decision maker to predict the order quantity by imposing loss aversion in the newsboy model with the change of selling price and purchase cost factors. Additionally, they showed the models based on utility functions perform better in forecasting the rational behavior due to loss aversion. Natarajan et al. (2017) allowed asymmetry and ambiguity in newsvendor models. The effects of decision makers emergency order in SPIM are discussed and analyzed by Pando et al. (2013) and Zhang et al. (2017). Zhang et al. (2017) compared two ways to treat the excess demand and came up with the better one.

In the aforementioned works, the product demand is assumed to be either normally distributed with $N(\mu, \sigma^2)$ or exponentially distributed with constant mean (λ) or somewhere distribution free. But the DMs face difficulties to forecast the exact demands of products in many practical problems. The demand distribution changes dynamically from time to time, which yields randomness in the mean demand. For example, the demand (D) is normally distributed with $D \sim N(\mu\,;\, 400)$ where $\mu \sim U(3000;\ 4000)$ or $D \sim N(\mu\,;\, 400)$ with $\mu \sim exp(0.0003)$. However, in newsboy problems, it is largely appreciated to consider demand variable having the standard normal distribution. From the probabilistic viewpoint and the above arguments, it would be more realistic to assume the values of μ and σ^2 should also be treated as random variables. For such cases, it is more convincing and practical to represent the product demand as birandom variable effectively captures two-folded randomness. Traditional probabilistic approaches cannot handle such complicated real world problems. In response, Peng and Liu (2007) developed a birandom theory to tackle such problems. Zhaojun and Liu (2013) showed the common formula on birandom variable and further, several researchers used this theory to solve inventory problems in the birandom environment. In the recent years, birandom theory is widely accepted as the mathematical language of uncertainty. Some more notable extensions and applications of newsboy problem can be found in the recent literature (Abdel-Malek and Otegbeye 2013; Chen and Ho 2013).

From its inception until today, birandom theory has progressed and been applied to different areas. Xu and Zhou (2009) introduced a class of multiple objective decision making problems using birandom variables and by transforming the birandom uncertain problem into its crisp equivalent form through expected value operator and used it in the flow shop scheduling problem. A Portfolio selection problem is analysed by Yan (2009) assumed the security returns as birandom variables. Xu and Ding (2011) developed the general chance constrained multi objective linear programming model with birandom parameters for solving a vendor selection problem. They presented a crisp equivalent model for a special case and gave a traditional method to solve the crisp model. Wang et al. (2012) established a class of job search problem with birandom variables, where the job searcher examined job offers from a finite set jobs having equivalent probability. A multi-mode resource constrained project scheduling problem (Zhang and Xu, 2013) of drilling grounding construction projects considering the uncertain parameters as birandom variables. In the earlier year, Xu et al. (2012) used birandom theory to develop the nonlinear multi objective bi-level models for finding the minimum cost in a network flow problem dealing a large scale construction project. Tavana et al. (2013) measured the efficiencies of decision making units after developing a data envelopment analysis (DEA) model with birandom input and output data. Nevertheless, many more real life applications can be found in the following literature: a multi-objective birandom inventory problem (Tao and Xu, 2013), a birandom multi-objective scheduling problem (Xu et al., 2013) in ship transportation, optimal portfolio selection with birandom returns(Cao and Shan, 2013), a modified genetic algorithm (Maity et al., 2015), chance-constrained programming model for municipal waste management with birandom variables (Zhou et al., 2015), and the CCUS (carbon capture, utilization, and storage) management system in birandom environment (Wang et al., 2017).

To the best of our knowledge, no researcher has investigated the SPIM with birandom demand till date. With these considerations, we discuss an inventory model with single period considering the demand for the birandom variable. We solve a real problem using the presented model in searching the optimum order quantity for maximum profit by using the expected value model. The principal aim of this paper is to deliver basic knowledge and suggest precise results of a complex inventory practical problem for the management.

The remaining part of our paper is presented in the following way. Section 2 presents some basic knowledge of birandom variable and related theorems. Section 3 introduces the birandom simulation for finding the expected value of the birandom variable. In section 4, we provide a mathematical model for newsboy problem with birandom demand. A numerical example is discussed in section 5. To validate the applicability of the proposed model we discuss a real case study in section 6. Finally, the conclusion and future research directions are presented in section 7.

2. Preliminaries

In this section we discuss the basic notations of birandom variables.

2.1. Birandom Variable

Roughly speaking a birandom variable is a random variable of a random variable, i.e., a function defined from a probability space to a collection of random variables is said to be a birandom variable. The formal definition of birandom variable and related theorems are defined in the following way.

Definition 1 (Peng and Liu, 2007). A birandom variable ξ is a mapping from a probability space (Ω, A, Pr) to a collection S of a random variable such that for any Borel subset B of the real line $\Re$ the induced function $Pr\{\xi(\omega) \in B\}$ is a measurable function with respect to ω.

For each given Borel subset B of the real line $\Re$, the function $Pr\{\xi(\omega) \in B\}$ is a random variable defined on the probability space (ω, A, Pr).

Lemma 1 (Peng and Liu 2007). Let an n dimensional birandom vector $\xi = (\xi_1, \xi_2, \dots, \xi_n)$ and $f: \Re^n \to \Re$ be a measurable function. Then $f(\xi)$ is a birandom variable.

Let two probability spaces $(\Omega_1, A_1, \mathrm{Pr}_1)$ and $(\Omega_2, A_2, \mathrm{Pr}_2)$, ξ_1 and ξ_2 be two birandom variables respectively taken from that probability spaces. Then $\xi = \xi_1 + \xi_2$ is a birandom variable on $(\Omega_1 \times \Omega_2, A_1 \times A_2, \mathrm{Pr}_1 \times \mathrm{Pr}_2)$ defined by

$$\xi(\omega_1, \omega_2) = \xi_1(\omega_1) + \xi_2(\omega_2), \forall(\omega_1, \omega_2) \in \Omega_1 \times \Omega_2$$

Widely, for the n-tuple operation on birandom variables defined as follows. Let a Borel measurable function defined as $f: \Re^n \to \Re$ and ξ_i be birandom variable defined on $(\Omega_i, A_i, \mathrm{Pr_i}), i = 1,2, \dots, n$ respectively. Then $\xi = f(\xi_1, \xi_2, \dots, \xi_n)$ is birandom variable on $(\Omega_1 \times \Omega_2 \times \dots \times \Omega_n, A_1 \times A_2 \times \dots \times A_n, \mathrm{Pr}_1 \times \mathrm{Pr}_2 \times \dots \times \mathrm{Pr_n})$, defined by

$$\xi(\omega_1, \omega_2, \dots, \omega_n) = f(\xi_1(\omega_1), \xi_2(\omega_2), \dots, \xi_n(\omega_n))$$
$$\forall(\omega_1, \omega_2, \dots, \omega_n) \in \Omega_1 \times \Omega_2 \times \dots \times \Omega_n$$

2.2. Expected Value of birandom variables

We can transform the complex uncertain problems into their equivalent crisp models, which will be easier to solve. Generally, expected value operator is applied to transform the birandom problem into its deterministic value model for calculating the objective functional value. First, we present the definition of the expected value operator of a birandom variable and then the expected value model of SPIM. The effective tool of an uncertain variable is expectation, which is applied in a different field of applications. Therefore, the idea of expected value of birandom variable is useful.

The expected value operator of birandom variable is defined as follows.

Definition 2 (Peng and Liu, 2007). Let ξ be a birandom variable defined on the probability (Ω, A, Pr). Then the expected value of birandom variable ξ is defined as

$$E[\xi]=\int_{0}^{\infty}\Pr\left\{\omega\in\Omega|E\left[\xi(\omega)\right]\geq t\right\}dt-\int_{-\infty}^{0}\Pr\left\{\omega\in\Omega|E\left[\xi(\omega)\right]\leq t\right\}dt \tag{1}$$

Provided that at least one of the above two integrals is finite.

Lemma 2 (Peng and Liu, 2007). Let ξ be a birandom variable defined on the probability (ω, A, Pr). If the expected value $E[\xi(\omega)]$ of the random variable $\xi(\omega)$ is finite for each ω, then $E[\xi(\omega)]$ is a random variable on (ω, A, Pr).

Lemma 3 (Peng and Liu, 2007). Let us consider two birandom variable ξ and η with finite expected value, then for any two real numbers a and b, we have

$$E[a\xi+b\eta]=aE[\xi]+bE[\eta]$$

We know that a function from a probability space (Ω, A, Pr) to a collection of random variables is called a birandom variable, from the definition of birandom variable. Birandom variables are two type. They are either discrete birandom variable or continuous birandom variable. Expectation theory of birandom variables will be discussed in the current subsection.

Definition 3 (Xu et al., 2009). For a birandom variable ξ, in the probability space (Ω, A, Pr), if $\xi(\omega)$ is a random variable with a continuous distribution function when $\omega \in \Omega$ and its expected value $E[\xi(\omega)]$ is a birandom variable. Then we call ξ continuous birandom variable.

Definition 4 (Xu et al., 2009). Suppose ξ is a birandom variable, then $\xi(\omega)$ is a random variable. If $f(x, \xi)$ be the density function of $\xi(\omega)$, and

$$E\left[\xi(\omega)\right]=\int_{x\in\Omega}xf(x)dx \tag{2}$$

Then the density function of birandom variable ξ is $f(x, \xi)$.

Definition 5 (Xu et al., 2009). For the continuous birandom variable ξ, if its density function is $f(x)$, we can define the expected value of ξ as follows

$$E[\xi]=\int_{0}^{\infty}Pr\left\{\int_{x\in\Omega}xf(x)\geq r\right\}dr-\int_{-\infty}^{0}Pr\left\{\int_{x\in\Omega}xf(x)\leq r\right\}dr \tag{3}$$

Definition 6 (Xu et al., 2009). If the density function of a birandom variable ξ is $f(x, \xi)$ and $g(x)$ is a continuous function. Then expectation for the birandom variable $g(\xi)$ is defined as

$$E\left[g(\xi)\right]=\int_{0}^{\infty}Pr\left\{\int_{x\in\Omega}g(x)f(x)\geq r\right\}dr-\int_{-\infty}^{0}Pr\left\{\int_{x\in\Omega}g(x)f(x)\leq r\right\}dr \tag{4}$$

Theorem 1 (Xu et al., 2009). Let $f(x, \xi)$ is the density function of the birandom variable ξ. Then the expected value of ξ exists if only if the expected value of random variable $\xi(\omega)$ exists.

Theorem 2 (Xu et al., 2009). The expectation of a birandom variable. $\xi \sim N(\mu, \sigma^2)$, where, $\mu \sim \mathrm{U(a, b)}$ is $\frac{a+b}{2}$.

Theorem 3. The expectation of a birandom variable $\xi \sim N(\mu, \sigma^2)$ where $\mu \sim \exp(\lambda)$ is $\frac{1}{\lambda}$.

Proof: By definition (2), we know

$$E[\xi] = \int_0^{\infty} \Pr\{\omega \in \Omega | E[\xi(\omega)] \geq t\} dt - \int_{-\infty}^{0} \Pr\{\omega \in \Omega | E[\xi(\omega)] \leq t\} dt$$

Since $\mu \sim \exp(\lambda)$, and obviously $E[\xi(\omega)] = \mu$, by definition 4 and 5, the above function can be transformed as follows,

$$E[\xi] = \int_0^{\infty} \Pr\{\mu \geq t\} dt - \int_{-\infty}^{0} \Pr\{\mu \leq t\} dt$$

Since, $\mu \sim \exp(\lambda)$, and we know that the density function and the distribution function of exponential distribution are as follows,

$$f(x) = \lambda e^{-\lambda x}, x \in [0, \infty) \ and$$

$$F(x) = 1 - e^{-\lambda x},\ x \in [0, \infty).$$

According to the definition of the distribution function we can obtain the following two functions from the distribution function

$$\Pr(\mu \leq x) = 1 - e^{-\lambda x},\ \ 0 \leq x < \infty \ and$$

$$\Pr(\mu \geq x) = e^{-\lambda x}, 0 \leq x < \infty$$

Obviously, $\int_{-\infty}^{0} \Pr\{\mu \leq t\} \, dt = 0$

Therefore

$$E[\xi] = \int_0^{\infty} \Pr\{\mu \geq t\} \, dt = \int_0^{\infty} e^{-\lambda t} dt = \left[\frac{e^{-\lambda t}}{\lambda}\right]_0^{\infty} = \frac{1}{\lambda}.$$

However, it is very hard to accomplish the mathematical expression of expected value for all types of birandom variables. But using birandom simulation, we could calculate the expected value of birandom variables, with the help of Strong Number Law.

3. Birandom Simulation

Let (Ω, A, Pr), be a probability space and a $f: \mathfrak{R}^n \to \mathfrak{R}$ be a measurable function. Consider that ξ is an $n -$ dimension birandom vector on the given probability space. Now we have to find the expectation $E[f(\xi)]$ of birandom variable. Using stochastic simulation, we can find the expected value for every $\omega \in \Omega$. Here, we have used an algorithm for birandom simulation to find the expectation of $E[f(\xi(\omega))]$, which is defined as follows.

Algorithm:

Step 1. Start
Step 2. Set l=0 and N= Number of iteration
Step 3. Sample ω from Ω according to the probability measure Pr

Step 4. $E[f(\xi(\omega))]$ *is find by the stochastic simulation.*
Step 5. Then $l \leftarrow l + E[f(\xi(\omega))]$
Step 6. Repeat the steps from second to fifth steps N *ttimes.*
Step 7. $E[f(\xi(\omega))] = \frac{l}{n}$.
Step 8. Stop

4. Mathematical Formulation

We are assuming a single period inventory problem with single product. Here all the costs (buying cost and selling cost) are deterministic. Salvage value is taken which is also deterministic. But the demand is birandom variable. The mathematical notation of a birandom newsboy problem is defined as follows:

$\bar{\bar{\xi}}$	:	The demand of market, a birandom variable
x	:	The quantity which to be order, a decision variable
$p = c(1+m)$	:	Selling price per unit
$s = c(1-d)$	:	Salvage value per unit
c	:	Purchasing cost per unit
$g\left(x, \bar{\bar{\xi}}\right)$	:	The profit for the order quantity x and demand $\bar{\bar{\xi}}$
μ	:	Expected value of birandom demand $\bar{\bar{\xi}}$
σ^2	:	Variance of the birandom demand $\bar{\bar{\xi}}$
m	:	Mark-up, i.e., return per dollar on unit sold
d	:	Discount rate, i.e., loss per dollar on unit unsold
$x^+ = \max\{x, 0\}$	:	The positive part of x

Then the profit can be expressed as

$$g\left(x, \bar{\bar{\xi}}\right) = p\left[\min\left\{x, \bar{\bar{\xi}}\right\}\right] + s\left(x - \bar{\bar{\xi}}\right)^+ - cx \tag{5}$$

Now $\min\left(x, \bar{\bar{\xi}}\right) = \bar{\bar{\xi}} - \left(\bar{\bar{\xi}} - \mathrm{x}\right)^+$

Where

$$\left(x - \bar{\bar{\xi}}\right)^+ = \left(x - \bar{\bar{\xi}}\right) + \left(\bar{\bar{\xi}} - x\right)^+ \tag{6}$$

$$g\left(x, \bar{\bar{\xi}}\right) = p\bar{\bar{\xi}} + s\left(x - \bar{\bar{\xi}}\right) - cx - (p - s)\left(\bar{\bar{\xi}} - x\right)^+ \tag{7}$$

Since the demand for the product is birandom, the profit function $g\left(x, \bar{\bar{\xi}}\right)$ is also consists of birandom variable. Hence, the expectation criteria is used for handling the birandom variable. Therefore, to find the optimal quantity, the decision maker will maximize the total expected value.

We can write the expected profit as

$$\Pi(x) = (p - s)\mu + (s - c)x - (p - s)E\left(\bar{\bar{\xi}} - x\right)^+ \tag{8}$$

Or using the definition of m and d, as

$$\Pi(x)=c[(m+d)\mu-xd-(m+d)E\left(\bar{\bar{\xi}}-x\right)^{+} \tag{9}$$

The information of $\bar{\bar{\xi}}$ is known. To maximize the profit function, we need the following lemma.

Lemma 4. For given a birandom variable $\bar{\bar{\xi}}$, we have the following inequality,

$$E\left(\bar{\bar{\xi}}-x\right)^{+} \leq \frac{\left[\sigma^2+(x-\mu)^2\right]^{\frac{1}{2}}-(x-\mu)}{2} \tag{10}$$

Proof: Notice that $\left(\bar{\bar{\xi}}-x\right)^{+} = \frac{\left|\bar{\bar{\xi}}-x\right|+\left(\bar{\bar{\xi}}-x\right)}{2}$

The result follows by taking expectations and by using the Cauchy-Schwarz inequality

$$E\left[\bar{\bar{\xi}}-x\right] \leq \left[E\left|\bar{\bar{\xi}}-x\right|^2\right]^{\frac{1}{2}} = [\sigma^2+(x-\mu)^2]^{\frac{1}{2}}$$

By using the lemma (4) the equation (9) will be rewritten as

$$\Pi(x)=c\left[(m+d)\mu-xd-(m+d)\frac{\left[\sigma^2+(x-\mu)^2\right]^{\frac{1}{2}}-(x-\mu)}{2}\right] \tag{11}$$

It is easy to validate that equation no (11) is strictly convex in x. Upon setting the derivative to zero and solving for x we obtain the ordering rule

$$x^{*}=\mu+\frac{\sigma}{2}\left(\left[\frac{m}{d}\right]^{\frac{1}{2}}-\left[\frac{d}{m}\right]^{\frac{1}{2}}\right) \tag{12}$$

5. Numerical Example

Assume that the unit purchase price of a perishable product is $c = \$40$, the unit selling price is $p = \$60$, and there is no salvage value ($s = 0$). Thus, $m = \frac{p}{c} - 1 = \frac{60}{40} - 1 = \frac{1}{2}$. Discount rate $d = 1 - \frac{s}{c} = 1$. Further assume that the product demand is a birandom variable with normal distribution $N(\mu_1, 400)$, and $\mu_1 \sim exp(0.0003)$. From theorem (3), we have $\xi \sim N(\mu_1, 400)$, where, $\lambda = 0.0003$.

Hence, by theorem (3) we can say that the mean (μ) of the birandom variable (ξ) is $\frac{1}{\lambda} = \frac{1}{0.0003} = 3333.33$, and $\sigma^2 = 400$. Now it remains to calculate the optimal order quantity and expected profit. For this purpose, we apply equation (12) and obtained the optimal order quantity, $x^* = 3326$. Hence, the expected profit is, $\Pi = \$66100$.

6. A Case Study

To endorse the model developed in this study, we sent our projected framework to five leading fish merchants in West Bengal, India. They sell only the freshest and best quality fishes, and maintains quality control at every stage of packaging and delivery in many different parts or areas of West Bengal. Among them two firms positively responded to explore this research proposal and we conducted necessary preliminary tasks on these companies. We selected a reputed fish merchant (*"Lakshmi fish enterprise", name changed*), situated in the "southern" West Bengal, which has several operational units nationwide. Our objective is to incorporate the perceptions of all participants (customer/retailer/company mangers) in the fish industry and to achieve its comprehensive outcomes since this research is purely grounded on birandom product demand information obtained from experts in the business. In this paper, we consider the perspectives of a wholesale fish merchant who buys fishes from the company, having a large market share in Kolkata zone.

In West Bengal, fish merchants generally sell a special fish in monsoon. The name of this fish is Hilsa. The business of this fish is a good example of SPIM. The business of this fish totally depends on its demand and supply in the monsoon season. Merchants have to decide how many fishes should be purchased from his or her supplier depending on the customer's demand. Buying more amount of Hilsa may not bring him more profit. Rather it can cause him a great loss since it cannot be preserved for long periods and the expired fish has no market value. If he/she buys too few amount of Hilsa he/she will lose the opportunity of making a higher profit. Thus, the actual inventory level cannot be determined precisely in such complex situation. It may be assumed for simplicity that the fish demand follows normal distribution. But under such circumferences, the manager looks after of some previous data, and finds the mean demand of "Hilsa" is also a random variable. This leads us to consider the "Hilsa" demand as a birandom variable. Each such fish sells for \$60 and costs for the shop owner \$40. Investigating the previous year data, the decision maker decides the demand follows the two types two- folded random variable (birandom).

Scenario 1: Normal distribution $N\sim(\mu_1, 400)$, with $\mu_1 \sim U(3000, 4000)$.

Scenario 2: Normal distribution $N\sim(\mu_1, 400)$, with $\mu_1 \sim N(3500, 500)$.

Therefore, according to our proposed model we have $c = 40, p = 60$, and there is no salvage value i.e., $s = 0$. In scenario 1, by theorem (2) the mean of the birandom variable is $\mu = 3500$, and $\sigma^2 = 400$. Therefore the optimal order quantity $x^* = 3492$. Expected profit $\Pi = \$69434$. And in scenario 2, using birandom simulation we get the mean of the birandom simulation $\mu = 3508$, and $\sigma^2 = 400$. Therefore, the optimal order quantity $x = 3500$, expected profit = \$69594. Finally, we shared the outcomes of this research work with the managers of our case enterprise, they are satisfied with the outcomes and willing to accept this result for their monsoon business of "Hilsa".

7. Conclusion

In this paper we have proposed a newsboy problem where the demand is considered as birandom variable. The market volatility and uncertainty in customers' behavior make the demand of the product a birandom variable. We use the expected value model for handling this birandom variable and to convert the BNM into its equivalent deterministic model. We discuss a case study of fish merchant to validate the usefulness and applicability of the proposed model. In this proposed model demand is the only parameter considered as birandom variable. However, in reality cost may be assume as a birandom variable. This is the one aspects to be considered for further investigation in the current model. Also, for future research work, one can develop chance constraint technique to convert the birandom model into deterministic one.

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EVALUATION OF IRANIAN WOOD AND CELLULOSE INDUSTRIES

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Abstract: *Iranian Wood and Cellulose Industries (IWCI) are distinguished via a minimum quantity of wood consumptions with high wastages rates along with favourite products generation. IWCI exposed to lots of obstacles in the way of maturation and expansion especially in terms of technologies assigned and overdependence on input materials entered into industries cycle. Present cluster study of IWCI empirically targeted an assessment of technologies, input and output materials streams, existing facilities in industries individually. SPSS Software along with Delphi Fuzzy theory and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods were assigned to evaluate the data of industries as findings of Iranian evaluator team once before construction of industries. T-test analysis had represented significant differences around (pvalue≤ 0.001, 0.002) among main criteria of IWCI such as the number of employees, power, water and fuel exploitations and the land area occupied by each industry. Using Friedman test the ranks values were obtained about 2.59, 4, 1.53, 1.88 and 5 for the number of employees, power, water, fuel consumed and land area applied in the location of industries. Analytical Hierarchy Process (AHP) via Delphi Fuzzy set, Fuzzy TOPSIS and TOPSIS resulted to a hierarchical classification among IWCI.*

Key words: *Evaluation; Iranian wood and cellulose industries; TOPSIS.*

1. Introduction

The use of wood in Iranian ancient refers to before the Aryan migration from about 4200 BC. Wood industry has got an extensive range of applications both as commercial and industrial demands in Iran. Obviously, population growth aligned with escalated consumption patterns, industries and urbanity developments, have culminated demands for wood and its products in Iran. Iranian statistics centre has recently reported to around 226 industrial production sites of furniture with approximately 10,000 employees are currently running along with around 46,700 wood industries offices operating 117,000 at the native workshops. The value-added of wood products has been recently reported approximately 30% apart of value-added percentage

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associated with the furniture industry (totally 70%). 5% of the industry's value-added devoted to both industrial printing (4.6%) plus Iranian Cellulose industries. The per capita consumption rates for various paper and paperboard types has been estimated at around 23 kg in 2016 with a rise from 12-13 kg to 23 kg in comparison to 10 years ago. This amount has been forecasted in high amounts, (with a factor of 2) for other nations over the world. On the other hand, Iranian people stake in various paper and paperboard consumptions are negligible. The prominent stake for both of paper and paperboard productions has devoted to linerboard and fluting applications which comprise approximately 50%; employed in sheets and cardboard boxes generations and their equipment. In the SWOT analysis, many strength points determined for IWI such as longtime production background, various academic and vocational centres and also well trained and well-experienced labour forces in various fields, creating a high value-added percentage, high-quality products manufacturing in comparison to imported products. However, many drawbacks have also reported for aforementioned industries such as dependency to rare domestic resources, old fashionable equipment and machinery, exhausted devices, bereavement in special tariff proclamations, high transportation outlays and deficiency of investment for requested infrastructure. According to aforementioned advantages and drawbacks, stakeholders need to consider to some opportunities to pave the way for more advancement and development in the field of wood industries.

Globally, the lumber & wood products are divided to many sections such as (1) Hardwood dimension and flouring mills (2) Millwork (3) Hardwood veneer and plywood (4) Softwood veneer and plywood (5) Structural wood members (6) Nailed and lock-corner wood boxes and shook (7) Wood pallets and skids (8) Wood containers (9) Wood preserving (10) Wood products, (11) Pulp mills (12) Wood kitchen cabinets (13) Prefabricated wood buildings and components (14) Wood household furniture, except upholstered wood television, radio, and phonograph cabinets (15) Wood office furniture (16) Sawmills and planing mills (17) Special product sawmills (18) Particleboard. In Iran, there are many cases of wood and cellulose products industries such as Cooler bangs (1), Carton (2), Industrial drying wood (3), Hydrophilic cotton (4), Sheet rolls and packing (5), Wax paper (6), Booklet (7), Hasp (8), Decal (9), Multilayer paper bags (10), Row board (11), Wooden and paper disposable products (12), Wooden pencil (13), Carbon paper (14), Parquet (15) Wooden sandpaper (16) (Iranian industries organization, 2018).

In accordance with the approval of government agencies, any industrial project prior to construction requires the financial, technical and environmental assessments etc. According to the current assessment of the Iranian Industries Organization, in a cluster study, about 16 types of wood and cellulose industries have been identified. In the present study, raw data are generally presented in the framework of a PhD thesis with existing methods for evaluating the project and obtaining the best possible decision-making processes.

Using Multi-Criteria Decision Making (MCDM) models to weight and rank the various data will result to generate different values for the same data employed. The MADM practices need to each alternative to be evaluated against amounts of rating devoted to the attributes, factors and criteria containing various units of measurement for each of them. To compare obtained results associated with each factor or criterion a normalization process is accomplished and the results will offer its own value in integrating the diverse measurement units. The main reason for the normalization process gets back to shift the various assessed units into a non-dimensional scale. By the way, normalized values follow non-declining amounts in the range of 0 and 1 (Gul et al., 2018). Applying AHP, for decision-making processes gets back to Saaty (1980), in an effective and robust practice to model the sophisticated decision difficulties. This practice encompasses complex factors and criteria by deconstructing and dividing them into various easy sub-items so that assign the hierarchical classification, in which the main objective placed in the top level, sub-objectives or accessory options at below clusters and in the following the possible options are embedded in the last level. By the definition, the AHP method is an economic multi-criteria practice of analysis pertaining to a weighting style, in which lots of proper contributions are released based on their relative importance. TOPSIS method, first time acknowledged by Hwang & Yoon (1981), who employed the basic implication of positive and negative ideal solutions in which the determined factors and criteria should have the shortest distance from the positive ideal solution, and the farthest distance from the negative ideal solution (Yazdani-Chamzini et al., 2014). In the uncertainty situation, TOPSIS method is assigned to realize and identify the difficulties so it offers a certain solution. An ideal solution includes the best response or alternative amounts for each factor and criterion. In some cases using TOPSIS for identifying ambiguous data brings some other difficulties so in this cases in order to overcome this restriction, the fuzzy set theory can be employed with the traditional TOPSIS approach to permitting decision-makers to integrate vague data, non-obtainable information, and relatively ignorant facts into the decision model to solve various difficulties and challenges successfully (Zare et al., 2016). Therefore, according to the objective of paper as evaluation of IWCI, the present study included the flow diagrams of running processes, input and output materials flows entered and outsourced from industries along with equipment and facilities used at each industry. The Fuzzy Delphi logic and Fuzzy TOPSIS and TOPSIS (based on real data) were assigned to assess the factors and criteria and in the following industries hierarchically classified, weighted and ranked, values were calculated based on available information.

2. Literature review

Mardani et al. (2016) assessed around 10 biggest Iranian hotels via fuzzy set. Yazdani-Chamzini et al. (2013) assigned Fuzzy TOPSIS to assess the difficulties of investment strategy selection. Zagorskas et al. (2014) investigated the growth in building refurbishment of new-build projects and historical buildings preservation involvements via TOPSIS technique. Nikas et al. (2018) evaluated the gap between climate policy to find a methodological framework to remove existing complex problems using both Delphi and TOPSIS methods. Cavallaro et al. (2016) employed a prioritization method for factors and criteria of combined heat and power systems via both Fuzzy Shannon entropy and Fuzzy TOPSIS methods. Moghimi & Anvari (2014) utilized Fuzzy MCDM approach among 8 Iranian cement companies pertaining to financial statements.

3. Methodology

3.1. Friedman test

Present cluster research of IWCI was empirically performed to evaluate and assess the data of industries. In order to carry out the research, secondary data were gathered from the Iranian Industrial organization database along with findings of evaluator team of environment protection agency. Then secondary data were processed by the

MCDM methods supported by SPSS software (IBM SPSS Statistic 20) in order to classify the aforementioned industries hierarchically. Data were analyzed using the Friedman test and statistic tests for distinguishing initial ranking and realizing significant relations among them. Friedman test assumes the data as a matrix with certain columns and rows ([Xij] n×k in a matrix with n rows, k columns). Actually, to the object, i is added the rank ri, j by judge number j, where it appears in whole n objects and m amount. Therefore, taking into account equations 1 to 6, the initial processing is done on the data by software. Then, equation 5 is used for a general ranking of any factor having the specified values in the columns. The overall ranking can be checked with the analogous test to Friedman test called Kendall. Kendall's W is a non-parametric statistic test and can be assigned for normalization of the results of Friedman test, as well as investigating agreement among values. W in equation 9 is linearly joined to the mean value of the Spearman's rank correlation coefficients between all pairs of the available rankings. The symbol of S (in equation 8), is the sum of squared deviations appeared below. Therefore, equations 6 to 9 are applied to process total rank given to object i which obtained from the Friedman test. The results obtained at this step can be used to investigate Friedman test results (Wittkowski, 1998).

$$\hat{\mathrm{r}}.\mathrm{j} = \frac{1}{\mathrm{n}} \sum_{i=1}^{n} rij \tag{1}$$

$$\hat{\mathrm{r}} = \frac{1}{\mathrm{nk}} \sum_{i=1}^{n} \sum_{j=1}^{k} rij \tag{2}$$

$$\mathrm{SSt} = \mathrm{n} \sum_{j=1}^{\cdot} (\hat{\mathrm{r}}.j - \hat{\mathrm{r}})^2 \tag{3}$$

$$\mathrm{SSe} = \frac{1}{\mathrm{n(k-1)}} \sum_{i=1}^{n} \sum_{j=1}^{k} (rij - \hat{\mathrm{r}})^2 \tag{4}$$

$$\mathrm{Q} = \frac{\mathrm{SSt}}{\mathrm{SSe}} \tag{5}$$

$$\mathrm{Ri} = \mathrm{n} \sum_{j=1}^{m} (ri, j, ..) \tag{6}$$

$$\mathrm{Rave} = 1/\mathrm{n} \sum_{i=1}^{n} \mathrm{Ri} \tag{7}$$

$$\mathrm{S} = \sum_{i=1}^{n} (\mathrm{Ri} - \mathrm{Rave})^2 \tag{8}$$

$$\mathrm{W} = \frac{12\ \mathrm{S}}{\mathrm{m}^2(n^3 - n)} \tag{9}$$

3.2 Fuzzy set theory

In this section, the equations of 10 to 17 are introduced, which are explained below. The Delphi Fuzzy system used in this research is displayed as triangular Fuzzy numbers according to Figure 1. The weighing system complies from a pattern as, $\sum_{j}^{n}$ Wj, (j=0-1). Initially, the factors and criteria used are represented by linguistic words, real and Fuzzy numbers according to Table 1.

Table 1. Delphi Fuzzy set

Linguistic words	Symbol	Fuzzy No	Crisp No
Very low	VL	(0.09,0, 0.1)	0.1362
Low	L	(0.2, 0.1, 0.1)	0.2272
Slightly low	SL	(0.3, 0.1, 0.2)	0.3695
Medium	M	(0.5, 0.1, 0.1)	0.5
Slightly high	SH	(0.6, 0.1, 0.2)	0.6304
High	H	(0.8, 0.1, 0.1)	0.7727
Very high	VH	(0.85, 0.1, 0)	0.8636

Current Fuzzy values (M, a, b) are able to transform as m2+b to m1-a. By the equations of 10 to 12 (N= m, a, b) Fuzzy numbers can be displayed in Figure 1. By the way, Fuzzy numbers are represented by some symbols and also real numbers which can be converted to Fuzzy numbers. In this research, equation 13 was used to prioritize factors. Using a data classification system, the actual numbers obtained by the evaluator team were classified in certain intervals. As a result, Table 5 was formulated as a criterion/factor versus symbol in the Likert scale. The special vector (A vector is defined as a rank value obtained from criteria and factors in columns) was acquired by the results of the Friedman test. The Weighted Sum Vector (WSV) is the summation of the weight of each criterion (W) multiply in assigned Fuzzy number (D) according to equation 14.

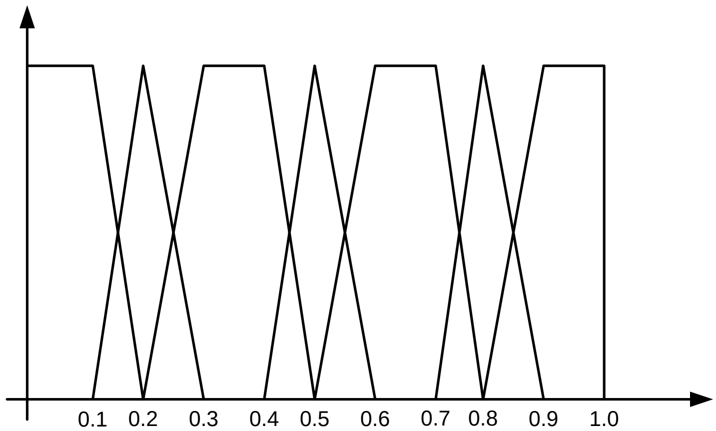

Figure 1. A triangular fuzzy numbers (Shiroye, 2013)

$$\mu R(M) = 1 - \frac{1}{1+a} * (1 - m) \qquad (10)$$

$$\mu L(M) = 1 - \frac{1}{1+b} * (m) \qquad (11)$$

$$A = \sum_j (Wj.Wij) \qquad (12)$$

$$WSV = \sum D \times W \qquad (13)$$

$$CI = \frac{\lambda \max - m}{m-1} \qquad (14)$$

$$\hat{r}.j = \frac{1}{n}\sum_{i=1}^{n} rij \tag{15}$$

Using equation 15, the natural attribution of incompatibility can be figured out upon a matrix set for data in which λmax is always ≥ m. λmax and m are the biggest eigenvalue of the pairwise comparison and criteria number respectively. Therefore, $\lambda \max - m$ represents the incompatibility degree in the matrix. In the equation 16, the symbols of CI and RI are the consistency index and random index which Saaty (1980) used them for a matrix holding a set of data from 1 to 10 and recognized a compatibility value as CR ≤ 0.1. The incidence of random inconsistencies suggested by Saaty (1980) is according to Table 2.

Table 2. Incidence of random inconsistencies (Saaty 1980)

m	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{16}$$

$$\mathrm{Z\,x} = \lambda \max X \tag{17}$$

The current research, obtained data were the findings of Iranian evaluator team once prior to the implementation of the industries sites. Therefore, data are offered as a reference information and there is no possibility of changing data. Therefore, the conditions described in Equation 16 cannot be applied to the evaluation style of this research. The studies and assumptions mentioned by Saaty (1980) are governed by the questionnaire methods and if the results are not met the assumptions and conditions of the formula or any failure to follow the results with the assumptions and conditions needs modifying and changing even rechecking the privileges, scores and marks given by experts. Equation 17 is utilized to estimate the priority vectors so Z, x and max are the values of pairwise comparison matrix, priority vector or Principal Eigenvector and maximum or principal Eigenvalue of matrix Z (Shirazi et al., 2017; Shiroye, 2013).

3.3 Fuzzy TOPSIS procedure

Using the fuzzy TOPSIS method to extract the final weight of data, is a type of evaluation of matrix containing industries criteria in which aij is the numerical value of each industry i, according to the index j. TOPSIS method is a very strong evaluation method and a technique for prioritizing by analogy to the ideal response. Based on the fact that the selected option should be kept in the shortest distance from the ideal response and the furthest distance from the worst response. In this research, the TOPSIS method was selected based on Hwang's rule for choosing the best options. Equation 18 was used to convert the matrix of industries factors into a non-dimension matrix.

$$\mathrm{Nd} = \frac{\mathrm{aij}}{\sqrt{\sum_{i=1}^{m}(aij)^2}} \tag{18}$$

The next step was to create a non-dimension matrix with the assumption that the weights (Wn.n) are indexed. The non-dimension matrix is obtained by equation 19. Therefore, the special vector (obtained from the Friedman test) was conducted on a non-dimension matrix to get the values for V.

$$\mathrm{V} = \mathrm{Nd} \times \mathrm{Wn.n} \tag{19}$$

The next step was to identify the ideal positive solution (A^+) and the ideal negative solution (A^-) according to the equations of 20 and 21. To perform this purpose the amounts were extracted based on equations at each column of V.

$$\mathrm{A}+ = \{(\max Vij|j \in J), (\min Vij|j \in j')|i = 1,2,\ldots,m\} = \{\mathrm{V1}+, \mathrm{V2}+, ..\mathrm{Vj}+, \mathrm{Vn}+\} \tag{20}$$

$$\mathrm{A}- = \{(\min \mathrm{i}\, Vij|j \in J), (\max Vij|j \in j')|i = 1,2,\ldots,m\} = \{\mathrm{V1}-, \mathrm{V2}-, ..\mathrm{Vj}-, \mathrm{Vn}-\} \tag{21}$$

Then the distance between each option was calculated using Euclidean intervals according to equations 22 and 23. The relative proximity to the ideal solution was calculated in accordance with equation 24. On the other hand, equation 24 represents approach coefficient (Zagorskas et al. 2014; Nikas et al. 2014; Mukhametzyanov & Pamucar, 2018).

$$\mathrm{di}+ = \left\{\left(\sum_{j=1}^{n}(Vij - Vj+)^2\right\}^{0.5} \;; i, = 1,2,3,\ldots m \tag{22}$$

$$\mathrm{di}- = \left\{\left(\sum_{j=1}^{n}(Vij - Vj-)^2\right\}^{0.5} \;; i, = 1,2,3,\ldots m \tag{23}$$

$$\mathrm{cli}+ = \frac{\mathrm{di}-}{\mathrm{di}(+) + (di-)} \tag{24}$$

4. Results and discussion

The wood was, at first, a vital ingredient for the construction of primary tools, homes and boats for moving in the rivers. Then, it was employed to make most of the useful things that people relied on for centuries to develop their lives style. Part of the technology of wood has left over by the efforts of industrialists, but most of it has been lost and replaced by other materials and methods that are the result of the industrial revolution of mankind. Wood is the only natural renewable resource. Oil and coal and other mines will eventually end, but a well-maintained forest will indefinitely continue to produce wood. Wood has a prominent place in the global economy. The annual production of wood in the world is 2,500 million cubic meters. The physical, chemical and mechanical properties of wood have made it a unique product for lots of applications at this time. Wood is one of the most useful materials we have which is sturdy, but it can be easily cut and made in different shapes. The bulk of wood comes from the trunk or body of trees. Wood hardness; this is important in the quality of work with those and other uses, such as parquet, which is continuously affected by wear. Softwoods are more likely to be consumed in carpentry. The impact resistance of wood is different because of the heterogeneous construction of wood in different directions and sizes. The wood in the direction of the impact has a lot of pressure, but it changes due to the introduction of a lot of force. Flexural Strength; the wood affected by bending is noticeably deformed. If the force applied is more than flexural, it will break the fibre. As the wet stick is more flexible, its resistance to impact is greater. In general, the more porous the wood is, the less the impact is. Wood durability; wood is not a durable object, it is worn out by insects and fungi. Of course, thicker wood is more durable and can be increased by some methods. Nowadays, there is a lot of consumption for wood in many other industries, including printing, chasing, furniture, carpentry, shoemaking, coiling, carving and railway wagoning, and many other industries, especially in the motherboard industry. Today, many products, such as a variety of compact fibres, bone fragments, chipboard, refractory boards, triplex and five-ply boards, and many others are used in machine systems, building and refurbishment work etc. Therefore, we tried to present wood applications and existing technologies to produce and make woody equipment. Our data were raw results of Iranian evaluator team once before construction of manufacturers in terms of energy consumed, input and output materials injected into generation process along with accessible facilities in each industry. Figure 2 shows the IWCI and their production processes and running technologies. Table 3 includes input materials entered to IWCI and Table 4 contains IWCI, number of staff, land area used and energy consumptions.

Up to down: Cooler bangs (1), Carton (2), Industrial drying wood (3), Hydrophilic cotton (4), Sheet rolls and packing (5), Wax paper (6), Booklet (7), Hasp (8), Decal (9), Multilayer paper bags (10), Row board (11), Wooden and paper disposable products (12), Wooden pencil (13), Carbon paper (14), Parquet (15), Sandpaper (16)

Figure 2. IWCI and their production processes

Table 3. Input materials entered to IWCI

Industry	Initial materials
(1)	Wood (1890t); Nylon networks (43260 kg); Packaging bags (9700 kg); Stapler needles (29120 bundle)
(2)	Three layers paper sheets (1454117 kg); Five layers paper sheets (955704 kg); Silicate glue (25498 kg); Dye (9956 kg); Nylon cords (1100 kg)
(3)	Wood pollens (9500 m^3)
(4)	Raw cotton (440t); Bleach with activity of 11-12 (55t); NaOH, 98% (17.6t); Washing liquid (4.4t); H_2SO_4 (4.4t); Nylon, thickness of 0.02 mm (40t); Softener (4.4t); Thiosulfate (8.8t)
(5)	Paper, 30 g/m^2 (947.5t); Three layers packaging cartons in sizes of 75*23*50 cm^3 (139000 No); Cardboard pipes, L= 23 cm (100t); Plastic bags (16.7t)
(6)	Paper rolls having 500 kg (685t); Al sheets, thickness of 10 micron (285t); Paraffin as rolls of 500 kg (52t); Special gum (3.1t); Packing paper (3.2t)
(7)	Paper of 60 g (379t); Cardboard, 175 g (43t); Plastic yarn (312000 g); Stapler wires (686 kg); Ink (22.8 kg); Cartons in sizes of 66*52.5*18 cm^3 (17333 No)
(8)	Timber (400 m^3); Timber layers of 2.5 mm (40000 kg); Formaldehyde jum 60% (8000 L); Glue (160 kg); Axe (60000 No); Spool 27-30 (15000 No); Brass pieces (15000 No); Paper washer (120000 No); Bolts and nuts (120000 No); Hasp bar (30000 No); Prong (30000 No); Nuts layout (120000 No); Polished oil (600 l); Thinner 2000 (200 l); Washing soap (400 kg); Nail with grade of 4 and 5 (100 kg)
(9)	Velvet and raw papers (6250000 No); Resin paste (312500 kg); Ink (800 kg); Resin glue (15625 kg)
(10)	Craft paper (2232t); Crepe paper (84t); Paper yarn (84t); filter cords as sweeper (18t); Gum, liquid silicate (180t); Ink (12t); PP strips, W= 2 cm (400000 m)
(11)	Wood veneer (126000 pieces); Urea glue (6300 kg); Filler and fixer pastes (8220 kg); Sandpaper (1260 m^2)
(12)	Dry wood (240000 kg); PE cover (27t); Nylon cover (20457 m^2); Plastic boxes (210000 No); Packaging carton (580 No); Tape (10000 m)
(13)	Slat in dimensions of 184*71*5.2 cm^3 (340200 No); Graphite of pencil (46638 No); Glue AW (6674.4 kg); Black dye (30034.8 kg); Other dyes (3337.2 kg); Al cellophone (2182 rolls); Boxes having 12 empty spaces (687204 rolls); Packaging cartons having 288 empty spaces (13772 rolls); Tape (1000 rolls)

Industry	Initial materials
(14)	Raw paper with width around 674 mm, length of 3000 m (1285 roll); Ink (36t); Ink of paper backside (26t); Carton with dimension of 100*105*88 cm^3 (4500 No); Boxes of 10*35*22 cm^3 (450000)
(15)	Oak pollen (4934 m^3); Paper sheet, W= 50 cm (157000 m^2); Carton in sizes of 49*49 cm^2 (25050 No); PP rope (5300 m); Glue materials (1500 kg)
(16)	AlO 93-98.5% (133000 kg); Formaldehyde urea gum (326000 kg); Craft paper (490000 kg); Wood ink (10200 kg); Gum (10200 kg)

W= width, L= length, PP= Polypropylene, PE= Polyethylene

Table 4. IWCI, numer of staff, land area used and energy consumptions

Industry	Nominal capacity (t)	Employees	Power (kw)	Water (m^3)	Fuel (Gj)	Land (m^2)
(1)	1400	29	125	10	3	9500
(2)	1500	20	100	5	3	3500
(3)	7500	24	174	12	29	5400
(4)	400	29	187	17	35	4000
(5)	1000	30	228	6	10	5800
(6)	1000	16	58	4	3	2400
(7)	2600000	30	174	12	29	2100
(8)	120000	10	212	10	23	4600
(9)	6250	23	116	7	7	4000
(10)	12000	35	155	8	7	5100
(11)	12000	72	575	20	25	15700
(12)	7565000	30	152	13	5	3300
(13)	324000	13	99	8	3	2100
(14)	450000 pockets	15	30	3	3	2100
(15)	150000m+150000 m^2	42	359	60	74	20600
(16)	2000000 m^2	20	209	12	31	7300

4.1 Delphi fuzzy set

SPSS Software, AHP and Fuzzy TOPSIS methods were assigned to classify around 16 IWCI. Using Friedman test the ranks values were obtained about 2.59, 4, 1.53, 1.88 and 5 for the number of employees, power, water, fuel consumed and land area. Tables 5 and 6 show Likert spectrum defined for criteria, Fuzzy set possessing values and linguistic words respectively.

Narimisa and Narimisa (2016) used paired comparisons matrix among main factors of Isfahan oil refinery so it resulted to a prioritization style as economic > land use > environmental > social. Azizi et al (2009) assigned AHP and Expert Choice 2000 upon Iranian particle board industries among major criteria intensities, so results revealed that the density of the products and its high intensity had the highest priority. Azizi (2007) assessed Iranian facial tissue industries based on weighing factors via AHP method and Expert Choice software. It revealed that softness, time of absorption, appearance quality, basis weight and price criteria had high priority respectively.

Table 5. Criteria / symbols versus factors based on likert scale

Criteria / symbols	Employees	Power (kw)	Water (m^3)	Fuel (Gj)	Land (m^2)	Symbol
Very high	121-140	+600	+60	+ 250	16501-24000	VH
High	101-120	501-600	51-60	201-250	12501-16500	H
Slightly high	81-100	401-500	41-50	101-200	10001-12500	SH
Medium	61-80	301-400	31-40	76-100	7501-10000	M
Slightly low	41-60	201-300	21-30	51-75	5001-7500	SL
Low	21-40	101-200	11-20	26-50	2501-5000	L
Very low	0-20	0-100	0-10	0-25	0-2500	VL

Table 6. Fuzzy decision-making approach to prioritize the factors

Industry	Nominal capacity	Employees	Power	Water	Fuel	Land	Weights
(1)	1400	L (0.2272)	L (0.2272)	VL (0.1362)	VL (0.1362)	M (0.5)	4.46
(2)	1500	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	L (0.2272)	2.498
(3)	7500	L (0.2272)	L (0.2272)	L (0.2272)	L (0.2272)	SL (0.3695)	4.11
(4)	400	L (0.2272)	L (0.2272)	L (0.2272)	L (0.2272)	L (0.2272)	3.408
(5)	1000	L (0.2272)	SL (0.3695)	VL (0.1362)	VL (0.1362)	SL (0.3695)	4.37
(6)	1000	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	2.043
(7)	2600000	L (0.2272)	L (0.2272)	L (0.2272)	L (0.2272)	VL (0.1362)	2.95
(8)	120000	VL (0.1362)	SL (0.3695)	VL (0.1362)	VL (0.1362)	L (0.2272)	3.431
(9)	6250	L (0.2272)	L (0.2272)	VL (0.1362)	VL (0.1362)	L (0.2272)	3.097
(10)	12000	L (0.2272)	L (0.2272)	VL (0.1362)	VL (0.1362)	SL (0.3695)	3.8
(11)	12000	M (0.5)	H (0.7727)	L (0.2272)	VL (0.1362)	H (0.7727)	8.85
(12)	7565000	L (0.2272)	L (0.2272)	VL (0.1362)	VL (0.1362)	L (0.2272)	3.097
(13)	324000	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	2.043
(14)	450000 pockets	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	VL (0.1362)	2.043
(15)	150000m+150000 m2	SL (0.3695)	M (0.5)	H (0.7727)	SL (0.3695)	VH (0.8636)	9.15
(16)	2000000 m2	VL (0.1362)	SL (0.3695)	VL (0.1362)	L (0.2272)	SL (0.3695)	4.31

4.2 Fuzzy TOPSIS procedure

Using equation 18 the existing data in table 6 were shifted to present data of Table 7. In the following was used equations of 19-24 to obtain Fuzzy TOPSIS values and their weights according to Table 8.

Table 7. Defuzzification matrix

Industry	Nominal capacity (t)	Employees	Power	Water	Fuel	Land
(1)	1400	0.25	0.174	0.1362	0.184	0.318
(2)	1500	0.15	0.104	0.1362	0.184	0.144
(3)	7500	0.25	0.174	0.2272	0.307	0.235
(4)	400	0.25	0.174	0.2272	0.307	0.144
(5)	1000	0.25	0.284	0.1362	0.184	0.235
(6)	1000	0.15	0.104	0.1362	0.184	0.086
(7)	2600000	0.25	0.174	0.2272	0.307	0.086
(8)	120000	0.15	0.284	0.1362	0.184	0.144
(9)	6250	0.25	0.174	0.1362	0.184	0.144
(10)	12000	0.25	0.174	0.1362	0.184	0.235
(11)	12000	0.549	0.174	0.2272	0.184	0.492
(12)	7565000	0.25	0.174	0.1362	0.184	0.144
(13)	324000	0.15	0.104	0.1362	0.184	0.086
(14)	450000 pockets	0.15	0.104	0.1362	0.184	0.086
(15)	150000m+ 150000 m^2	0.4056	0.384	0.7727	0.5	0.55
(16)	2000000 m^2	0.25	0.284	0.1362	0.307	0.235

Ideal and anti-ideal solutions in the TOPSIS procedure were complied from the obtained values for A^+ and A^- that in the following has been explained; A^+= 1.42, 1.536, 0.347, 0.94, 2.75 and A^- = 0.388, 0.416, 0.208, 0.345, 0.43. Based on ideal and anti-ideal amounts were computed di^+ and di^- and also cli^+.

In lots of researches, AHP is applied to extract weights for criteria, while Fuzzy TOPSIS employed to support the ranking of options. Mardani et al (2016) evaluated around 10 biggest Iranian hotels via fuzzy set theory in different provinces focusing on prominent key energy-saving technologies and solutions. So, 17 key energy factors were chosen in the first screening among about 40 energy factors classified into 5 groups. Findings revealed rank ratios around 0.403, 0.225, 0.151, 0.091 and 0.083 for the equipment efficiency, system efficiency, heating and cooling demands reductions, energy management and renewable energy respectively. The fuzzy AHP among 17 factors presented ranks around 0.662, 0.541 and 0.532 for active space cooling, building insulation and tourist accommodation service respectively.

Table 8. Fuzzy TOPSIS values and their weights

Industry	Nominal capacity (t)	Employees	Power	Water	Fuel	Land	di+	di-	cli+
(1)	1400	0.647	0.696	0.208	0.345	1.59	1.7369	1.2210	0.412
(2)	1500	0.388	0.416	0.208	0.345	0.72	1.744	0.29	0.142
(3)	7500	0.647	0.696	0.347	0.577	1.175	1.97	0.88	0.308
(4)	400	0.647	0.696	0.347	0.577	0. 72	2.357	0.55	0.189
(5)	1000	0.647	1.136	0.208	0.345	1.175	2.12	1	0.31
(6)	1000	0.388	0.416	0. 208	0. 345	0.43	2.78	0	-
(7)	2600000	0.647	0.696	0.347	0. 577	0.43	2.610	0.218	0.77
(8)	120000	0.388	1.136	0. 208	.0 345	0. 72	2.391	0.77	0.24
(9)	6250	0.647	0.696	0. 208	0. 345	0. 72	2.4	0.48	0.16
(10)	12000	0.647	0.696	0. 208	0. 345	1.175	2.038	0.7	0.255
(11)	12000	1.42	0.696	0. 347	0. 345	2.46	1.069	2.3	0.683
(12)	7565000	0.647	0.696	0. 208	0. 345	0. 72	2.407	0.48	0.166
(13)	324000	0.388	0.416	0. 208	0. 345	0.43	2.78	0	-
(14)	450000 pockets	0.388	0.416	0. 208	0. 345	0.43	2.8	0	-
(15)	150000m+ 150000 m2	1.050	1.536	0. 347	0.94	2.75	0.37	2.73	0.88
(16)	2000000 m2	0.647	1.136	0. 208	0. 577	1.175	1.840	1.090	0.37

Yazdani-Chamzini et al. (2013) used Fuzzy TOPSIS to assess the problem of investment strategy selection. The fuzzy TOPSIS methodology applied for prioritizing the existing alternatives. The findings offered that the implemented model has a high potential to evaluate the data. Zagorskas et al. (2014) studied the growth in building refurbishment of new-build projects and historical buildings preservation involvements in terms of practice for assigning best insulation options. According to the research, 5 modern insulation materials had chosen and evaluations revealed that TOPSIS technique with grey numbers was a dominant technique to realize. Nikas et al. (2018) evaluated the gap between climate policy to find a methodological framework and remove existing complex problems using both Delphi and TOPSIS methods. By the way, they reached to find ranks for factors and criteria and closeness to ideal solutions. Cavallaro et al. (2016) studied a prioritization method for factors and criteria of combined heat and power systems via Fuzzy Shannon entropy and Fuzzy TOPSIS. Findings represented a classification as Turbine > steam turbine > fuel cell > reciprocating engine > micro-turbine. Moghimi & Anvari (2014) employed Fuzzy MCDM approach among 8 Iranian cement companies listed in the Tehran Stock Exchange based on financial statements. Hence, the ranking of companies has done as Sabhan, Sarab, Sedasht, Safar, Sekaroun, Sakarma, Sanir and Sahrmoz with priority scores of 0.55, 0.51, 0.50, 0.49, 0.42, 0.37, 0.36 and 0.33 respectively. Radfar & Ebrahimi (2012) used Fuzzy multi-criteria decision making for Iranian shipping industries to prioritize the investment methods in technology transfer. Obtained results led to introduce Joint venture and the subsidiary companies as the highest and lowest priorities, respectively. Parsa et al. (2016) utilized Fuzzy TOPSIS technique for National Iranian Gas Company to evaluate performance. It was performed a scoring and ranking system among them. Sorayaei et al. (2012) used a Fuzzy network model for forecasting stock exchange of the automobile industries. So, the results indicated the bubble growth of stock exchange of Iran automobile industries. Kavousi & Salamzadeh (2016) applied TOPSIS technique for National Iranian Copper Industries to identify and prioritize factors influencing the success of a strategic planning process. In the following steps, indicators were weighted and prioritized. Ebrahimnejad et al. (2008) asserted his findings by Fuzzy Build - Operate - Transfer + MADM in order to evaluate Iranian Power Plant Industry in terms of risk identification and management. Therefore, a new ranking model was presented based on fuzzy. Tash & Nasrabadi (2013) exploited Fuzzy TOPSIS for ranking of Iran's Monopolistic Industry. Behrouzi et al. (2011) investigated 133 automotive industries using Fuzzy MADM + SPSS analysis in order to performance measurement. The classifying options, weighting and ranking systems were the prominent findings of this research. Zare et al. (2016) employed Fuzzy TOPSIS by using the nearest weighted interval approximations for the Aluminum waste management system selection problem. By the way, a few scenarios introduced to figure out the solutions, so scenarios were ranked based on their closeness coefficient to the ideal solution. Therefore, scenario of S_4 was distinguished as the most prominent practice with a weight of 0.723514 and then following scenario of S_1 with a value of 0.448137, scenario S_5 with a value of 0.354226, scenario S_2 with a value of 0.314215 and scenario S_3 with a value of 0.204909 were ranked from second to fifth as an overwhelming method to compute and prioritize factors respectively.

4.3 TOPSIS Method

In this step same procedure was done on data to classify IWCI. The difference between this method and the previous one was the use of real data for industries classification. Therefore, the existing data (in Table 4) were shifted to Table 9 and then to Table 10 using the equation of 18-24.

Table 9. Matrix based on (real data) in Table 4

Industry	Nominal capacity (t)	Employees	Power	Water	Fuel	Land
(1)	1400	0.235	0.140	0.136	0.029	0.3
(2)	1500	0.162	0.112	0.068	0.029	0.110
(3)	7500	0.195	0.195	0.164	0.279	0.170
(4)	400	0.235	0.209	0.232	0.337	0.126
(5)	1000	0.243	0.255	0.082	0.096	0.183
(6)	1000	0.13	0.065	0.054	0.028	0.075
(7)	2600000	0.243	0.195	0.164	0.279	0.066
(8)	120000	0.08	0.237	0.136	0.221	0.145
(9)	6250	0.186	0.13	0.095	0.067	0.126
(10)	12000	0.283	0.173	0.109	0.067	0.161
(11)	12000	0.583	0.644	0.273	0.24	0.496
(12)	7565000	0.243	0.170	0.177	0.048	0.104
(13)	324000	0.105	0.110	0.109	0.028	0.066
(14)	450000 pockets	0.121	0.033	0.041	0.028	0.066
(15)	150000m+150000 m^2	0.340	0.402	0.82	0.713	0.651
(16)	2000000 m^2	0.162	0.234	0.164	0.298	0.231

Table 10. TOPSIS values

Industry	Nominal capacity (t)	Employees	Power	Water	Fuel	Land	di+	di-	cli+
(1)	1400	0.60865	0.56	0.2080	0.5452	1.5	3.111	1.4	0.310
(2)	1500	0.41958	0.448	0.10404	0.05452	0.55	4.087	0.0.44	0.099
(3)	7500	0.50505	0.78	0.25092	0.52452	0.85	3.412	1.16	0.254
(4)	400	0.60865	0.836	0.35496	0.63356	0.63	3.47	1.17	0.252
(5)	1000	0.62937	1.02	0.12546	0.18048	0.915	3.36	1.25	0.27
(6)	1000	0.3367	0.26	0.08262	0.05264	0.375	4.25	0.189	0.040
(7)	2600000	0.62937	0.78	0.25092	0.52452	0.33	3.77	0.92	0.196
(8)	120000	0.2072	0.948	0.20808	0.41548	0.725	3.56	0.986	0.216
(9)	6250	0.48174	0.52	0.14535	0.12596	0.63	3.85	0.57	0.129
(10)	12000	0.73297	0.692	0.16677	0.12596	0.805	3.57	0.91	0.202
(11)	12000	1.51	2.576	0.41769	0.4512	2.48	1.5	3.547	0.7
(12)	7565000	0.62937	0.68	0.27081	0.09024	0.52	3.8	0.747	0.165
(13)	324000	0.27195	0.44	0.16677	0.05264	0.33	4.182	0.412	0.09
(14)	450000 pockets	0.31339	0.132	0.06273	0.5264	0.33	4.24	0.486	0.102
(15)	150000m+150000 m^2	0.8806	1.608	1.2546	1.34044	3.255	1.155	3.775	0.765
(16)	2000000 m^2	0.41958	0.936	0.25092	0.56024	1.155	3.146	1.27	0.287

Ideal and anti-ideal solutions in current TOPSIS procedure were complied from the obtained values for A^+ and A^- as; A^+= 1.51, 2.576, 1.2546, 1.34044, 3.255 and A^- = 0.2072, 0.132, 0.06273, 0.05264, 0.33. Finally, IWCI was classified based on 3 methods of Fuzzy Set Logic, Fuzzy TOPSIS, TOPSIS based on real data as below:

Fuzzy Set Logic: 15 > 11 > 16 > 5 > 1 > 3 > 10 > 4 > 8 > 7 > 9 = 12 > 2 > 6 > 13 = 14;

Fuzzy TOPSIS: 15 > 7 > 11 > 1 > 5 > 16 > 3 > 10 > 8 > 4 > 12 > 9 > 2 >; (6=13=14);

TOPSIS: 15 > 11 > 1 > 16 > 5 > 3 > 4 > 8 > 10 > 7 > 12 > 9 > 14 > 2 > 13 > 6

Further study on the industries of IWCI was revealed the statistics and list of facilities and equipment used according to Table 11. Awareness of the existing facilities in IWCI helps stakeholders to understand new developments in utilized facilities. Also, the information provided can be compared with the facilities and equipment industries in other countries.

Table 11. All available facilities of IWCI

Industry	Facilities
(1)	Saw, 500 kg/h, 15 hp (1 No); Bangs producer machine, 260 kg/h, 15 hp (1 No); Baling machine, 8 tons/h, 2.5 hp (1 No)
(2)	Lining machines, 10 and 14 m2/min (1 and 1 No); Cutting machine, 170 m/h, 4 kw (1 No); Dye cast machine (1 No); Split machines, 10 m2/min; Saw, 3 kw, 30 m/min (3o No); Print machine, 3.5 kw (1 No); Carton maker machine, 2000 cartons/h, 3 kw (1 No); Packaging machine (1 No)
(3)	Motor saw of 590 degree, (1 No); Saw with w= 140 cm, 30 kw (1 No); Saw 100, 15 kw, 1500 rpm (2 No); Cutting machine, 5 kw, 1440 rpm (1 No); Grinder, 5 kw (1 No); Dryer machines (3 No); Wagons, in size of 1.5*3 m2 (48 No); Derrick, 5 ton (2 No); Compressor, 110 atm, 2000 L, 7 kw, 4 m3/min (1 No)
(4)	Cleaning machine, 130 kg/h, 4 kw (1 No); Block machine (1 No); Cotton baking pot, 125 kg/h, 35 kw (1 No); Feeding tank (1 No); Centrifuge, 130 kg/h, 5 kw (1 No); Dryer, 300 kg/h, 25 kw (1 No); Wraping machine, 150 kg/h, 5 kw (1 No); Carding machine, 60 kg/h, 5 kw (1 No)
(5)	Cutting and perforation machine, 5 kw, 10 kg/min (1 No); Rolling machine, 8 kw, 4.5 kg/min (8 No); Air suction fan, 2 kw (2 No); Fitted lab (1 No)
(6)	Roll flattening machine (1 No); Gluing machine (1 No); Printing machine (1 No); Paraffin addition machine (1 No); Cutting machine (1 No); Derrick, 2 tonss (1 No)
(7)	Cutting machine, 5 kw (1 No); Stapler machine, 0.6 kw (2 No); Labelling machine, 1.5 kw (1 No)
(8)	Shaver, 5 kw (1 No); Saw, 11 kw (1 No); Saw sharpener, 1.5 kw (1 No); 5-Storeys thermal press, 20 kw (2 No); Boiler, 0.5 ton, 2 kw (1 No); 5-ways device, 2.5 kw (1 No); Perforating machine, 2.5 kw (1 No); FS 1000 machine, w= 1000 mm (1 No); Automat sewing machine, 7 kw (1 No); Rond sanding, 2 and 3 kw (1 and 1 No); Cutting machine, 3 kw (1 No); Tape buffing machine, 4 kw (1 No); Polishing machine, 4 kw (1 No); Drill 1.5 kw (2 No); Gum roller and mixer, 5 kw (1 No)

(9)	Steel mixing tanks, 1 ton (2 No); Printing machine, 2 m/min (1 No); Drying and flocking machines, 500 kg (1 No); Fluff removal machine, 5 m/s (2 No); Screen printing machines, 1 m/min (6 No); Sheet dryer machine, 2 m/min (30 No); Printing machines, 3 m/min (2 No); Flattening machine, 2 m/min (1 No); Al frames (500 No); Cleaner along with plastic knive (1 No)
(10)	Envelope manufacturing machine, L and w= 5-110 cm and 35-60 cm (1 No); Two-sided sewing machine, L= 65-95 cm, capacity of 1500 No/h (2 No); One-sided sewing machine, L= 65-90 cm, capacity 1500 No/h (2 No); Packaging machine, in bundles of 100-150, 50 No/h (2 No); Gum dough generation device, 1 ton (1 No); Feeding roll paper, 50 m/min (1 No); Compressor, 7-10 kg/cm2 (1 No); Testing and checking equipment (1 No); Repair workshop (1 No)
(11)	Derrick, 5 tons (1 No); Automatic saw, 48, 38 and 42 inch (1, 1 and 4 No); Circular conveyor, L= 3 m (10 No); Circular saw, 40 inch (2 No); Dryer furnace, model of 10 m BMF-KIN (8 No); Derrick, 2 tons (1 No); Cutting saw (5 No)
(12)	Primary wood Cutting machine, 28 inch, 2.5 kw, 5 tons (2 No); Secondary wood cutting machine, I 3 model, w= 100 mm, 35 rpm, 30 kw (2 No); Low-diameter round timber manufacturing machine, K 20.2, w= 80 mm, d= 80 mm, 20 rpm, 5 kw, weight of packs 550 kg (1 No); Wood cutting machine of AZ-2.5, 3 KW, weigh of packs 50 kg (1 No); Wood thickness setting machine, 6 kw, weigh of pack 60 kg (1 No); Cutting machine with circular saw, MU-VS 3, 2 KW, weigh of pack, 120 kg (1 No); Polishing machine, Pot 1000 model, 0.5 kw, 20 rpm (1 No); Packaging machine, 10.5 hp, 3 kw, pure weigh of 10 kg (1 No); Paper milling machine, Ramonas model, 3 tons, 14-18 kw (1 No)
(13)	Complete line of wooden pencil production, 1200 tablet/shift, 28.5 kw (1 No); Cyclone along with centrifuge machine, steel carbon, d and h= 68 and 1000 mm (1 No)
(14)	Printing press machine, 100 m/min (1 No); Roll flattening machine, 30-160 m/min (1 No); Gillutine 34 rpm (1 No); Lab and repair workshop (1 and 1 No)
(15)	Semi automatic saw, 5.5 and 11 kw (1 and 3 No); Saw for cutting dry boards (2 No); Multi-saw machine (1 No); Automatic grinder, 7.5 kw (2 No); 15-saws machine, 15 kw (1 No); Finishing operation line such as buffing and dyeing operations (1 No); Wood carving machine, 63 cm, 5.5 kw (1 No); Curing machine, 70 cm, 5.5 kw (1 No); Saw A80, 6 kw (1 No); Automatic packaging machine (1 No); Dye drying line (1 No)
(16)	Spray system as electrostatic and gravity (1 No); Heating and ventilation as tunnel dryer (1 No); Preparation section for resin and gum (1 No); Motive power (1 No)

W= width, L= length

4.4 Statistical analysis results

T-test analysis had represented significant differences around (p-value≤ 0.001, 0.002 among the main criteria of IWCI such as the number of employees, power, water and fuel consumptions and the land area occupied by each industry. Pearson correlation sig. (2-tailed), Kendall's correlation coefficient sig. (2-tailed) and

Spearman's correlation coefficient analysis had manifested the highest significant differences about 0.886, 0.653 and 0.820 between both factors of fuel and water consumptions respectively. The categories of water, fuel, power consumptions, number of employees and the land area used had shown equal probabilities around 0.982, 0.437 (via one-sample Chi-Square test), 0.299 (via one-sample Kolmogorov Smirnov test) and 0.309 and 0.185 (via one-sample Kolmogorov Smirnov test). Therefore, the Null hypothesis was retained among factors. Kolmogorov – Smirnov Z was conducted to figure out normal distribution among factors so obtained results revealed values about 0.966, 0.974, 1.243, 0.907 and 1.090 for the number of employees, power, water, fuel consumed and the land area occupied by industries individually. Therefore, the obtained findings have supported the presence of a normal distribution trend among factors. Hassanpour (2017) investigated 6 different kinds of Iranian recycling industries comprising factors of power-water and fuel-land with a result as ($p_{value} \leq .016$ and 0.023) via SPSS analysis respectively. Unnisa & Hassanpour (2018) came into view a significant difference among factors such as initial feed, employees, power, water, fuel and land ($p_{value} \leq .001$) in an assessment upon 4 various kinds of Iranian brick manufacturing industries.

5. Conclusion

By present study was empirically assessed IWCI in terms of an inventory of materials, processes and facilities employed. Data were evaluated by three methods of Delphi logic, Fuzzy TOPSIS, TOPSIS along with SPSS analysis of data. It was found that TOPSIS (based on real data) was more precise than Fuzzy TOPSIS and Delphi Fuzzy set to classify industries. The SPSS software presented correlations, significant differences and Null hypothesis among the data to complete IWCI evaluation procedure. Some of the main achievements of this study can be cited to awareness of the flow of input materials injected into industries according to the type of materials and their required values, the prediction of the type of pollutants released into the environment and developing researches towards industrial ecology studies, the identification of existing facilities and devices in the industries and as well as technologies employed for the purposes of industry 4.0, getting enough knowledge about the amount of energy consumed in industries and the amount of product produced by each industry, providing economic estimates of industries in the easiest possible way, managing industries regarding the enough information to evaluate efficient industries in studies related to data envelopment analysis etc.

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ANFIS MODEL FOR THE PREDICTION OF GENERATED ELECTRICITY OF PHOTOVOLTAIC MODULES

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Abstract: *The fact that conventional energy sources are exhaustive and limited are increasingly encouraging research in the field of alternative and renewable energy sources. The electricity generated by solar photovoltaic modules and panels occupies an ever greater percentage in total electricity production, so it is clear that photovoltaic systems are increasingly integrating with the existing electricity network into one system or functioning as autonomous systems. The aim of the research is to create a model based on the principles of the fuzzy logic and artificial neural networks that will perform the task of predicting the maximum energy of photovoltaic modules as accurately as possible. The prediction should facilitate work in planning production and consumption, system management, economic analysis. The most important methods used in the research are modeling and simulation. Input and output variables are selected and in the ANFIS (Adaptive Neuro Fuzzy Inference System) model a set of their values is presented. Based on them it comes to the function of dependency. The prediction rating of the created model was performed on a separate data set for testing and a model with the lowest average test error value was selected. The performance of the model was compared with the mathematical model through sensitivity analysis, which led to the conclusion that the ANFIS model gives more accurate results.*

Key words (bold): *prediction, ANFIS (Adaptive Neuro Fuzzy Inference System), photovoltaic modules, artificial neural networks, fuzzy logic, RMSE (Root Mean Square Error).*

1. Introduction

Today, huge attention is paid to the fact that conventional energy sources are exhaustive and limited, and their use is a major source of pollution. Renewable

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energy sources, such as sun, wind, waves, etc., are increasingly being promoted. The electricity generated by solar photovoltaic modules and panels occupies an ever greater percentage in total electricity production. Therefore, it is clear that solar systems increasingly integrate with the existing electricity network into one system or function as autonomous systems (Ding et al., 2011). In order to supervise these systems, planning of production and consumption, management, economic analysis, it is necessary to make an accurate prediction of electricity generation. Therefore, the aim of the research is to create a model based on the fuzzy logic and artificial neural networks that will perform the specified task as accurately as possible.

Generated power and energy of photovoltaic systems depend on several factors, and the intensity of the solar radiation and the temperature of the module (Mahmodian et al., 2012), or ambient temperature (Zhu et al., 2017), are indicated as the main sources. Due to the dynamic nature of the energy generated over time and the non-linear dependence of the input and output variables, the prediction is a complex task. Today there are two current prediction methods, physical and statistical. The physical method first predicts meteorological parameters that affect the generated power or energy, and then these same parameters are used in equations. The statistical method is based on a set of data from the past (Zhu et al., 2017; Zhu et al., 2015; Wang et al., 2017). Common statistical methods include SVM (Support Vector Machine) (Zhu et al., 2017), Markov Chains and artificial neural networks (Zhu et al., 2017). Because of the properties that allow them to have a good non-linear approximation and generalization, artificial neural networks are most often used in the prediction of the performance of photovoltaic modules (Antonanzas et al., 2016). In addition, using artificial neural networks avoids complicated mathematical principles, since the network learns from training data. Various types of artificial neural networks are used, some of which are GRNN, FFBR (Feedforward Back Propagation) (Saberian et al., 2014), k-NN (K-nearest neighbors), SVM (Wolff et al., 2016), RBFNN (Radial Basis Function Neural Network), BPNN (Back Propagation Neural Network) (Mandal et al., 2012), recurrent neural networks, etc. (Mellit et al., 2009). Hybrid approaches that involve a combination of physical and statistical methods are often used (Wang et al., 2017).

The paper presents the materials and methods used, as well as the individual steps during the research process. Theoretical review of the neuro-fuzzy systems is particularly emphasized. The results of the research and discussion also take a special part in the work, where tables and graphs are given. The sensitivity analysis was performed in order to compare the values obtained with the ANFIS model with the mathematical model. Based on the research presented by the work, appropriate conclusions were made.

2. Materials and methods

The most important methods used in the research are modeling and simulation. The task of the model, represented by this paper, is the prediction of the generated electricity of the photovoltaic modules at the daily level. It is necessary to first select the input and output variables and present the set of their values (obtained by simulation) on the basis of which the model itself will come to the function of dependance. The model represents the integration of the principle of fuzzy logic and artificial neural networks into an ANFIS (Adaptive Neuro Fuzzy Inference System). Assessment of the ability of the prediction of the created model is done on a separate data set for testing and a model with the lowest average test error is chosen.

2.1. Selection of variables and data collection

The solar cell represents a PN coupling of a semiconductor which, on the basis of the photovoltaic effect, under the influence of the Sunlight, releases the charge carriers, resulting in current in a closed circuit. More interconnected cells comprise a module, and more modules, a photovoltaic panel.

According to its structure, the solar cell is most often constructed from semiconductor materials (Si, Ge, GaAs), and represents a pn compound that absorbs photons from solar radiation and uses their energy to create electron-cavity pairs. The internal electric field that exists on an impoverished area of the pn junction separating couples holders that are created within or near the pn junction. From the front and back of the solar cell, contacts are collected that collect separate energies, and an electromotive force appears at the ends of the cell. The electrons and cavities in the semiconductor tend to move from a higher density region to a less-density region. When multiple solar cells transmit to a serial or parallel connection, a photovoltaic panel with the desired output voltage or current is obtained. Due to the effect of solar radiation on the surface of the solar cell or panel, there are changes in several important parameters of the solar cell (photovoltaic panels), the concentration of free carriers and the width of the energy gap between the semiconductor. The change in these parameters is conditioned by the intensity of the radiation and the influence of the outside temperature. The increase in temperature on the panel affects the output parameters of the photovoltaic panel, the output current and voltage, and thus the power. A solar cell model based on two semiconductor diodes was selected to create a photovoltaic panel model. Figure 1 shows the solar cell model (Castaner et al., 2002):

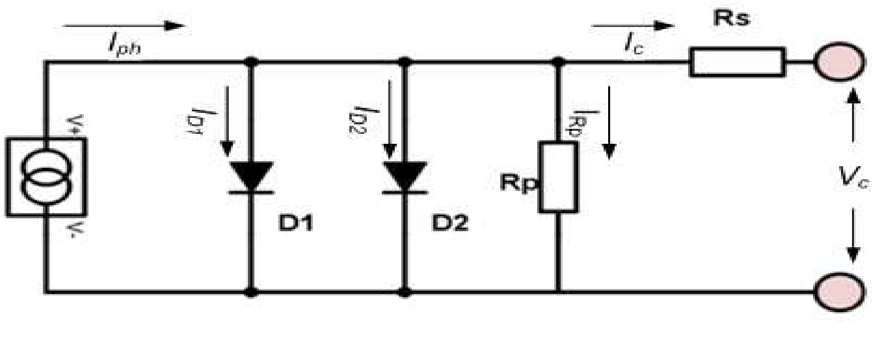

Figure 1. Solar cell model with two diodes (Castaner et al., 2002)

The dependence of the short-circuit current on the intensity of the incident solar radiation and the temperature of the environment and the module can be represented by the following pattern (Castaner et al., 2002; Chandani et al., 2014; Guifang, 2014):

$$I_{scM} = \frac{I_{scMr}}{1000} \cdot E + \left(\frac{dI_{scM}}{dT} \right) \cdot \left(T_c - T_r \right) \quad (1)$$

and the open-circuit voltage is given by the approximate relation (Castaner et al., 2002; Chandani et al., 2014; Guifang, 2014):

$$V_{ocM} \approx V_{ocMr} + \left(\frac{\partial V_{ocM}}{\partial T}\right)_E \cdot \left(T_c - T_r\right) + V_T \cdot \ln \frac{I_{scM}}{I_{scMr}} \quad (2)$$

where: IscMr - short-circuit current of the photovoltaic module at the reference temperature, E - intensity of the solar radiation VocM - the open-circuit voltage of the photovoltaic module, the VocMr - the open-circuit voltage of the photovoltaic module at the reference temperature, T - ambient temperature, Tc - temperature of the module, Tr - reference temperature.

The output performance of photovoltaic modules depends to a large extent on the intensity of radiation and temperature. Therefore, for the input variables of the model, the daily amount of solar radiation (measured in $kWh/m^2/day$) and the average temperature of the module (in °C), are chosen. As the output variable is observed the virtual maximum energy that the photovoltaic modules can supply at the maximum power point for one day, measured in kWh/day.

Data collection for model training is carried out by the simulation method in PVsyst software, which is intended for engineers, architects and researchers involved in the analysis and construction of photovoltaic systems, i.e. systems that convert Solar radiation into electricity. PVsyst is an industrial standard, but it is also very useful as an educational software. A simulation model of an autonomous photovoltaic system has been created which supplies consumers with electricity exclusively generated by solar modules, independent of the public electricity network. The selected location is in Banja Luka (RS, BiH), and the model envisages a daily electricity consumption of 915 Wh/day. The real components are available, so that two photovoltaic modules are specified (two modules are the panel) of LG Electronics with a maximum power of 300 Wp and a total area of 3 m2, batteries have a total capacity of 400 Ah. Once the system is defined, its block diagram can be seen in Figure 2. It is important to point out that the regulator, belonging to this system, contains a maximum power point tracker (MPPT - Maximum Power Point Tracker) because of the low degree of conversion of solar radiation into electricity. The MPPT is implemented as a microcontroller which, together with the DC-DC converter, transmits the maximum power from the module to the system.

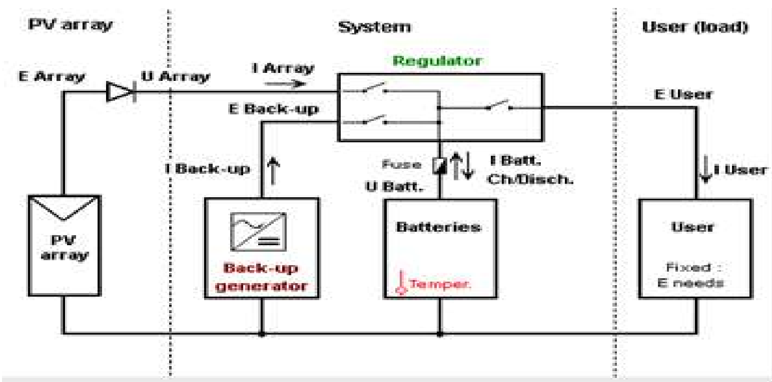

Figure 2. Block diagram of the photovoltaic autonomous system in the PVsyst program

Figure 3 shows the general block diagram of the photovoltaic system. The A/D converter provides an input signal for the MPPT that is connected to a pulse width modulator (Pulse Width Modulator - PWM). In PW modulation, the mean value of the signal changes depending on the length of the period and the duration of the rectangular pulse. A modulated signal represents an input signal for a DC-DC converter that transforms the DC voltage of one value to the DC voltage of the second value.

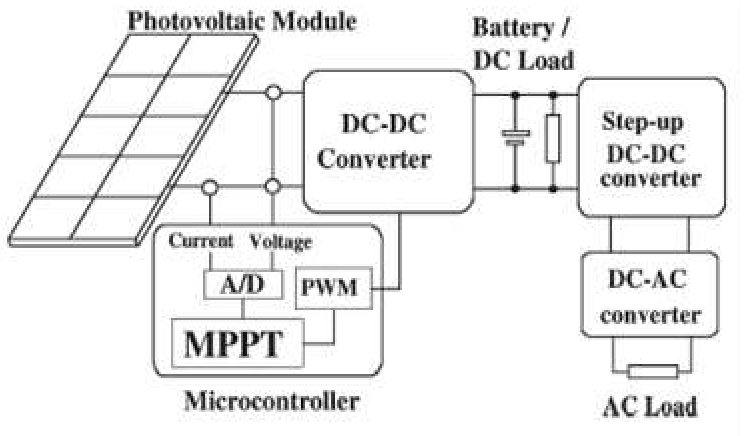

Figure 3. Block diagram of photovoltaic system (Gules Roger et al., 2008)

Training data for the ANFIS model is obtained by performing simulations on the model of the photovoltaic system for a period of one year. The values of the input and output variables are selected for five days each month, which makes a total of 60 training vectors. In addition, a special set of data for testing and testing of the ANFIS model has been created, which consists of realized values of the variables for one day during each month - 12 vectors.

2.2. Artificial neural networks and fuzzy logic

Artificial neural networks represent an attempt to model the human brain. Similarity with the work of the human brain is reflected through the structure, function and method of processing data and information. No matter what network it is, their common feature is the ability to learn. Therefore, their main application is to look for dependencies between data that are not in a strict linear relationship. The training process is based on adjusting the weight of network connections. However, the network can be trained structurally, i.e. the correct choice of the number of neurons, layers, etc. (Bašić et al., 2008).

Fuzzy logic is an extension of classical logic, allowing the work with uncertainties to make the computer adapt to the human way of thinking. The word fuzzy implies something unclear, indeterminate, but that does not mean that there is something unclear with the fuzzy logic itself, but that it has enabled the presentation of uncertainty.

By applying the fuzzy logic in various fields, it was difficult to create a fuzzy-inference system with good performance. Tasks such as finding adequate membership functions and the fuzzy inference rules pose problems to experts in a particular field. Hence the idea that the principles of the fuzzy logic and neural networks are combined in a unique system called the neuro-fuzzy system, combining both the ability to learn and logical conclusion. ANFIS is one of the most commonly used architectures of the neuro-fuzzy system (Figure 4).

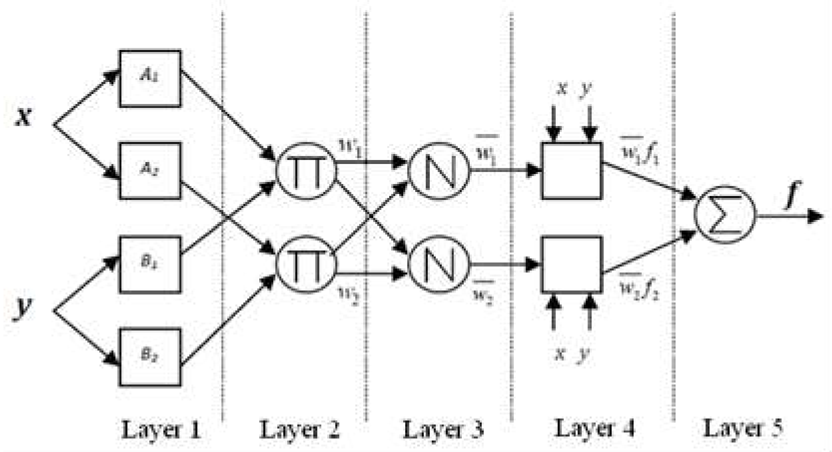

Figure 4. Architecture of the ANFIS model

Nodes of the first hidden layer define the fuzzy sets, i.e. fuzzy membership functions corresponding to the input variables. The nodes of this and the fourth layer are adaptive, which means that their parameters change during the training process. Therefore, in Figure 4 they have a rectangular shape in contrast to the fixed, circular nods. The nodes of the second hidden layer are fixed and perform an operation of multiplying the input signals (operation AND), which determines the degree of consistency of the premise (IF part) of each rule **-** w_i, which has a general shape:

IF *x is A* **AND** *y is B*, **THEN** z=*f*(x,y),

where A and B are fuzzy sets corresponding to the input variable, and z = *f*(x, y) function that is a consequence of the rule (Salleh et al., 2016; Rasit, 2009). The function z = *f*(x, y), can be a polynomial of zero or first order, i.e. constant or linear function. The third hidden layer normalizes the values obtained at the output of the nodes of the second hidden layer. In the case shown in Figure 4, with two nodes in the second layer, the normalized value at the output of the node of the third hidden layer has the following mathematical form:

$$\overline{w_i} = \frac{w_i}{w_1 + w_2} \tag{3}$$

Each node of the fourth hidden layer is an adaptive node with a function it realizes, which can be written as follows:

$$\overline{w_i} f_i = \overline{w_i}\left(p_i x + q_i y + r_i\right) \tag{4}$$

where p_i , q_i and r_i conclusion parameters. The fifth layer calculates the output as the sum of all input signals:

$$f = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{5}$$

The ANFIS model for the prediction of generated electricity of photovoltaic modules was created in the MATLAB software package. The ANFIS editor, thanks to the graphical user interface, allows easy definition and work with the model. The algorithm describing the process from creation to model evaluation can be written in the following steps:

1. Loading data for training, checking and testing (60 training vectors, 12 for checking and testing),
2. Defining the number and shape of the fuzzy membership functions of the input variables and the form of the membeship function of the output variable,
3. Model training (Hybrid training algorithm, tolerance error=0, epoch number=60),
4. Testing the ANFIS model, RMSE (*Root Mean Square Error*).
5. Testing data allow you to evaluate the ability of the ANFIS model to execute a prediction of the value of the output variable.

The outputs of the ANFIS model are compared with already known values and, based on this, RMSE is calculated as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left[n(k) - n(k)\right]^2} \tag{6}$$

where N is the number of individual observations (the number of data vectors for testing, N = 12), $n(k)$ is the expected value (obtained by the simulation in the PVsyst program), $n(k)$ - the value obtained by the model. The verification data is primarily aimed at preventing the occurrence of *overfitting*.

3. Results and Discussion

Table 1 shows the different values of the average testing error, depending on the shape of the membership function of the input variables, their number, and the output form of the ANFIS model. The model with the lowest value of the average testing error or RMSE=0.209 is chosen. Such an error value is achieved with the triangular form of the fuzzy membership functions (two of them for each input variable) and the linear function of the output of the model.

Table 1. Different values of the average testing error (RMSE) for model

Shape of the membership functions of input variables	Form of output function of ANFIS model					
	Linear			Constant		
	Number of membership functions of the input variables					
	2 2	3 3	4 4	2 2	3 3	4 4
trimf	0.209	0.321	6.321	0.243	0.211	0.361
trapmf	0.245	0.938	0.442	0.483	0.292	0.981
gbellmf	0.223	1.047	39.464	0.348	0.220	0.396
gaussmf	0.212	0.642	36.433	0.288	0.215	0.335
gauss2mf	0.252	1.141	46.554	0.383	0.225	0.573
pimf	0.256	1.206	0.508	0.609	0.351	3.229
dsigmf	0.254	0.620	11.073	0.578	0.302	0.498
psigmf	0.254	0.620	11.073	0.578	0.302	0.498
	5 5	2 3	3 2	5 5	2 3	3 2
trimf	10.450	0.221	0.240	0.335	0.217	0.256
trapmf	1.141	0.244	0.418	1.060	2.289	0.439
gbellmf	8.447	0.286	0.535	0.530	0.216	0.331
gaussmf	19.091	0.252	0.665	0.272	0.213	0.291
gauss2mf	280.229	0.399	0.296	16.590	0.245	0.344
pimf	3.839	0.240	0.727	6.537	0.330	0.558
dsigmf	34.961	0.226	0.661	6.608	0.307	0.518
psigmf	34.961	0.226	0.661	6.608	0.307	0.518

The graphical results of the prediction of the selected model are given in Figure 5. Red stars represent the values given by the model, while the blue points are known values (data for testing). From Figure 5 it is evident that the generated daily electricity has the greatest value in the summer months, because it is presented on the apsis one day for each month of the year.

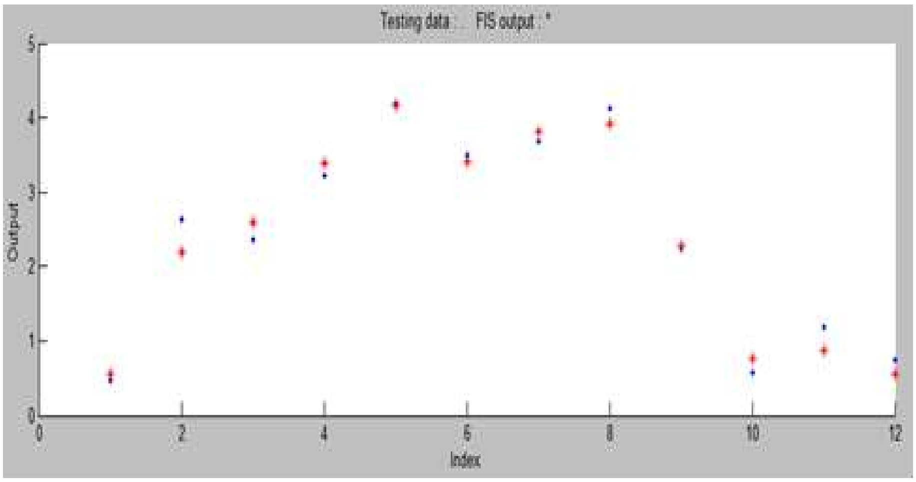

Figure 5. Graphical representation of the prediction for the selected ANFIS model

Figure 6 shows the shape of the membership functions of the input variables. As can be seen from Table 1, membership functions have a triangular form.

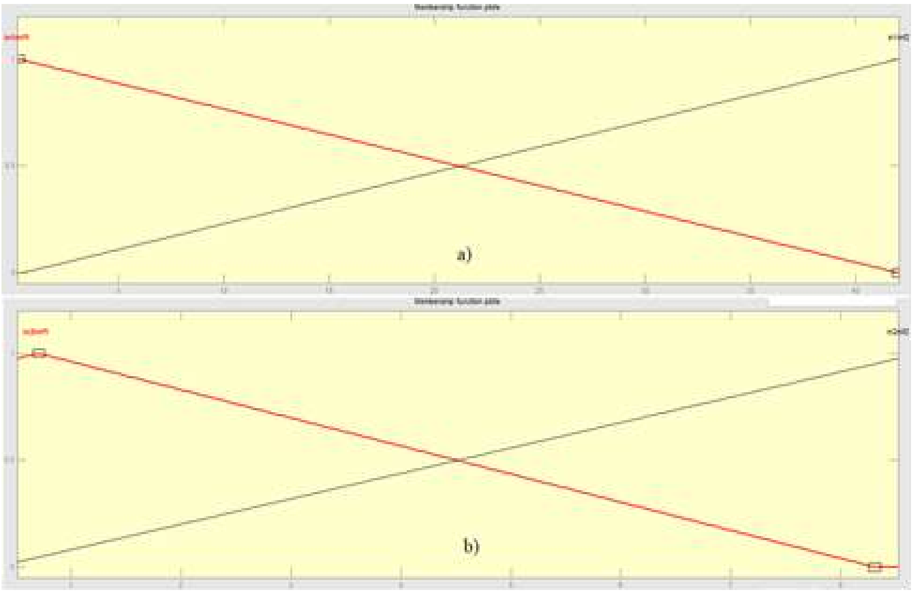

Figure 6. Forms of the membership functions of the input variables: a) Average temperature of the module; b) Daily amount of solar radiation

Figure 7 shows the structure of the selected ANFIS model where the number of nodes in each layer of the network is visible.

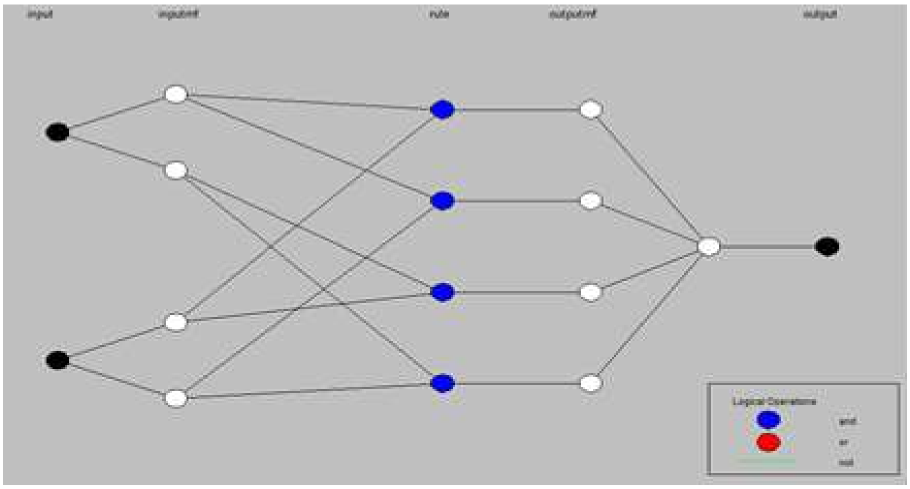

Figure 7. The structure of the selected ANFIS model

The surface that represents the dependence of the output variable of the two inputs in the selected ANFIS model is shown in Figure 8. It can be concluded that when the energy of the solar radiation increases, the maximum virtual energy of the photovoltaic modules increases. In contrast, the average temperature adversely affects the output variable, as its increase results in a slight decrease in the maximum virtual energy of the photovoltaic modules.

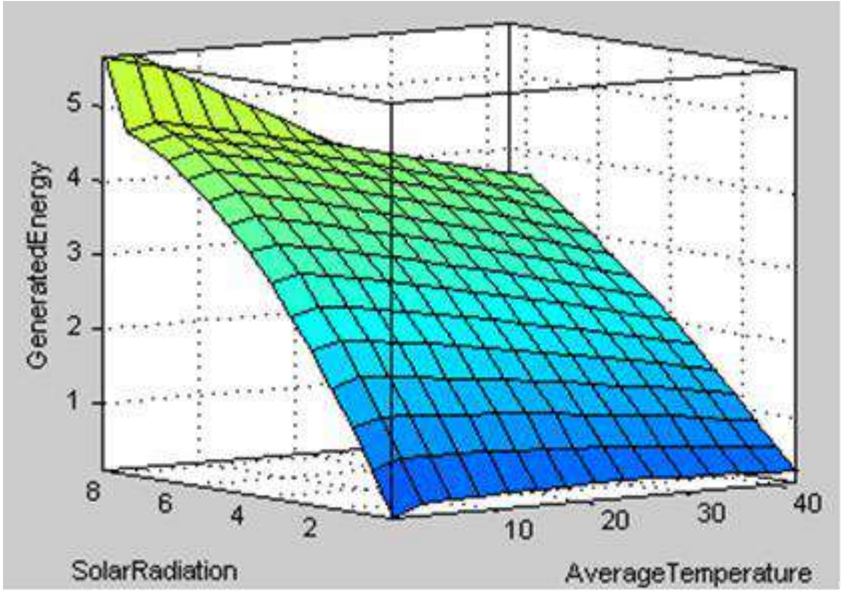

Figure 8. The surface of the dependence of the maximum virtual energy from the solar radiation and the average temperature of the module

4. Sensitivity analysis

In order to perform the sensitivity analysis, in this section will be compared the values of the prediction created by the ANFIS model and the regression mathematical model. The regression was performed on a data set for training the ANFIS model. Table 2 shows 15 different mathematical models together with the corresponding prediction correlation indexes. For simpler presentation, the selected variables carry the following tags:

- Daily amount of solar radiation - E
- Average temperature of the module - T
- Virtual maximum generated energy – Electricity.

Table 2. Regression mathematical models

Number	Model	R^2 pred (%)
1	Electricity = 0.386 – 0.00128 T + 0.5045 E	87.90
2	Electricity = 0.049 + 0.0446 T + 0.5027 E – 0.001189 T^2	88.60
3	Electricity = -0.146 + 0.0144 T + 0.882 E – 0.000764 T^2 – 0.0407 E^2	90.78
4	Electricity = -0.164 + 0.0186 T + 0.882 E – 0.00101 T^2 – 0.0407 E^2 + 0.000004 T^3	90.53

ANFIS model for the prediction of generated electricity of photovoltaic modules

Number	Model	R^2 pred (%)
5	Electricity = -0.184 + 0.0163 T + 0.923 E – 0.00091 T^2 – 0.0522 E^2 + 0.000003 T^3 + 0.00089 E^3	90.26
6	Electricity = -0.065 + 0.842 E – 0.0502 E^2 + 0.00130 E^3	89.75
7	Electricity = -0.046 – 0.01682 T + 1.032 E – 0.0769 E^2 + 0.00250 E^3	90.29
8	Electricity = 0.039 – 0.01639 T + 0.920 E – 0.0447 E^2	90.50
9	Electricity = -0.020 + 0.7851 E – 0.0336 E^2	90.01
10	Electricity = 0.6886 + 0.1767 E^2 – 0.01552 E^3	87.75
11	Electricity = 0.170 – 0.01507 T + 0.7518 E – 0.003306 E^3	90.30
12	Electricity = -0.122 + 0.986 E – 0.000454 T^2 – 0.0649 E^2 + 0.00167 E^3	90.66
13	Electricity = 0.069 + 0.7538 E – 0.000437 T^2 – 0.003279 E^3	90.75
14	Electricity = 0.7324 – 0.000275 T^2 + 0.1913 E^2 – 0.01704 E^3	87.87
15	Electricity = -0.174 + 0.0134 T + 0.925 E – 0.000744 T^2 – 0.0531 E^2 + 0.00095 E^3	90.52

As can be concluded from Table 2, the largest correlation index has a model numbered at number 3, 90.78%. It is a second-degree model that has the following form:

$$\text{Electricity} = -0.146 + 0.0144\,T + 0.882\,E - 0.000764\,T^2 - 0.0407\,E^2$$

Table 3 gives an overview of the expected values of the generated photovoltaic module energy (test data), as well as the values obtained by ANFIS and the regression model, for the same input values. Values are expressed in kWh/day.

Table 3. The expected values of the generated energy and the values obtained by the prediction of ANFIS and the mathematical model

Expected value of generated energy	Value obtained by an ANFIS model	Value obtained by the regression mathematical model
0.48	0.56	0.57
2.64	2.19	2.09
2.36	2.60	2.49
3.23	3.39	3.41
4.19	4.17	4.22
3.50	3.41	3.42
3.68	3.81	3.83
4.12	3.93	3.92
2.24	2.28	2.28
0.58	0.76	0.71
1.19	0.88	0.76
0.75	0.56	0.56

In addition to a tabular display, these values can also be represented graphically, as shown in Figure 9

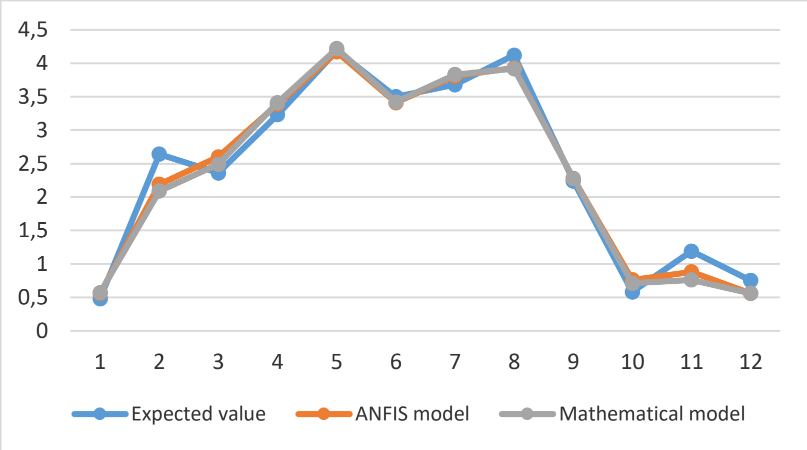

Figure 9. Diagram of expected values, values obtained by ANFIS and mathematical model

By comparing the output variable from the test data with the values obtained by the specified mathematical model, the RMSE = 0.235 value is obtained, which is more than the selected ANFIS model (0.209). Therefore, it is clear that the ANFIS model shows better performance.

5. Conclusion

The research presented by the paper focuses on the development of a model for the prediction of maximum energy generated photovoltaic modules based on neuro-fuzzy principles. The model represents a simple solution that requires the value of the output variable for the given values of the energy of the Sun's radiation and the average temperature of the module. Model training was performed according to the data obtained by the simulation, so that it is possible to deviate if the values obtained by the prediction were compared with the actual measured values. Nevertheless, PVsyst is a widely used software, so that data obtained by simulating the performance of photovoltaic modules can be considered relevant for the training of the ANFIS model. It is obvious that the selected model yields better results than mathematical model, although it has a high percentage of adequacy. The maximum energy generated depends to a large extent on the energy of the Sun's radiation, while the influence of the temperature is considerably smaller and negative. Future research may take into account other factors that influence the generation of energy in order to increase accuracy.

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FUCOM METHOD IN GROUP DECISION-MAKING: SELECTION OF FORKLIFT IN A WAREHOUSE

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Abstract. *A warehouse system as a time transformation of the flows of goods plays an essential role in a complete logistics chain. The efficiency of a complete warehouse system largely depends on the efficiency of carrying out transport and handling operations. Therefore, it is essential to have adequate means of internal transport that will influence the efficiency of the warehouse system by its performance. In this paper, the evaluation and selection of side-loading forklift using the FUCOM-WASPAS model, which has been used for the first time in the literature in this paper, is performed. The FUCOM method was used to obtain the weight values of the criteria, while WASPAS was applied for the evaluation and ranking of forklifts. A possibility to apply the FUCOM method in group decision-making was presented. A comparative analysis, in which other methods of multi-criteria decision-making were applied, was carried out. The analysis showed the stability of the results obtained.*

Key words: *FUCOM method, Forklift, WASPAS method, Warehouse, group decision-making*

1. Introduction

In the day-to-day performance of various activities and processes, logistics as an integral and indispensable part of each business system plays a very important role (Stević et al., 2017a). There is a need to rationalize activities and processes that may significantly affect a company's competitive position (Stević et al., 2017b). A warehouse as a special logistics subsystem and transport represent the major cause of logistics costs and there is a constant search for potential places of savings in these subsystems. In the very beginning, a warehouse was just a place used to separate

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surplus products, while today its function is completely different (Stojčić et al., 2018). Compared to the former static function, today's warehouses represent dynamic systems in which the movement of goods is dominant. Taking into account the above considerations, it is necessary to perform transport and handling operations as rationally as possible. From this aspect, forklifts within internal transport and warehousing operations play an important role.

Internal transport is the basis of every production process, both in functional and organizational terms. Accordingly, rationalizing the movement of the means of transport and selecting the most convenient means of transport would lead to more efficient exploitation and reduction of costs. Forklifts are the most widely used, most useful and most practical means of internal transport. Forklifts are transport work machines for unloading, transport, warehousing and loading of various freight. There are a number of forklifts of different characteristics on the market. The side-loading forklift is intended for handling all types of freight.

In this paper, seven criteria that could be taken into account when selecting a side-loading forklift were chosen. The aim of the paper is to obtain the best solution, i.e. an appropriate side-loading forklift that will meet the requirements of the Euro-Roal company where the research was carried out using multi-criteria decision-making. The choice of a specific side-loading forklift is conditioned by the optimality of the criteria that refer to the purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor and the supply of spare parts. In the paper, the FUCOM (Full Consistency Method) and WASPAS (Weighted Aggregated Sum Product Assessment) method were used to enable the evaluation and selection of a used side-loading forklift at the Euro-Roal company. Using the FUCOM method, the determination of relative weights was performed, while using the WASPAS method, the ranking was completed.

The remainder of the paper is organized as follows. In the second section of the paper, the methods used in the work, the FUCOM and WASPAS methods, are presented. FUCOM provides a possibility to determine accurately the weight coefficients of all the elements that are mutually compared. WASPAS represents a relatively new method of multi-criteria decision-making (MCDM) that is derived from two methods: Weighted Sum Model (WSM) and Weighted Product Model (WPM). The third section of the paper demonstrates the applicability of FUCOM method in group decision-making. Based on the expert assessment of three decision-makers, the weight values of criteria are obtained. The fourth section is the evaluation and selection of forklifts using the WASPAS method, while in the fifth section, a comparative analysis is carried out using other methods. The paper ends with conclusions and directions for future research.

2. Methods

By applying multi-criteria decision-making methods, it is possible to select adequate strategies, rationalize certain logistics and other processes, and make appropriate decisions that affect the company's business or their subsystems, as evidenced by the following research (Tzeng and Huang, 2012; Prakash and Barua, 2016; Żak and Węgliński, 2014; Hanaoka and Kunadhamraks, 2009; Zavadskas et al., 2018; Stojić et al., 2018; Radović et al., 2018; Sremac et al., 2018)

2.1. FUCOM (Full COnsistency Method)

FUCOM (Pamučar et al., 2018) is a new MCDM method for determination of criteria weights. The problems of multi-criteria decision-making are characterized by the choice of the most acceptable alternative out of a set of the alternatives presented on the basis of the defined criteria. A model of multi-criteria decision-making can be presented by a mathematical equation $\max\left[f_1(x), f_2(x),..., f_n(x)\right]$, $n \geq 2$, with the condition that $x \in A = \left[a_1, a_2, ..., a_m\right]$; where *n* represents the number of the criteria, *m* is the number of the alternatives, f_j represents the criteria ($j = 1, 2, ..., n$) and *A* represents the set of the alternatives a_i ($i = 1, 2, ..., m$). The values f_{ij} of each considered criterion f_j for each considered alternative a_i are known, namely $f_{ij} = f_j(a_i), \quad \forall(i, j); \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n$. The relation shows that each value of the attribute depends on the j^{th} criterion and the i^{th} alternative.

Real problems do not usually have the criteria of the same degree of significance. It is therefore necessary that the significance factors of particular criteria should be defined by using appropriate weight coefficients for the criteria, so that their sum is one. Determining the relative weights of criteria in multi-criteria decision-making models is always a specific problem inevitably accompanied by subjectivity. This process is very important and has a significant impact on the final decision-making result, since weight coefficients in some methods crucially influence the solution. Therefore, particular attention in this paper is paid to the problem of determining the weights of criteria, and the new FUCOM model for determining the weight coefficients of criteria is proposed. This method enables the precise determination of the values of the weight coefficients of all of the elements mutually compared at a certain level of hierarchy, simultaneously satisfying the conditions of comparison consistency.

In real life, pairwise comparison values $a_{ij} = w_i / w_j$ (where a_{ij} shows the relative preference of criterion *i* to criterion *j*) are not based on accurate measurements, but rather on subjective estimates. There is also a deviation of the values a_{ij} from the ideal ratios w_i / w_j (where w_i and w_j represents criteria weights of criterion *i* and criterion *j*). If, for example, it is determined that A is of much greater significance than B, B of greater importance than C, and C of greater importance than A, there is inconsistency in problem solving and the reliability of the results decreases. This is especially true when there are a large number of the pairwise comparisons of criteria. FUCOM reduces the possibility of errors in a comparison to the least possible extent due to: (1) a small number of comparisons (*n-1*) and (2) the constraints defined when calculating the optimal values of criteria. FUCOM provides the ability to validate the model by calculating the error value for the obtained weight vectors by determining deviation from full consistency (DFC). On the other hand, in other models for determining the weights of criteria (the BWM, the AHP models), the redundancy of the pairwise comparison appears, which makes them less vulnerable to errors in judgment, while the FUCOM methodological procedure eliminates this problem.

In the following section, the procedure for obtaining the weight coefficients of criteria by using FUCOM is presented.

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria $C = \{C_1, C_2, ..., C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > \ldots > C_{j(k)} \tag{1}$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of ">" between these criteria in the expression (1)

Step 2. In the second step, a comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k=1,2,\ldots,n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of the evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vectors of the comparative priorities of the evaluation criteria are obtained, as in the expression (2):

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, decision-makers define the comparative priority $\varphi_{k/(k+1)}$ among the observed criteria. Thus, for example, if two stones A and B, which, respectively, have the weights of $w_A = 300$ grams and $w_B = 255$ grams are observed, the comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B is $\varphi_{A/B} = 300/255 = 1.18$. Additionally, if the weights A and B cannot be determined precisely, but a predefined scale is used, e.g. from 1 to 9, then it can be said that stones A and B have weights $w_A = 8$ and $w_B = 7$. respectively. Then the comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B can be determined as $\varphi_{A/B} = 8/7 = 1.14$. This means that stone A in relation to stone B has a greater priority (weight) by 1.18 (in the case of precise measurements), i.e. by 1.14 (in the case of application of measuring scale). In the same manner, decision-makers define the comparative priority among the observed criteria $\varphi_{k/(k+1)}$. When solving real problems, decision-makers compare the ranked criteria based on internal knowledge, so they determine the comparative priority $\varphi_{k/(k+1)}$ based on subjective preferences. If the decision-maker thinks that the criterion of the $C_{j(k)}$ rank has the same significance as the criterion of the $C_{j(k+1)}$ rank, then the comparative priority is $\varphi_{k/(k+1)} = 1$.

b) Based on a predefined scale for the comparison of criteria, decision-makers compare the criteria and thus determine the significance of each individual criterion in the expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of the criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}} = 1$), a conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

For example: a problem with three criteria ranked as C2>C1>C3 is being subjected to consideration. Suppose that the scale $\varpi_{C_{j(k)}} \in [1,9]$ is used to determine the priorities of the criteria and that, based on the decision-maker's preferences, the following priorities of the criteria $\varpi_{C_2} = 1$, $\varpi_{C_1} = 3.5$ and $\varpi_{C_3} = 6$ are obtained. On the basis of the obtained priorities of the criteria and condition $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ we obtain following calculations $\frac{w_2}{w_1} = \frac{3.5}{1}$ i.e. $w_2 = 3.5 \cdot w_1$, $\frac{w_1}{w_3} = \frac{6}{3.5}$ i.e. $w_1 = 1.714 \cdot w_3$. In that way, the following comparative priorities are calculated: $\varphi_{C_2/C_1} = 3.5/1 = 3.5$ and $\varphi_{C_1/C_3} = 6/3.5 = 1.714$ (expression (2)).

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of using integer, decimal values or the values from the predefined scale for the pairwise comparison of the criteria.

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions:

(1) that the ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (3), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency, i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi = 0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of the weight coefficients $(w_1, w_2, ..., w_n)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of the value χ. In that manner, the requirement for maximum consistency is satisfied.

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \le \chi,\ \forall j \\
&\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \ge 0,\ \forall j
\end{aligned} \tag{5}$$

By solving model (5), the final values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ and the degree of DFC (χ) are generated.

2.2. WASPAS method

The weighted aggregated sum product assessment (WASPAS) method (Zavadskas et al., 2012) represents a relatively new MCDM method that is derived from two methods: Weighted Sum Model (WSM) and Weighted Product Model (WPM).

The WASPAS method consists of the following steps:

Step 1. Forming the initial decision-making matrix (X). The first step is to evaluate *m* alternatives according to *n* criteria. The alternatives are shown by vectors $A_i = (x_{i1}, x_{i2}, ..., x_{in})$ where x_{ij} is the value of i^{th} alternative according to j^{th} criterion ($i = 1, 2, ..., m;\ j = 1, 2, ..., n$).

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & ... & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ ... & ... & ... & ... \\ x_{m1} & x_{m2} & ... & x_{mn} \end{bmatrix} \end{array} \tag{6}$$

where *m* denotes the number of the alternative, and *n* denotes the total number of criteria.

Step 2. In this step, normalization of the initial matrix is required by applying the following equations:

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \quad for \quad C_1, C_2, ..., C_n \in B \tag{7}$$

$$n_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad for \quad C_1, C_2, ..., C_n \in C \tag{8}$$

Step 3. Weighting the normalized matrix, so that the previously obtained matrix needs to be multiplied by the weight values of criteria:

$$V_n = \left[v_{ij} \right]_{m \times n} \tag{9}$$

$$V_{ij} = w_j \times n_{ij}, \quad i = 1, 2, \ldots, m, \ j \tag{10}$$

Step 4. Summing all the values of the alternatives obtained (summing by rows):

$$Q_i = \left[q_{ij} \right]_{1 \times m} \tag{11}$$

$$q_{ij} = \sum_{j=1}^{n} v_{ij} \tag{12}$$

Step 5: Determining a weighted product model by applying the following equation:

$$P_i = \left[p_{ij} \right]_{1 \times m} \tag{13}$$

$$p_{ij} = \prod_{j=1}^{n} \left(v_{ij} \right)^{w_j} \tag{14}$$

Step 6. Determining the relative values of alternatives A_i:

$$A_i = \left[a_{ij} \right]_{1 \times m} \tag{15}$$

$$A_i = \lambda \times Q_i + \left(1 - \lambda \right) \times P_i \tag{16}$$

The coefficient λ ranges from 0, 0.1, 0.2,….1.0

Step 7. Ranking the alternatives. The highest value of alternatives implies the best-ranked one, while the smallest value refers to the worst alternative.

3. FUCOM method in group decision-making processes

The optimal choice of overhaul mechanization, in this case a forklift, depends solely on the precise determination and selection of appropriate criteria and their evaluation. The weights of the selected criteria were determined on the basis of their importance and needs of "Euro-Roal", Doboj Jug,, which were presented by experts and employees responsible for overhaul mechanization. Table 1 gives the name, label and description of the criteria used for the selection of a forklift.

Table 1. Criteria for forklift selection

Name and label of criteria	Criterion description
Purchase price (C_1)	Forklift prices on the market are different and depend on manufacturers. When making an investment decision, the purchase price should not be decisive to the buyer, but it has a significant impact on the final decision. In an unsystematic approach, once the basic conditions are met, the purchase price is often a decisive factor.

Age (C_2)	The age or year of production characterizes the production period of a forklift. Forklifts manufactured recently have better specifications and options for adjustment to the requirements.
Working hours (C_3)	Forklift utilization time is one of the most important criteria when selecting a forklift. The less the hours of the forklift utilization are, the lesser possibility of its breakdown is.
Maximum load capacity (C_4)	Maximum load capacity is a criterion that represents the load capacity that a forklift can lift and it is expressed in kilograms.
Maximum lift height (C_5)	Maximum lift height is a criterion that represents the height that a forklift can reach when lifting.
Ecological factors (C_6)	Impact of forklift operation on the environment.
Supply of spare parts (C_7)	In experience, some representatives working in the market of the Republic of Serbia do not have in stock all necessary spare parts that are subject to frequent replacements, and their delivery is being waited for weeks, so the repairs of the means are long lasting. This criterion is in a group of qualitative criteria and is expressed by a fuzzified Likert scale.

Table 2 shows seven criteria that were evaluated by three decision-makers. The decision-makers evaluated the criteria according to their importance to the company.

Table 2. Comparison of criteria

	DM1	DM2	DM3
C1	5	5	5
C2	4	2	2
C3	1	1	1
C4	2	3	3
C5	3	4	4
C6	7	7	7
C7	6	6	6

Determining the significance of criteria according to Petrović et al. (2017) is one of the most important stages in a decision-making process.

3.1. Determining the weight values of criteria for DM1

Step 1. In the first step, the decision-makers rank the criteria:

$C_3 > C_4 > C_5 > C_2 > C_1 > C_7 > C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a parwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C_1. The comparison is based on the scale $[1,9]$. Thus, we obtain the significance of the criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 3).

Table 3. The significance of criteria

Criteria	C3	C4	C5	C2	C1	C7	C6
$\varpi_{C_{j(k)}}$	1	2.2	3,8	4.5	5	6,5	7

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{c_3/c_4} = 2.20/1.0 = 2.20$; $\varphi_{c_4/c_5} = 3.8/2.20 = 1.73$; $\varphi_{c_5/c_2} = 4.50/3.8 = 1.18$;

$\varphi_{c_2/c_1} = 5.00/4.50 = 1.11$; $\varphi_{c_1/c_7} = 6.50/5.00 = 1.30$; $\varphi_{c_7/c_3} = 7.00/6.50 = 1.08$

Step 3. The final values of weight coefficients should meet two conditions: (1) The final values of weight coefficient should meet the condition (3), i.e. that:

$$w_3/w_4 = 2.20;\ w_4/w_5 = 1.73;\ w_5/w_2 = 1.18;\ w_2/w_1 = 1.11;\ w_1/w_7 = 1.30;$$

$$w_7/w_6 = 1.08$$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_5} = 2.20 \times 1.73 = 3.81;\ \frac{w_4}{w_2} = 1.73 \times 1.18 = 2.04;\ \frac{w_5}{w_1} = 1.18 \times 1.11 = 1.31;$$

$$\frac{w_2}{w_7} = 1.11 \times 1.30 = 1.44;\ \frac{w_1}{w_6} = 1.30 \times 1.08 = 1.40$$

Using the expression (5), we can define the final model for determining weight coefficients:

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_8}{w_4} - 2.20\right| \le \chi, \left|\frac{w_4}{w_5} - 1.73\right| \le \chi, \left|\frac{w_5}{w_2} - 1.18\right| \le \chi, \left|\frac{w_2}{w_1} - 1.11\right| \le \chi, \left|\frac{w_1}{w_7} - 1.30\right| \le \chi, \left|\frac{w_7}{w_6} - 1.08\right| \le \chi, \\
&\left|\frac{w_8}{w_5} - 3.81\right| \le \chi, \left|\frac{w_4}{w_2} - 2.04\right| \le \chi, \left|\frac{w_5}{w_1} - 1.31\right| \le \chi, \left|\frac{w_2}{w_7} - 1.44\right| \le \chi, \left|\frac{w_1}{w_6} - 1.40\right| \le \chi, \\
&\sum_{j=1}^{7} w_j = 1, \\
&w_j \ge 0,\ \forall j
\end{aligned}$$

By solving this model, we obtain the final values of weight coefficients for: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts $(0.082, 0.091, 0.410, 0.186, 0.108, 0.059, 0.068)^T$ and the deviation from a complete consistency, a result $x = 0.001$.

After calculating, it can be concluded that the most important criterion is working hours. For this element, the final value of the weight coefficient is 0.410.

3.2. Determining the weight values of criteria for DM2

Step 1. In the first step, the decision-makers ranked the criteria:

$C_3 > C_2 > C_4 = C_5 > C_1 > C_7 > C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a pairwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C1. The comparison is based on the scale $\left[1,9\right]$. Thus, we obtain the significance of the criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 4).

Table 4. The significance of criteria

Criteria	**C3**	**C2**	**C4**	**C5**	**C1**	**C7**	**C6**
$\varpi_{C_{j(k)}}$	1	2.8	3.5	3.5	4.2	5.5	6.5

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{c_3/c_2} = 2.80/1.0 = 2.80$; $\varphi_{c_2/c_4} = 3.5/2.80 = 1.25$; $\varphi_{c_4/c_5} = 3.50/3.50 = 1.00$;

$\varphi_{c_5/c_1} = 4.20/3.50 = 1.20$; $\varphi_{c_1/c_7} = 5.50/4.20 = 1.30$; $\varphi_{c_7/c_6} = 6.50/5.50 = 1.18$

Step 3. The final values of weight coefficients should meet two conditions:

(1) The final values of weight coefficient should meet the condition (3), i.e. that:

$$w_3/w_2 = 2.80;\ w_2/w_4 = 1.25;\ w_4/w_5 = 1.00;\ w_5/w_1 = 1.20;\ w_1/w_7 = 1.30;$$
$$w_7/w_6 = 1.18$$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_4} = 2.80\times1.25 = 3.50;\ \frac{w_2}{w_5} = 1.25\times1.00 = 1.25;\ \frac{w_4}{w_1} = 1.00\times1.20 = 1.20;$$
$$\frac{w_5}{w_7} = 1.20\times1.30 = 1.56;\ \frac{w_1}{w_6} = 1.30\times1.18 = 1.53$$

Using the expression (5), we can define the final model for determining weight coefficients.

$$\min \chi$$
$$s.t.$$
$$\left|\frac{w_3}{w_2} - 2.80\right| \le \chi, \left|\frac{w_2}{w_4} - 1.25\right| \le \chi, \left|\frac{w_4}{w_5} - 1.00\right| \le \chi, \left|\frac{w_5}{w_1} - 1.20\right| \le \chi, \left|\frac{w_1}{w_7} - 1.30\right| \le \chi, \left|\frac{w_7}{w_6} - 1.18\right| \le \chi,$$
$$\left|\frac{w_3}{w_4} - 3.50\right| \le \chi, \left|\frac{w_2}{w_5} - 1.25\right| \le \chi, \left|\frac{w_4}{w_1} - 1.20\right| \le \chi, \left|\frac{w_5}{w_7} - 1.56\right| \le \chi, \left|\frac{w_1}{w_6} - 1.53\right| \le \chi,$$
$$\sum_{j=1}^{7} w_j = 1,$$
$$w_j \ge 0,\ \forall j$$

By solving this model, we obtain the final values of weight coefficients: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts (0.094, 0.140, 0.398, 0.115, 0.116, 0.064, 0.077)^{T} and the deviation from a complete consistency, a result x = 0.004.

After calculating, it can be concluded that the most important criterion is working hours. For this element, the final value of the weight coefficient is 0.398.

3.3. Determining the weight values of criteria for DM3

Step 1. In the first step, the decision-makers ranked the criteria:

$C_3>C_2>C_4=C_5>C_1>C_7>C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a pairwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C_1. The comparison is based on the scale $[1,9]$. Thus, we obtain the significance of criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 5).

Table 5. The significance of criteria

Criteria	C_3	C_2	C_4	C_5	C_1	C_7	C_6
$\varpi_{C_{j(k)}}$	1	2.8	3.5	3.5	4.5	6	7

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{c_3/c_2} = 2.80/1.0 = 2.80$; $\varphi_{c_2/c_4} = 3.5/2.80 = 1.25$; $\varphi_{c_4/c_5} = 3.50/3.50 = 1.00$;

$\varphi_{c_5/c_1} = 4.50/3.50 = 1.29$; $\varphi_{c_1/c_7} = 6.00/4.50 = 1.34$; $\varphi_{c_7/c_6} = 7.00/6.00 = 1.17$

Step 3. The final values of weight coefficients should meet two conditions:

1) The final values of weight coefficients should meet the condition (3), i.e. that:

$w_3/w_2 = 2.80; w_2/w_4 = 1.25; w_4/w_5 = 1.00; w_5/w_1 = 1.29; w_1/w_7 = 1.34;$

$w_7/w_6 = 1.17$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_4} = 2.80 \times 1.25 = 3.50; \frac{w_2}{w_5} = 1.25 \times 1.00 = 1.25; \frac{w_4}{w_1} = 1.00 \times 1.29 = 1.29;$$

$$\frac{w_5}{w_7} = 1.29 \times 1.34 = 1.73; \frac{w_1}{w_6} = 1.73 \times 1.17 = 2.02$$

Using the expression (5), we can define the final model for determining weight coefficients:

$$\min \chi$$

$$s.t.$$

$$\left|\frac{w_3}{w_2} - 2.80\right| \le \chi, \left|\frac{w_2}{w_4} - 1.25\right| \le \chi, \left|\frac{w_4}{w_5} - 1.00\right| \le \chi, \left|\frac{w_5}{w_1} - 1.29\right| \le \chi, \left|\frac{w_1}{w_7} - 1.34\right| \le \chi, \left|\frac{w_7}{w_6} - 1.17\right| \le \chi,$$

$$\left|\frac{w_3}{w_4} - 3.50\right| \le \chi, \left|\frac{w_2}{w_5} - 1.25\right| \le \chi, \left|\frac{w_4}{w_1} - 1.29\right| \le \chi, \left|\frac{w_5}{w_7} - 1.73\right| \le \chi, \left|\frac{w_1}{w_6} - 2.02\right| \le \chi,$$

$$\sum_{j=1}^{7} w_j = 1,$$

$$w_j \ge 0, \ \forall j$$

By solving this model, we obtain the final values of weight coefficients: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts $(0.095, 0.170, 0.418, 0.110, 0.112, 0.050, 0.065)^T$ and the deviation from a complete consistency, a result $x = 0.001$.

After calculating, it can be concluded that the most important criterion (Table 6) is working hours. For this element, the final value of the weight coefficient is 0.418.

Table 6. The criterion values for each decision-maker and values obtained by applying a geometric mean

DM1	DM2	DM3	The values obtained by applying a geometric mean
0.082	0.094	0.095	0.090
0.091	0.140	0.170	0.129
0.410	0.398	0.418	0.409
0.186	0.115	0.110	0.133
0.108	0.116	0.112	0.112
0.059	0.064	0.050	0.057
0.068	0.077	0.065	0.070

The final values of weight coefficients were obtained by LINGO software. From the table of results, it is clear that in this case working hours (C_3) and maximum load capacity (C_4) are the most important criteria.

4. The selection of forklift in a warehouse using the WASPAS method

The Euro-Roal company owns several forklifts over 20 years of age and, in order to improve and refine their fleet, 10 alternatives (Figure 1) (side-loading forklifts) will be evaluated. One of them, which would be suitable for the Euro-Roal, will be selected.

Figure 1. The alternatives in a multi-criteria model

Table 7 shows a formed multi-criteria model consisting of ten alternatives and seven criteria.

Table 7. Initial decision-making matrix

Alternatives	CRITERIA						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Forklift 1	7.950	10	5012	4000	5400	5	7.67
Forklift 2	12.900	10	7140	3000	3500	7	7.67
Forklift 3	17.800	9	6500	5000	4500	7	5
Forklift 4	19.300	19	4312	3000	6000	3	3.67
Forklift 5	10.870	18	12000	3000	4000	5	3
Forklift 6	30.400	7	4800	4000	4000	7.67	9
Forklift 7	8.093	25	12000	4000	5900	3	5
Forklift 8	29.800	11	3720	3000	5100	9	9
Forklift 9	13.750	17	15350	4500	4800	3	5
Forklift 10	18.297	13	6122	3000	4000	5	7
	min	min	min	max	max	max	max
	7.950	7	3720	5000	6000	5	7

The criteria that prefer minimal values are normalized by applying the following procedure:

$$x_{11} = \frac{7950}{7950} = 1; x_{21} = \frac{7950}{12900} = 0.616; x_{31} = \frac{7950}{17800} = 0.446; x_{41} = \frac{7950}{19300} = 0.411;$$

$$x_{51} = \frac{7950}{10870} = 0.731 \quad . \quad . \quad . \quad x_{10-1} = \frac{7950}{18297} = 0.434;$$

The criteria that prefer maximum values are normalized by applying the following procedure:

$$x_{14} = \frac{4000}{5000} = 0.80; x_{24} = \frac{3000}{5000} = 0.60; x_{34} = \frac{5000}{5000} = 1.00; x_{44} = \frac{3000}{5000} = 0.60;$$

$$x_{54} = \frac{3000}{5000} = 0.60; \quad . \quad . \quad . \quad x_{10-4} = \frac{3000}{5000} = 0.60;$$

Table 8. Normalized matrix

Alternatives	CRITERIA						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Forklift 1	1.000	0.700	0.742	0.800	0.900	0.556	0.852
Forklift 2	0.616	0.700	0.521	0.600	0.583	0.778	0.852
Forklift 3	0.447	0.778	0.572	1.000	0.750	0.778	0.556
Forklift 4	0.412	0.368	0.863	0.600	1.000	0.333	0.408
Forklift 5	0.731	0.389	0.310	0.600	0.667	0.556	0.333
Forklift 6	0.262	1.000	0.775	0.800	0.667	0.852	1.000
Forklift 7	0.982	0.280	0.310	0.800	0.983	0.333	0.556
Forklift 8	0.267	0.636	1.000	0.600	0.850	1.000	1.000
Forklift 9	0.578	0.412	0.242	0.900	0.800	0.333	0.556
Forklift 10	0.434	0.538	0.608	0.600	0.667	0.556	0.778
W	0.090	0.129	0.409	0.133	0.112	0.057	0.070

Weighting the normalized matrix, so that the previously obtained matrix needs to be multiplied by the weight values of criteria:

$x_{11} = 0.090 \times 1.000 = 0.090; x_{21} = 0.090 \times 0.616 = 0.055 \quad . \quad . \quad . \quad x_{10-1} = 0.090 \times 0.434 = 0.039$

In Table 9, after obtaining the values v_{ij}, the matrix is weighted, so that obtained values are multiplied by the values of weight coefficients.

Table 9. Weighted normalized matrix

Alternatives	CRITERIA						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Forklift 1	0.090	0.090	0.304	0.106	0.101	0.032	0.060
Forklift 2	0.055	0.090	0.213	0.080	0.065	0.044	0.060
Forklift 3	0.040	0.100	0.234	0.133	0.084	0.044	0.039
Forklift 4	0.037	0.048	0.353	0.080	0.112	0.019	0.029
Forklift 5	0.066	0.050	0.127	0.080	0.075	0.032	0.023
Forklift 6	0.024	0.129	0.317	0.106	0.075	0.049	0.070
Forklift 7	0.088	0.036	0.127	0.106	0.110	0.019	0.039
Forklift 8	0.024	0.082	0.409	0.080	0.095	0.057	0.070
Forklift 9	0.052	0.053	0.099	0.120	0.090	0.019	0.039
Forklift 10	0.039	0.069	0.249	0.080	0.075	0.032	0.054

$$Q_1 = 0.090 + 0.090 + 0.304 + 0.106 + 0.101 + 0.032 + 0.060 = 0.783$$

Determining a weighted product model using the following equation:

$$p_1 = (1.000)^{0.090} \times (0.700)^{0.129} \times (0.742)^{0.409} \times (0.800)^{0.133} \times (0.900)^{0.112} \times (0.556)^{0.557}$$
$$\times (0.852)^{0.070} = 0.776$$

Determining the relative values of alternatives A_i:

$$A_1 = 0.5 \times 0.783 + (1 - 0.5) \times 0.782 = 0.779$$

Ranking the alternatives. The highest value of alternatives shows the best-ranked one, while the smallest value refers to the worst alternative. Table 10 presents the results of ranking of forklifts based on the previous calculation.

Table 10. Results and ranking the forklifts

	P	A	Rank
Forklift 1	0.776	0.779	2
Forklift 2	0.600	0.604	6
Forklift 3	0.656	0.666	4
Forklift 4	0.630	0.653	5
Forklift 5	0.426	0.439	10
Forklift 6	0.734	0.752	3
Forklift 7	0.458	0.492	8
Forklift 8	0.768	0.793	1
Forklift 9	0.412	0.442	9
Forklift 10	0.593	0.595	7

Determining the relative weights of criteria was performed by the FUCOM method, while the ranking was performed using the WASPAS method. Based on the results of the applied model, a solution that meets the current needs of the Euro-Roal company has been found, which is Alternative 8, i.e. the BAUMANN EHX 30/14/51 forklift

5. Sensitivity analysis and discussion

A logical sequence in most processes of multi-criteria decision-making is sensitivity analysis. For the sensitivity analysis of this model, the results of the SAW method (MacCrimon, 1968), the WASPAS method and the ARAS method (Zavadskas and Turskis, 2010) were compared.

Table 11 and Figure 2 show the results and ranking the forklifts according to SAW, WASPAS and ARAS methods.

Table 11. The results of sensitivity analysis according to SAW, WASPAS and ARAS methods

	SAW		WASPAS		ARAS	
A1	0.782	2	0.779	2	0.779	2
A2	0.608	6	0.604	6	0.607	6
A3	0.675	5	0.666	4	0.666	5
A4	0.677	4	0.653	5	0.671	4
A5	0.452	10	0.439	10	0.445	10
A6	0.769	3	0.752	3	0.768	3
A7	0.526	8	0.492	8	0.508	8
A8	0.817	1	0.793	1	0.817	1
A9	0.471	9	0.442	9	0.453	9
A10	0.598	7	0.595	7	0.594	7

Alternative 1 according to SAW, WASPAS and ARAS has the same rank (2). Alternative 2 according to SAW, WASPAS and ARAS has the same rank (6). Alternative 3 according to the SAW and ARAS methods is ranked fifth, whereas according to the WASPAS method, it is positioned fourth. Alternative 4 according to the SAW and ARAS methods is ranked fourth, whereas according to the WASPAS method, the fifth position is taken. Alternative 5 according to SAW, WASPAS and ARAS has the same rank (10). Alternative 6 according to SAW, WASPAS and ARAS has the same rank (3). Alternative 7 according to SAW, WASPAS and ARAS has the same rank (8). Alternative 8 is the best solution according to all methods. Alternative 9 according to SAW, WASPAS and ARAS has the same rank (9). Alternative 10 according to SAW, WASPAS and ARAS has the same rank (7).

Figure 2. Sensitivity analysis

6. Conclusion

In this paper, a selection of transport and handling means was carried out in a warehouse system applying a combined FUCOM-WASPAS model. FUCOM was implemented throughout a group decision-making process where an expert team was formed to evaluate the significance of the criteria. Obtaining the final weight values of the criteria was achieved using a geometric mean. The research has been conducted in a company whose primary task is to trade and distribute aluminum profiles. The applied model allows for an objective consideration of input parameters that have an impact on making a final decision. Comparative analysis, which implies the application of two additional MCDM methods, presents the stability of originally obtained results if the model is generally observed throughout all possible variants. If individual positions are taken into account then the model shows the sensitivity to certain changes. Future research regarding this paper relates to the formation of a model for determining the efficiency of using the selected side-loading forklift.

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ROUTE PLANNING FOR HAZARDOUS MATERIALS TRANSPORTATION: MULTI-CRITERIA DECISION-MAKING APPROACH

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Abstract: *Transport of hazardous material (THM) represents a complex area involving a large number of participants. The imperative of THM is minimization of risks in the entire process of transportation from the aspect of everyone involved in it, which is not an easy task at all. To achieve this, it is necessary in its early phase to carry out adequate evaluation and selection of an optimal transport route. In this paper, optimal route criteria for THM are selected using a new approach in the field of multi-criteria decision-making. Weight coefficients of these criteria were determined by applying the Full Consistency Method (FUCOM). Evaluation and selection of suppliers is determined by applying the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and the MABAC (Multi-attributive Border Approximation Area Comparison) methods. In order to establish the stability of models and validate the results obtained from the FUCOM-TOPSIS-MABAC model, a sensitivity analysis (of ten different scenarios) was performed. The sensitivity analysis implied changes of the weight coefficients criteria with respect to their original value. The proposed route model was tested on the real example of the transport Eurodiesel in Serbia.*

Key words: *Hazardous Materials Routing, FUCOM, TOPSIS, MABAC, Multi-criteria Decision-making.*

1. Introduction

The rapid development of industry, based on the development of techniques and technology increased the usage of substances, materials, elements, which are hazardous to human health and safety as well as environment safety. Modern industry,

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especially the one of chemical character, also contributes to the faster development of new materials whose usage can cause huge destruction and damage.

The issues of storage and transport, shipping (loading), discharging (unloading) or reloading, or the issues of the activities related to process of transport and storage of these substances are very sensitive. Especially during these activities the risk of unwanted consequences is significantly high and each accident can turn into catastrophe.

From the aspect of transport, realization of each transport process of hazardous material implies a certain risk of an unwanted(accident) event, caused by scattering (effusion, shedding, etc.) of burden, with the consequences related to the nature of the hazardous material that is being transported. By mentioning all of these risks, the transport safety is a very important and responsible task. In the case of an accident, the consequences can be very large and can cause damage to people and their environment, namely, death, diseases of human beings, plant and animals, pollution of environment, destruction of natural and national resources, damage of industrial buildings, traffic communications and their respective facilities.

Potential danger, on one hand, and the need for transport of hazardous materials, on the other hand, both lead to the necessity of setting specific requirements related to risk reduction and attempts to increase the safety in the transport of hazardous materials. With the growth of ecological consciousness, there is also a growing demand for reduction of transport risks, but also in handling, in general, hazardous materials. Because of these reasons, numerous countries, institutions and organizations have different regulations and other regulatory measures in order to manage the safety of these transport processes.

To keep the hazardous materials transport process safe, it is necessary to manage the risk. Risk management represents a very complex process, consisting of several steps and elements. Certainly one of the most important steps in this process is the selection of routes for the movement of vehicles that carry hazardous load (material). The problem of routing in the transport of hazardous materials, as a problem of multi-criteria factors, became popular in the 90s of the last century. Approaches to solving this problem are numerous and depend on many factors, such as the methods used to identify risks, the criteria that are considered, the ways in which these criteria are valued, etc. This is necessary because the requirements for transporting hazardous materials are very complicated; this implies a very difficult task for the managers assigned to properly evaluate potential hazardous materials transport routes (THM) that will enable efficient and safe transportation. In order to minimize THM risks, efficient management strategy has become a key risk minimization component (Pamucar et al., 2016).

When considering the efficiency of the entire THM it is impossible not to notice that it largely depends on adequate route selection because this process represents one of the most important factors that directly affect the overall risk and safety of transport. Only by properly evaluating and selecting routes this logistical subsystem can efficiently perform tasks related to end-user supply. In this paper, the choice of optimum route for THM was performed using linear programming and multi-criteria evaluation of the THM route. The weight coefficients of the criteria are determined by linear programming. Evaluation and selection of route for THM was performed using TOPSIS and MABAC methods. These multi-criteria techniques were chosen because the TOPSIS method is one of the most commonly used multi-criteria techniques (Song et al, 2014), while the MABAC method is one of the newest methods in this area that has found a wide and efficient application in many areas (Yu et al, 2016; Xue et al, 2016; Peng and Dai, 2016; Peng and Yang, 2016; Roy et al, 2016; Gigovic et al, 2017; Pamucar et al., 2018).

This paper has more goals. The first objective is to improve the methodology for route optimization for the THM. The second goal of this paper is the popularization of the operational research, especially linear programming and multi-criteria techniques, through their application for decision-making in a real business and business system. The third goal of the paper is a proposal of a model that comprehensively addresses the problem of hazmat rutting with respect to both cost aspects and different aspects of risk, as well as a number of uncertainties in the decision-making process. By proposing the new model of the LP-TOPSIS-MABAC hybrid model, it is trying to show that academic research models can be more practical and useful for actually planning the routes.

The paper is structurally divided into six sections. In the next section, an overview of the literature with an accent on the criteria for selecting the optimal route for THM is given. In addition, the methods used to optimize the THM process have been presented. In the third section, the FUCOM-TOPSIS-MABAC hybrid model algorithms are presented: (1) FUCOM - for defining weight coefficient criteria, (2) TOPSIS model - for THM route evaluation and (3) MABAC model for THM route evaluation. The fourth section is the application of the above mentioned techniques of operational research to a real problem. In the fifth section, a sensitivity analysis was performed defining different sets with different criteria values based on which the stability of the proposed model was verified. Section six is conclusion with the guidelines for future research.

2. Literature review

Multi-criteria decision-making is widely applied in all areas, and when it comes to transport, more precisely the sub-system of transport carried out by THM is often used to select transport routes (Pamucar et al., 2016). For the purposes of this paper, the author's works have been analyzed to deal with the problem of choosing the optimal route for the THM and thus the choice of criterion of choice. Among them, it was noted that the sources the authors rely on are often similar, so most of the criteria are repeated in the works of different authors. Consequently, in this paper are presented and analyzed the characteristic works, which are set out according to the methodology and criteria applied.

Wijerante et al., (1993) have developed a method for determining undetermined routes in the network when there are multiple, uncertain measures based on which route estimates are made and applied to a transport hazard example in the territory of New York State (United States). In order to evaluate the route options and choose optimal, they based their analysis on three criteria: time of transport, incidence of traffic accidents resulting from hazardous substances and operating costs.

The issue of risk modeling in the transport of hazardous materials and the question of the importance of the way of evaluating this risk was addressed by Erkut and Verter (1998). They presented an overview of the models and methods most commonly used in theory and practice, and their empirical analysis was conducted on the American road network. They concluded that choosing the optimum route for THM depends on the way of risk assessment, i.e. they have shown the impact of different risk assessment models on selecting the optimal route for THM.

To consider the THM impact on the environment was of great importance when choosing the route, as shown in Monprapussornte al., (2009). The authors also pointed out to the possibility of applying a decision support system, such as the Multi Criteria Decision Analysis (MCDA) and the Geographic Information System (GIS), which make easier the selection of routes while planning THM, while respecting the environmental criteria. In that study Monprapussornte al., (2009) the environmental factor has been identified as one of the key factors in addition to those that are economically linked to safety and the ability to react in emergency situations.

To establish a network of roads for THM, Law and Rocchi (2008) conducted research in Canada. The goal of this study was to establish a network of THM routes in Canada. The authors have analyzed and used current methodological approaches (MCDM, routing algorithms etc.) that used different route agencies when determining routes in some other cities and regions. Law and Rocchi (2008) have proposed criteria for route evaluation as well as methodology for choosing the optimal route for THM based on the MCDM approach.

Huang et al., (2004) and Huang and Fery (2005) dealt with the choice of the THM route in Singapore as the third oil refinery in the world. Given the increased number of trucks carrying hazardous goods in this city, the authors have pointed out the need to improve the tracking and safety of trucks driving on the city and suburban road network at THM. To select the optimal directions for THM authors proposed risk mapping and GIS application in combination with genetic algorithms in this study.

Samuel (2007) presented a time study, which covers the time period from 1995 to 2007, in which he analyzed 1850 incidents in transport of flammable-liquid substances. Focus studies include shipments of hazardous cargo from five US states (California, Illinois, Iowa, New Jersey, and Texas), which were selected due to their size and geographic location differences. The main objective of this study was to analyze the frequency of incidents during THM and as a result of the analysis, thirteen criteria for route selection were set out.

The importance of safety when transporting hazardous materials was pointed out as well by Dilgir, et al., (2005). They consider that THM that run on roads that pass through larger cities are not only a challenge for transporters, but also for city planners and services designed to respond to emergency situations. Dilgir, et al., (2005) point out that road safety is a key criterion for efficient route selection for THM and suggest the use of MCDM techniques to solve this problem. Sattayaprasert et al., (2008) have proposed multi-criteria models to form an efficient logistic network, with particular reference to the risk inherent in THM. Using the Analytic Hierarchy Process (AHP) Sattayaprasert et al., (2008) have observed a case of study related to petrol logistics as one of the most frequently transported hazardous cargoes in Thailand. The AHP structure of the criteria which they have established is based on the evaluation and opinions of the expert group and the local community.

As most of the authors of the previously analyzed papers pointed to the consequences of cargo carrying hazardous cargo, Oluwoye (2007) deals with the effects and risks of the environment if accidents occur during this type of transport. Oluwoye(2007) states that if an economical and efficient risk management strategy is to be achieved, optimization must be carried out to minimize costs and impact on the environment. Milovanovic (2012) also deals with the topic of selecting an adequate route from the aspect of risk management and provides an overview of the risk management process in hazardous materials transport, i.e. the phases of the risk management process, as well as a detailed description of each phase. In order to determine the level of risk Milovanovic (2012) defines two types of parameters. The first group of parameters affects the probability of an incident while the other group of parameters affects the consequences of an incident.

Li and Leung (2011) also viewed a multi-objective optimization problem as the problem of selecting the transport route hazmat on the urban network. They proposed a compromise programming approach to modify the Dijkstring's algorithm while for the attribution of weight coefficient they used the Analytic Hierarchy Process, considering that they will minimize human subjectivity in decision-making.

From the previous literature analysis, it can be said that the multi-criteria analysis is used as a tool for achieving the best possible trade – off among different objectives (Li & Leung, 2011). It should be borne in mind that the optimality of multi-objective solutions in the hazmat routing domain implies the so-called "Pareto-optimality". More about Pareto concept can be seen in (Das et al., 2012). In the application of the multi-criteria analysis method for selecting the hazmat transport route, hybrid models are often proposed in which these methods combine with the classical shortest path algorithms or Geographic information systems - GIS (AHP method and Dijkstra's algorithm) (Verma, 2011; Li & Leung, 2011), AHP method and GIS (Long &Liew, 2003; Huang, 2006; Sattayaprasert et al., 2008). The application of other multi-criteria analysis methods, such as PROMETHEE and TOPSIS, in vehicle routing problems, can be seen in (Bandyopadhyay& Bhattacharya, 2013; Jia et al., 2013; Talarico, 2015).

The literature review shows that in the literature there are known crisp multi-criteria algorithms based on the most common application of GIS models with AHP, TOPSIS and PROMETHEE algorithms. Considering that the TOPSIS method falls into the methods found to be the widest application in solving multi-criteria models (Song et al., 2014; Stevic et al., 2016; Zhang et al., 2017) it is justified to further develop the TOPSIS method algorithm through the application of other approaches. In order to achieve greater objectivity in decision-making over the last several years, numerous multi-criteria models have been developed among which the swords and MABAC methods (Pamucar&Cirovic, 2015).The authors agreed to apply the MABAC method due to many advantages it recommends: (1) the mathematical framework of the method remains the same regardless of the number of alternatives and criteria; (2) the possibility of applying in the case of a number of alternatives and criteria; (3) a clearly defined ranking of alternatives is expressed in numerical value, which allows a better understanding of the results; (4) it is applicable to the qualitative and quantitative criterion type and (5) it provides stable solutions regardless of the change in the scale of qualitative criteria and the change in the formulation of the quantitative criteria (Pamucar&Cirovic, 2015). The original model based on the Linear Programming (LP) was suggested for determining weight criteria. The main advantages of the LP models are as follows: (1) Weight coefficients obtained with the LP model represent fair values since the input data is obtained with a small number comparing to the real criteria; (2) The mathematical framework of the model remains the same regardless of the number of criteria; (3) The LP model provides stable solutions regardless of the type of scale used to represent the expert preferences. Taking into account all the advantages of the LP, TOPSIS and MABAC models in the decision-making process, the authors have decided in this paper to present the hybrid LP-TOPSIS-MABAC model for selecting the optimal route for THM.

3. Multi-criteria model for choosing the optimal route for THM

The model for optimal route selection for THM is realized through two phases. In the first phase of the hybrid FUCOM-TOPSIS-MABAC model using the linear programming model, the weighting coefficients of the evaluation criterion are calculated. In the second phase of the FUCOM -TOPSIS-MABAC model, a THM route evaluation is performed using TOPSIS and MABAC models.

3.1. Determining weight coefficient criteria - FUCOM model

FUCOM (Pamucar et al., 2018) is a new MCDM method for determination of criteria weights. In the following section, FUCOM algorithm is shown, which implies the following steps:

Step 1. Determining the set of evaluation criteria. This starts from the assumption that the process of decision-making involves *m* experts. In this step, experts consider the set of evaluation criteria and select the final set of criteria $C=\{c_1,c_2,...c_n\}$, where *n* represents the total number of criteria.

Step 2. The second step is to rank the criteria according to their significance. The criterion we expect to have the highest weight coefficient gets the first rank, while the least important criterion gets the last rank. The remaining criteria get the rankings between the most important and the least important criterion. The ranks of the criteria are presented by the experts in descending order in accordance with the expected values of weight coefficients $C_{j(1)}^{(e)} > C_{j(2)}^{(e)} > ... > C_{j(k)}^{(e)}$, where *k* represents the rank of the observed criterion, whereas *e* represents the mark of expert $1 \le e \le m$.

Step 3. The third step is to compare the ranked criteria together and compare the significance of the evaluation criterion. Comparative significance of the criterion of evaluation is an advantage that has a higher ranking criterion in relation to the lower rank criterion.

The final values of the weight coefficients should meet the following two conditions:

(1) The relation of the weight coefficients should be the same as the comparative importance between observed criteria ($\varphi_{k/(k+1)}^{(e)}$), which is defined in *Step 2*, meeting the condition:

$$\frac{w_k^{(e)}}{w_{k+1}^{(e)}} = \varphi_{k/(k+1)}^{(e)} \tag{1}$$

(2) Apart from the condition (1), the final values of the weight coefficients should meet the condition of mathematical transitivity, so that $\varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} = \varphi_{k/(k+2)}^{(e)}$. Taking into consideration the fact that $\varphi_{k/(k+1)}^{(e)} = \frac{w_k^{(e)}}{w_{k+1}^{(e)}}$ and $\varphi_{(k+1)/(k+2)}^{(e)} = \frac{w_{k+1}^{(e)}}{w_{k+2}^{(e)}}$, $\frac{w_k^{(e)}}{w_{k+1}^{(e)}} \otimes \frac{w_{k+1}^{(e)}}{w_{k+2}^{(e)}} = \frac{w_k^{(e)}}{w_{k+2}^{(e)}}$ is obtained. In that manner, the second condition that the final values of the weight coefficients of the evaluation criteria should meet is:

$$\frac{w_k^{(e)}}{w_{k+2}^{(e)}} = \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} \tag{2}$$

Step 4. Solving the optimization model (3) the final values of the weighting coefficients of the evaluation criteria are calculated $\left(w_1, w_2, ..., w_n\right)^T$ .The minimum deviation from the maximum consistency (DFC) of the comparison (χ) is only met if transitivity is fully complied with, when the conditions are met, where $\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)} = 0$ and $\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)} = 0$. Then, the condition of the maximum consistency is met, respectively, for the obtained values of the weight coefficients, the deviation from the maximum consistency being $\chi = 0$. In order to meet the mentioned conditions, it is necessary to determine the values of the weight coefficients of evaluation criteria $\left(w_1^{(e)}, w_2^{(e)}, ..., w_n^{(e)}\right)^T$ meeting the condition, where $\left|\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)}\right| \leq \chi$ and $\left|\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)}\right| \leq \chi$, while minimizing the values, thus meeting the condition of the maximum consistency.

Based on the mentioned assumptions, the final model for determining the values of the weight coefficients of the evaluation criteria can be defined as follows:

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_k^{(e)}}{w_{k+1}^{(e)}} - \varphi_{k/(k+1)}^{(e)}\right| \leq \chi, \ \forall j \\
&\left|\frac{w_k^{(e)}}{w_{k+2}^{(e)}} - \varphi_{k/(k+1)}^{(e)} \otimes \varphi_{(k+1)/(k+2)}^{(e)}\right| \leq \chi, \ \forall j \\
&\sum_{j=1}^{n} w_j^{(e)} = 1, \ \forall j \\
&w_j^{(e)} \geq 0, \ \forall j
\end{aligned} \tag{3}$$

By solving Model (3), the final values of the evaluation criteria $\left(w_1^{(e)}, w_2^{(e)}, ..., w_n^{(e)}\right)^T$ and the DFC ($\chi^{(e)}$) for every expert are obtained.

3.2. TOPSIS method

The TOPSIS method implies ranking alternatives with respect to the multiple criteria based on distance comparison with an ideal solution and a negative ideal solution (Chang et al., 2010). The ideal solution minimizes the cost-type criteria and maximizes the criteria of the benefit type, while the negative ideal solution works the other way around. A simple example is an effort to make (identify) decisions in business decision-making maximizing profit and minimizing the risk. The optimal alternative is the one that is geometrically closest to the ideal solution, that is, the farthest from the ideal negative solution (Srdjevic et al., 2002). The ranking of alternatives is based on a "relative connection with an ideal solution", thus avoiding the situation that the alternative simultaneously has the same resemblance to the ideal and the negative ideal solution. The ideal solution is defined by using the best value rating alternatives for each individual criterion. A negative ideal solution represents the worst value rating alternative. TOPSIS method consists of 6 steps that are shown in the following section.

Step 1. Normalization of decision matrix values. For the majority of multi-criteria decision-making, the first step is the normalization of the elements of the decision matrix to obtain a matrix in which all elements are non–dimensional in size. The TOPSIS method applies vector normalization that is represented by expressions (4) and (5):

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} \text{ ,for “benefit“ criteria type,} \tag{4}$$

$$x_{ij} = 1 - \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \text{, fort ”cost” criteria type} \tag{5}$$

After normalization, we get a matrix X in which all the elements are standardized and are in the interval [0, 1].

$$X = \begin{array}{c} A_1 \\ A_2 \\ \cdot \\ A_3 \end{array} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \tag{6}$$

Step 2. Multiplication of normalized matrix values X with the weight coefficient criteria

$$v_{ij} = x_{ij} \cdot w_j; \quad j = 1, 2, \dots, m \tag{7}$$

Using the relation (7) we get elements of weight normalized matrix $V = (v_{ij})$, where everyone is v_{ij} a product of normalized alternate performance and an appropriate weighting coefficient of the criterion.

$$V = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_3 \end{array} \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1m} \\ v_{21} & v_{22} & \dots & v_{2m} \\ \dots & \dots & & \dots \\ v_{n1} & v_{n2} & \dots & v_{nm} \end{bmatrix} = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_3 \end{array} \begin{bmatrix} w_1 \cdot x_{11} & w_2 \cdot x_{12} & \dots & w_m \cdot x_{1m} \\ w_1 \cdot x_{21} & w_2 \cdot x_{22} & \dots & w_m \cdot x_{2m} \\ \dots & \dots & \dots & \dots \quad \dots \\ w_1 \cdot x_{n1} & w_2 \cdot x_{n2} & \dots & w_m \cdot x_{nm} \end{bmatrix} \tag{8}$$

Step 3. Determining ideal solutions. Ideal solution A^* and negative ideal solution A^- are determined by the relation:

$$A^* = \left\{ (\max v_{ij} \mid j \in G), (\min v_{ij}, j \in G), i = 1,..,n \right\} = \left\{ v_1^*, v_2^*, \dots, v_m^* \right\} \tag{9}$$

$$A^- = \left\{ (\min v_{ij} \mid j \in G), (\max v_{ij}, j \in G^{'}), i = 1,..,n \right\} = \left\{ v_1^-, v_2^-, \dots, v_m^- \right\} \tag{10}$$

where :

$G = \left\{ j = 1, 2, \dots, m \mid \right\}$, for ”benefit”criteria type

$G^{'} = \left\{ j = 1, 2, \dots, m \mid \right\}$,for ”cost” criteria type

Step 4. Determining the distance of alternatives to ideal solutions. In this step, using the following links:

$$S_i^* = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^*)^2}, \quad i = 1,...,n \tag{11}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2}, \quad i = 1,...,n \tag{12}$$

calculated n dimensional Euclidean distances of all the alternatives of an ideal and ideal negative solution.

Step 5. Determining the relative proximity of an alternative to an ideal solution. For each alternative, a relative interval is determined

$$Q_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,...,n \tag{13}$$

where $0 \le Q_i^* \le 1$. Alternative A_i is closer to ideal solution if Q_i^* is close to 1, or, which is the same, if S_i^* is closer to 0.

Step 6. Ranking alternatives. Alternatives are ranked by decreasing values Q_i^*. The best alternative is the one whose value Q_i^* is the highest and *vice versa*.

3.3. MABAC method

The basic function of the MABAC method is to define the distance of the criterion function of each observed alternative from the boundary approximating area. In the following section, the procedure for conducting the MABAC method consists of five steps.

Step 1. Normalization of element from initial matrix (X):

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & & t_{2n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \end{array} \tag{14}$$

Elements of normalized matrix (N) are determined using the expression:

(a) for the "benefit" type criteria (a higher value criterion is more desirable))

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{15}$$

(b) for “cost “ type criteria (a lower value criterion is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{16}$$

where x_{ij}, x_i^+ and x_i^- represent the elements of initial decision matrix (X), whereby x_i^+ and x_i^- defined as:

$x_i^+ = \max(x_1, x_2, ..., x_m)$ and represents the maximum value of the observed criterion by alternatives and

$x_i^- = \min(x_1, x_2, ..., x_m)$ and represents the minimum values of the observed criterion by alternatives.

Step 2. Calculation of weighted matrix elements (V).Calculation of weighted matrix elements (V) are calculated based on expression (17):

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{17}$$

where t_{ij} represent elements of a normalized matrix (N), w_i represents the weighting criterion coefficients. Using expression (17) we get weighted matrix V:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & \cdots & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & \cdots & w_n \cdot t_{2n} + w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & \cdots & w_n \cdot t_{mn} + w_n \end{bmatrix}$$

where n represents the total number of criteria, m represents the total number of alternatives.

Step 3. Determination of matrix of border approximate domains (G). The Boundary Approximate Area (GAO) is determined according to expression (18):

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{18}$$

where v_{ij} represent elements of a heavy matrix (V), m represents the total number of alternatives.

After calculating value g_i according to the criteria, a matrix of border approximating areas is formed G (19) formats n x 1 (n represents the total number of criteria by which a choice of alternatives is offered):

$$\begin{array}{c} \quad\; C_1 \quad C_2 \quad \cdots \quad C_n \\ G = \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \end{array} \tag{19}$$

Step 4. Calculation of the matrix elements of the distance of alternatives from boundary approximating area (Q):

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{20}$$

Alternative distance from border approximate area (q_{ij}) is defined as the difference between the elements of a heavy matrix (V) and values of border approximate areas (G):

$$Q = V - G = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{21}$$

where g_i represents a border approximate area for criterion C_i, v_{ij} represents the elements of a heavy matrix (V), n represents the number of criteria, m represents the number of alternatives.

Alternative A_i may belong to borderline approximate area (G), upper approximate area (G^+) or lower approximate area (G^-), regarding $A_i \in \left\{G \vee G^+ \vee G^-\right\}$. Upper approximate area (G^+) represents the area in which the ideal alternative is (A^+), lower approximate area (G^-) represents the area where the anti-ideal alternative is(A^-).

Step 5. Ranking alternatives. Calculation of criterion values by alternatives (22) is obtained as a sum of limiting alternatives to border-approximating areas (q_i). Summing up matrix elements Q we get the final values of the criterion functional alternatives in a row:

$$S_i = \sum_{j=1}^{n} q_{ij},\ j=1,2,...,n,\ i=1,2,...,m \tag{22}$$

4. Selection of THM routes using the FUCOM-TOPSIS-MABAC model

The FUCOM-TOPSIS-MABAC model was tested on the example of choosing the optimal route for THM (Eurodiesel) in the Petroleum Industry of Serbia. THM is performed on the village Leskovac - Šabac. During THM, the vehicle moves from Kragujevac and has a zero drive to the warehouse in the village of Leskovac. Transport can be carried out over four routes that represent alternatives:

A1 - route: Kragujevac – Knic - v. Leskovac – Knic – Preljina – Ljig – Mionica – Valjevo – Koceljeva – Vladimirci – Šabac

A2 - route: Kragujevac – Knic - v. Leskovac – Knic – Preljina – Ljig – Lajkovac – Ub – Šabac

A3 - route: Kragujevac – Knic – v. Leskovac – Knic – Kragujevac – Topola – Mladenovac – Mali Pozarevac – Beograd – Dobanovci – Šimanovci – Šabac

A4 -route: Kragujevac – Knic – v. Leskovac – Knic – Kragujevac – Batocina – Beograd - Dobanovci – Šimanovci – Šabac.

The analysis of the literature presented in the second section of the work contains five criteria for the evaluation of the THM route: Number of rail crossings on the route (C1), Existence of traffic jam on the route (C2), Number of traffic accidents in the last ten years (C3), Reaction of rescue services (emergency aid, fire brigade and police) (C4) and Travel Line Length (C5).

The existence of rail crossing of the road route (C1) carrying hazardous goods presents a great danger from the point of view of traffic accidents (incident situations) due to the fact that there is a large stopping distance to braking of locomotives. Trails with a greater number of rail crossings have a greater degree of risk than those with fewer or no crossings at all.

Traffic jams (C2) directly affect the probability of incident situations. Increasing the number of vehicles that use a certain part of the route directly affects an increase in probability of incident situations. Since traffic accidents with the involvement of individual vehicles are common, traffic jams appear to be an important factor in determining not only the frequency of traffic accidents but also their weights. The following relationships were used to estimate the probability of occurrence of incident situations depending on traffic jam:

– the ratio of traffic speed and traffic capacity is less than 0.5,
– traffic flow velocity and traffic capacity between 0,5 and 0,7 and
– traffic speed ratio and road capacity greater than 0.7.

In order to estimate the probability of occurrence of an incident situation, depending on the number of traffic accidents (C3) on a particular section, the following scale was used within the route:

– 1 to 2 traffic accidents per kilometer per year,
– from 2 to 7 traffic accidents per kilometer per year and
– from 7 to 15 traffic accidents per kilometer per year.

Emergency Response Service (C4) represents the time for which city services (fire services, emergency services and police) react in the case of an accident. It is very important to determine the number of properly trained and well-prepared fire brigades and ambulance services as soon as possible from the base to any point along the route. This determines the effects of these services on softening the consequences of an accident involving the participation of vehicles transporting hazardous materials. On the scale from 1 to 9, values are defined that indicate the response time. Number one represents a small response time, and the number nine means quite a long response time on a particular route.

The minimum distance (C5) between the start and end point of the THM on the route is determined on the basis of available satellite images of the traffic routes. Only first and second line roads were considered.

This research study involved six road safety experts with a minimum of 10 years of experience in managing the transport of hazardous materials. In the first phase of the FUCOM-TOPSIS-MABAC model, the weighting coefficients of the evaluation criteria are calculated using linear programming.

4.1. FUCOM: Defining the weight of the criteria

Experiment surveys obtained the ranking criteria and significance of the criteria that was further used in the LP model. Table 1 shows the results of surveyed experts.

Table 1. Ranking of criteria and determination of significance

Experts	Rank/significance				
E_1	C2	C4	C1	C3	C5
	1	2	2.8	3	3.5
E_2	C3	C2	C5	C4	C1
	1	1.3	1.7	1.5	3
E_3	C4	C5	C1	C2	C3
	1	1.34	1	1.6	1.45
E_4	C5	C4	C2	C1	C3
	1	1.28	1.35	1.62	1.07
E_5	C5	C4	C2	C3	C1
	1	1.2	1.3	1.5	1.6
E_6	C5	C4	C1	C2	C3
	1	1.2	1.4	1.2	1.3

In the next step, based on the model (3), the weight coefficients of the criteria are estimated. Since the research involved six experts, the FUCOM model, which was solved using the LINGO 17.0 software, was formed from any expert. FUCOM models are shown in the next section.

$$Expert\ 1-\min\chi$$

$$\begin{cases}\left|\frac{w_2}{w_4}-2\right|\le\chi,\ \left|\frac{w_4}{w_1}-2.8\right|\le\chi,\ \left|\frac{w_1}{w_3}-3\right|\le\chi,\\ \left|\frac{w_3}{w_5}-3.5\right|\le\chi,\left|\frac{w_2}{w_1}-2\right|\le\chi,\left|\frac{w_4}{w_3}-5.6\right|\le\chi,\\ \left|\frac{w_1}{w_5}-10.5\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

$$Expert\ 2-\min\chi$$

$$\begin{cases}\left|\frac{w_3}{w_2}-1.3\right|\le\chi,\ \left|\frac{w_2}{w_5}-1.7\right|\le\chi,\ \left|\frac{w_5}{w_4}-1.5\right|\le\chi,\\ \left|\frac{w_4}{w_1}-3\right|\le\chi,\left|\frac{w_3}{w_5}-2.21\right|\le\chi,\left|\frac{w_2}{w_4}-2.55\right|\le\chi,\\ \left|\frac{w_5}{w_1}-4.5\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

$$Expert\ 3-\min\chi$$

$$\begin{cases}\left|\frac{w_4}{w_5}-1.34\right|\le\chi,\ \left|\frac{w_5}{w_1}-1\right|\le\chi,\ \left|\frac{w_1}{w_2}-1.6\right|\le\chi,\\ \left|\frac{w_2}{w_3}-1.45\right|\le\chi,\left|\frac{w_4}{w_1}-1.34\right|\le\chi,\left|\frac{w_5}{w_2}-1.6\right|\le\chi,\\ \left|\frac{w_1}{w_3}-2.32\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

$$Expert\ 4-\min\chi$$

$$\begin{cases}\left|\frac{w_5}{w_4}-1.28\right|\le\chi,\ \left|\frac{w_4}{w_2}-1.35\right|\le\chi,\ \left|\frac{w_2}{w_1}-1.62\right|\le\chi,\\ \left|\frac{w_1}{w_3}-1.07\right|\le\chi,\left|\frac{w_5}{w_2}-1.73\right|\le\chi,\left|\frac{w_4}{w_1}-2.19\right|\le\chi,\\ \left|\frac{w_2}{w_3}-1.73\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

$$Expert\ 5-\min\chi$$

$$\begin{cases}\left|\frac{w_5}{w_4}-1.2\right|\le\chi,\ \left|\frac{w_4}{w_2}-1.3\right|\le\chi,\ \left|\frac{w_2}{w_3}-1.5\right|\le\chi,\\ \left|\frac{w_3}{w_1}-1.6\right|\le\chi,\left|\frac{w_5}{w_2}-1.56\right|\le\chi,\left|\frac{w_4}{w_3}-1.95\right|\le\chi,\\ \left|\frac{w_2}{w_1}-2.4\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

$$Expert\ 6-\min\chi$$

$$\begin{cases}\left|\frac{w_5}{w_4}-1.2\right|\le\chi,\ \left|\frac{w_4}{w_1}-1.4\right|\le\chi,\ \left|\frac{w_1}{w_2}-1.2\right|\le\chi,\\ \left|\frac{w_2}{w_3}-1.3\right|\le\chi,\left|\frac{w_5}{w_1}-1.68\right|\le\chi,\left|\frac{w_4}{w_2}-1.68\right|\le\chi,\\ \left|\frac{w_1}{w_3}-1.56\right|\le\chi,\\ \sum_{j=1}^{5}w_j=1,\ w_j\ge0,\forall j\end{cases}$$

By solving the presented linear programming models, the final values of the weight coefficients of each expert are defined, Table 2. By evaluating the obtained values, the optimal values of the weight coefficients of the criteria were further determined to be used for the evaluation of the routes using TOPSIS and MABAC methods.

Table 2. Calculation of weight coefficients of the criteria

Experts	Weight coefficient of criteria				
	C1	*C2*	*C3*	*C4*	*C5*
E1	0.1017	0.5698	0.0339	0.2849	0.0097
E2	0.0382	0.2932	0.3811	0.1150	0.1724
E3	0.2275	0.1422	0.0981	0.3048	0.2275
E4	0.1171	0.1897	0.1094	0.2561	0.3278
E5	0.0843	0.2023	0.1349	0.2630	0.3156
E6	0.1800	0.1500	0.1154	0.2521	0.3025
Average value	0.1248	0.2579	0.1455	0.2460	0.2259

4.2. Application of the TOPSIS model

The TOPSIS method algorithm is applied to initial decision matrix D:

$$D = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 3 & 0,65 & 8 & 8 & 232 \\ 2 & 0,50 & 7 & 6 & 233 \\ 1 & 0,45 & 5 & 5 & 250 \\ 1 & 0,20 & 2 & 4 & 280 \end{bmatrix}$$

*Step 1. N*ormalized matrix (X) is obtained by normalizing the elements of initial decision matrix (D), expression (4)

$$X = \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,2254 & 0,3205 & 0,3287 & 0,3263 & 0,5351 \\ 0,4836 & 0,4773 & 0,4126 & 0,4947 & 0,5331 \\ 0,7418 & 0,5296 & 0,5804 & 0,5789 & 0,499 \\ 0,7418 & 0,8322 & 0,8322 & 0,6631 & 0,4389 \end{bmatrix}$$

Step 2. By multiplying the normalized matrix and weight coefficients of the criteria, expression (7), a heavier normalized matrix is constructed (8)

$$T = \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,0281 & 0,0827 & 0,0478 & 0,0803 & 0,1209 \\ 0,0604 & 0,1231 & 0,06 & 0,1217 & 0,1204 \\ 0,0926 & 0,1366 & 0,0844 & 0,1424 & 0,1127 \\ 0,0926 & 0,204 & 0,1211 & 0,1631 & 0,0991 \end{bmatrix}$$

Step 3. Using expressions (9) and (10) ideal and negative-ideal solutions are calculated:

Ideal solution: A* = { 0.0926, 0.204, 0.1211,0.1631, 0.12} and

Negative ideal solution: A^{-}= {0.0281, 0.0827, 0.0478, 0.0803, 0.0991}.

Step 4: Using expressions (11) and (12) Euclidean distance alternatives are calculated from ideal and negative-ideal solutions, Table 3.

Table 3. Distance from ideal and negative-ideal solutions

Alternative	*Si**	*Si⁻*
A1	0.0218	0.1764
A2	0.0707	0.1141
A3	0.1116	0.0799
A4	0.1764	0.0218

Steps 5 and 6. Using expression (13) the relative proximity of the alternatives to the ideal solution is calculated and we get the final rank of the alternative: A4> A3> A2> A1.

4.3. Application of the MABAC model

The MABAC method algorithm applies to the same initial decision matrix D, as well as the TOPSIS model.

Step1: Since all functions of the *min* type are used to normalize the initial matrix of decision making, we use expression (12). By applying this relation we receive a normalized matrix N:

$$N = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0 & 0 & 0 & 0 & 0 \\ 0,5 & 0,33 & 0,1667 & 0,5 & 0,9792 \\ 1 & 0,44 & 0,5 & 0,75 & 0,625 \\ 1 & 0,95 & 1 & 1 & 1 \end{bmatrix}$$

Step 2: In step 2, applying expression (13), elements of a heavy normalized matrix are calculated:

$$V = \begin{array}{c} route \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ 0,1248 & 0,2579 & 0,1455 & 0,246 & 0,2259 \\ 0,1872 & 0,343 & 0,1698 & 0,369 & 0,4471 \\ 0,2496 & 0,3714 & 0,2183 & 0,4305 & 0,3671 \\ 0,2496 & 0,5029 & 0,291 & 0,492 & 0,4518 \end{bmatrix}$$

Step 3: In step 3, boundary approximate domain matrix (G) is calculated. Boundary approximation area (GAO) for each criterion is determined according to (18).

$$G = \begin{bmatrix} C1 & C2 & C3 & C4 & C5 \\ 0,1954 & 0,3585 & 0,199 & 0,3724 & 0,2597 \end{bmatrix}$$

Step 4: Using expression (21) we calculate the elements of a matrix (20), which represents the distance of an alternative to GAO.

$$Q = \begin{bmatrix} \min f_1 & \min f_2 & \min f_3 & \min f_4 & \min f_5 \\ -0,0706 & -0,1006 & -0,0535 & -0,1264 & -0,1338 \\ -0,0082 & -0,0155 & -0,0292 & -0,0034 & +0,0874 \\ +0,0542 & +0,0129 & +0,0193 & +0,0581 & +0,0074 \\ +,0542 & +0,1444 & +0,092 & +0,1196 & +0,0921 \end{bmatrix}$$

Step 5: Calculation of the value of the criterion functions for each alternative is obtained as the sum of the distance of the alternatives from the boundary approximate fields. By summarizing the elements of the Q matrix in rows, we obtain the final values of the criterion functions of the alternative and the final ranking alternative that reads: A4> A3> A2> A1. In Table 4 a comparative analysis of the route ranges for THM obtained using TOPSIS and MABAC methods is given.

Table 4. Route ranges using TOPSIS and MABAC methods

Route	Rank	
	TOPSIS	MABAC
A1	4	4
A2	3	3
A3	2	2
A4	1	1

4.4. Sensitivity analysis of the solution

Since the results of multi-criteria decision-making depend on the value of the weight coefficient of the evaluation criteria, in the following section the analysis of the sensitivity of the results to the change in the weight of the criteria is presented. Sometimes the ranking alternatives vary with very small changes in weight coefficients. Therefore, the results of these multi-criteria decision-making methods follow the sensitivity analysis on these changes as a rule. The analysis of the sensitivity of the ranks of alternatives to changes in the weight coefficients of the criteria was carried out through ten scenarios given in Table 5.

Table 5. Scenarios of sensitivity analysis

Scenario	Weight criteria	Scenario	Weight criteria
S1	w_{c1}=1.25× $w_{c11(old)}$; w_{ci}=0.25× $w_{ci(old)}$	*S6*	w_{c1}=1.55× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$
S2	w_{c2}=1.25× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$	*S7*	w_{c2}=1.55× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$
S3	w_{c3}=1.25× $w_{c11(old)}$; w_{ci}=0.25× $w_{ci(old)}$	*S8*	w_{c3}=1.55× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$
S4	w_{c4}=1.25× $w_{c11(old)}$; w_{ci}=0.25× $w_{ci(old)}$	*S9*	w_{c4}=1.55× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$
S5	w_{c5}=1.25× $w_{c11(old)}$; w_{ci}=0.25× $w_{ci(old)}$	*S10*	w_{c5}=1.55× $w_{c11(old)}$; w_{ci}=0.55× $w_{ci(old)}$

The scenarios of the sensitivity analysis are grouped into two phases. Within each phase of the sensitivity analysis, the weight coefficients of the criteria were increased by 25% and 55%, respectively. In each of the ten scenarios, only one criterion is favored for which the weight coefficient is increased for the stated values. In the same scenario, with the remaining criteria, weight coefficients were reduced by 25% (S1-S5) and 55% (S6-S10). Changes in the ranking alternatives during the 10 scenarios in TOPSIS and MABAC methods are presented in Figure1.

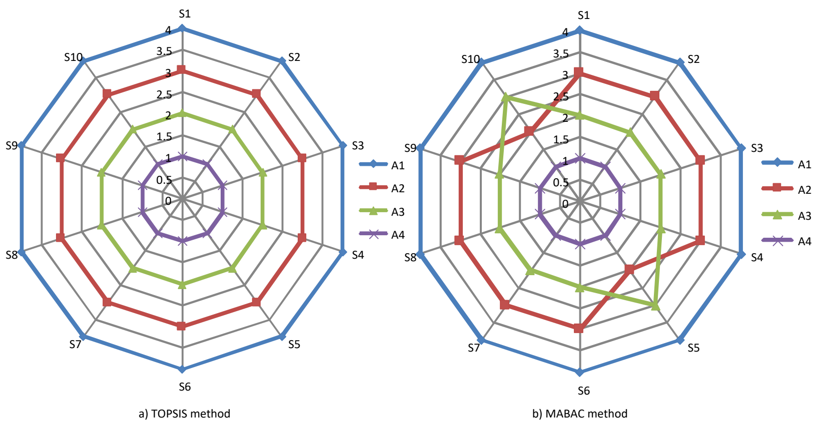

Figure 1. Changes in the ranking alternatives in 10 scenarios

The results show that assigning different weight to the criteria through the 10 scenarios shown does not lead to a significant change in the ranking of the alternative. By comparing the first-ranked alternatives (A4 and A3) in scenarios 1-10 with initial rankings from TOPSIS and MABAC models, we note that the rank of first-ranked alternatives is confirmed. By analyzing the rankings through 10 scenarios, we also notice that the A4 alternative in all 10 scenarios has kept its ranking. Based on this, we can conclude that there is a satisfactory closeness of ranks and that the proposed ranking is confirmed and credible.

5. Conclusions

The new FUCOM-TOPSIS-MABAC model for route evaluation for THM is presented here. Verification of the FUCOM-TOPSIS-MABAC model was carried out on a real case from the practice in which the transport of Eurodiesel was considered for the needs of the Ministry of Defense of the Republic of Serbia. One of the contributions of this paper is the new FUCOM-TOPSIS-MABAC model that provides for an objective aggregation of expert decisions. The second contribution of this paper is the development of the linear programming model for determining the weight coefficients of the evaluation criteria, which contributes to the improvement of the literature that considers the theoretical and practical application of multi-criteria techniques. The third contribution of this study is to improve the methodology of route evaluation for THM through a new approach to determining the weight coefficient of the criteria.

Using the hybrid FUCOM-TOPSIS-MABAC model, it is possible to solve the problems of multi-criteria decision-making in a simple way and make decisions that have a significant impact on increasing safety and reducing risk in THM. The analysis of the results shows that the ranks of the alternatives using the LP-TOPSIS model are in complete correlation with the obtained ranks of the LP-MABAC model. In selecting the most suitable route for THM, both methods (FUCOM-TOPSIS and FUCOM-MABAC) from the aspect of stability of the obtained results prove to be reliable. This was confirmed by analyzing the sensitivity of multi-criteria techniques, which was done through ten scenarios.

Further research related to this paper relates to the post analysis of the internal transport in the observed company in order to verify the minimization of risks arising from the proposed method of organization of THM. When it comes to the field of multi-criteria decision-making, further research directions relate to the application of uncertain theories in combination with other methods and the attempt to develop new hybrid models that would further enrich this widely applied field.

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DETERMINING THE IMPORTANCE OF THE CRITERIA OF TRAFFIC ACCESSIBILITY USING FUZZY AHP AND ROUGH AHP METHOD

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Abstract: *A large number of authors base research on a small number of traffic access criteria using one of the decision-making methods. The methods on which research can be based are multi-criteria decision-making in combination with fuzzy logic and rough numbers that give relevant results and are widely applied in all fields of science today. When using these methods, it is necessary to emphasize that there is a certain degree of subjectivity of the decision maker, but this can be minimized using fuzzy or rough numbers. This research refers to traffic accessibility of suburban areas, where the system of urban public transport is operational. The aim of this paper is to compare the significance of particular criteria using the Fuzzy AHP method and the Rough AHP method, which would show differences in the values of weight significance criteria and their ranking. The research has shown that the factors such as a network of public transport (PT) lines, the network of accessible roads in a settlement, Built infrastructure, travel time and the timetable have the greatest importance in description of traffic accessibility.*

Key words: *Traffic Accessibility; Multi-crteria decision making; Rough Numbers; Fuzzy AHP; Rough AHP Method.*

1. Introduction

Traffic accessibility as a function of public transport strengthens the economy, deals with the conservation of energy and resources, reduces congestion, improves the quality of air and our health, provides critical assistance in emergency situations and catastrophes, increases the development and value of real estate, increases mobility in small urban and rural communities, and reduces health costs. All of this contributes to a better quality of life.

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This paper gives a qualitative approach, not an analytical one. Experts are consulted to measure different criteria. The approach is in essence based upon opinion and not mathematical or scientific accuracy. Therefore, the starting point in this paper is the fact that it is possible, based on the experience so far, to gain an insight in the potentials of a new approach to observing traffic accessibility, especially in suburban areas where the system of urban public transport is operative.

Relevant criteria for traffic accessibility were described and measured (taking into account social equality). These criteria influence the reduction of the usage of passenger vehicles in suburban areas and create a more favorable environment for urban public transport in view of improving efficiency of the transport system and its sustainable development. As instruments of transport policy, measures that can be taken to manage the transportation needs of users (passengers) do not ask for great material investment, making them even more attractive.

The selection criteria for traffic accessibility that have an impact on the development of suburbs is a complicated process. It requires a detailed and permanent analysis of all relevant factors, which can have a smaller or greater impact. In order to identify the right criteria and sub-criteria that affect traffic accessibility, it is necessary to possess real knowledge of transportation systems, city infrastructure, demographic conditions, geographical surroundings, and fields related to decision-making and management. The choice of the criteria of traffic accessibility affecting different suburban communities is a complex process. Problems of finding an optimal solution, that is, tasks of optimization, are found and solved in every day life. They are found almost everywhere, in technical and economic systems, in the family, companies, sports clubs etc. (Vujošević, 2012). The decision-making process and the choice of "best" alternatives are usually based on more than one criterion and a set of constraints.

The decision maker should ultimately adopt a solution. The decision taken by the decision maker is called the best or preferred solution. The task of multi-criteria optimization is to help the decision-maker choose the solution he considers to be the best in the given conditions. Therefore, efforts to solve the set multi-criteria problem are often called multi-criteria analysis. When making a decision, the choice of some of the alternatives is assessed to solve a particular problem. In the decision-making issue there are goals that are to be achieved by decision, the criteria that measure the achievement of these goals, the weight of those criteria that reflect their importance and alternative solutions to the problem (Hot, 2014).

At the beginning of the paper, a general introduction with an overview of existing research and literature dealing with similar issues was given. In the second section, the concept of accessibility is explained and traffic accessibility criteria relevant for further research are presented. The third section describes the methodology that has been applied and the methods used to compare the significance of the criterion. The fourth section presents the results of the research, followed by a discussion of the results obtained and a conclusion.

2. Literature review

The international project MORECO (mobility and residence costs) explains the conjuncture between future places of living and accessibility. Special emphasis is put on the consequences that the uncontrollable spread of settlements causes to public transport services. The main goal of the project was to promote sustainable mobility through the development of a polycentric system of settlements. The main operative goal of the project was to promote the implementation of decisions made by private and public actors on locations that are close to public transport stops (Gulič, 2015). Litman (2017) wrote about the concept of accessibility and the ways it can be incorporated into transport planning. Many factors can have an impact on accessibility, including movability (physical motion), quality of transport, networking of traffic systems, mobility, and land use.

The main aim of paper (Stanković et al., 2018) is the definition and quantification of criteria that have the greatest impact on the traffic accessibility of suburban settlements, and development of a model for assessing traffic accessibility. This model refers to the traffic accessibility of suburban settlements in which the public transport system functions and represents a qualitative approach to research. One of the most popular methods of multi-criteria decision making, FAHP was used. Daily use of multi-criteria decision-making methods (Mardani et al., 2015; Gul et al., 2016) certainly contributed to the growing popularity of this area. In the paper (Akkaya et al., 2015) an integrated fuzzy AHP and fuzzy MOORA model is proposed for solving problems in the field of industrial engineering. Chen and Yang (2011) used limited Fuzzy AHP and Fuzzy TOPSIS for selection suppliers. There are a considerable number of publications dealing specifically with the comparison of classical AHP and fuzzy AHP (Stević, 2018). AHP is often used in combination with other methods where authors use AHP to estimate the weight of the criteria (Stević et al., 2015).

In addition to the fuzzy theory, a very suitable tool for treating uncertainty without the influence of subjectivism is the theory of rough sets, first presented (Pawlak, 1982). Unlike fuzzy theory and probability theory in which the degree of indeterminacy is defined on the basis of the assumption, in the theory of rough sets, indeterminacy is determined by the approximation which is the basic concept of the theory of rough sets. The theory of rough sets uses only internal knowledge, that is, operational data, and there is no need to rely on modeling assumptions. In rough sets, measurement of uncertainty is based on the uncertainty already contained in the data (Khoo & Zhai, 2011). This leads to objective indicators that are contained in the data. In addition, the theory of rough sets is suitable for applications that are characterized by a small number of data, and for which statistical methods are not suitable (Pawlak, 1991, 1993; Stević, 2018).

3. Methodology

In selecting the best assessment or decision-making method for criteria selection, research and the scientific literature in this field show that the problem could be solved by applying the multi-criteria decision-making method. The analytic hierarchy process (AHP) is a multi-criteria method that supports decision making with conflict criteria and alternatives. It has been thoroughly studied and improved through various scientific papers at prestigious universities worldwide (Roy et al., 2018; Badi et al., 2018; Lukovac et al., 2018). The AHP method has great significance for problem structuring and the decision-making process. Comparison was later carried out by pairs of elements in the hierarchy (aims, criteria and alternatives). These assessments can be made as comparisons between two elements at a set level of the hierarchy, taking into account their influence at a higher level. The comparison of the elements in pairs reveals the relevance of a specific element in comparison to another to meet the level of the aims and the criteria (Saaty et al. 1991).

3.1. Fuzzy AHP method

Let X = {x_1, x_2, . . . , x_n} be a set of objects, and U = {u_1, u_2, . . . , u_m} set of goals. According to the methodology of the expanded analysis by Chang (1996), for each taken object, an expanded analysis of the goal uj was carried out. The values of the extended analysis m for each object can be presented as follows (Chang, 1996):

$$M_{gi}^{1}, M_{gi}^{2}, M_{gi}^{m}, i = 1, 2, \dots, n., \tag{1}$$

where is $M_{g}^{j}, j = 1, 2, \dots, m.$, fuzzy triangular numbers.

Chang's extended analysis contains the following steps:

Step 1: Values of fuzzy extensions for *i-th* object are:

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}, \tag{2}$$

In order to get the expression $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$, it is necessary to carry out additional fuzzy operations with m values of extended analysis, given in the following expressions:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right); \tag{3}$$

and

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right). \tag{4}$$

Inverse vector:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right]. \tag{5}$$

Step 2: Level of probability $S_2 > S_1$ is defined as:

$$V(S_2 \geq S_1) = \begin{Bmatrix} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & other \end{Bmatrix} \tag{6}$$

For comparison of S_1 and S_2, both values are required $V(S_1 \geq S_2)$ и $V(S_2 \geq S_1)$.

Step 3: Level of probability which states that convex fuzzy number is greater than *k* convex number S_i *(i=1, 2,..., k)* can be defined by the expression:

$$V(S_i \geq S_1, S_2, \dots, S_k) = minV(S_i \geq S_k), \quad i = 1, 2, \dots k \tag{7}$$

Weight vector is given by the following expression:

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^{T}, \tag{8}$$

where is:

$$d'(A_i) = \min V(S_i \geq S_k), \ \ k \neq i, \ \ k = 1, 2, \dots, n; \tag{9}$$

and A_i (i = 1, 2, ..., n) n of the element.

Step 4: Through normalization, weight vector is:

$$W = \left(d(A_1), d(A_2), \dots, d(A_n)\right)^{T}, \tag{10}$$

where W does not represent a fuzzy number.

Through the application of the fuzzy AHP method, the main disadvantage of the classical AHP method is alleviated, and this is indicated by an insufficiently large scale of comparisons. To this end, different scale have been developed based on fuzzy triangular numbers, where the decision-maker has the ability to evaluate the significance of the criteria much more closely and more easily. Within Table 2, linguistic variables are converted into triangular fuzzy numbers:

Table 2. Linguistic scale of significance (Srichetta & Thurachon, 2012)

Linguistic Scale	TFNs	Reciprocal TFNs
Equally important	(1, 1, 1)	(1,1,1)
Weakly more important	(1/2, 1, 3/2)	(2/3, 1, 2)
Strong more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strong more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Absolutely more important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

3.2. Rough AHP method

The rough AHP consists of the following steps (Zhai et al., 2009; Stević, 2018):

Step 1: Identification of the target of the research, followed by identification of the criteria and potential solutions. In this step, it is necessary to form a hierarchical structure, as is the case with the classic AHP.

Step 2: Formation of a group matrix of pairs in pairs from e_{th} experts, expressed as:

$$B_e = \begin{bmatrix} 1 & x_{12}^e & \cdots & x_{1m}^e \\ x_{21}^e & 1 & \cdots & x_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^e & x_{m2}^e & \cdots & 1 \end{bmatrix} \tag{11}$$

where is x_{gh}^e $(1 \le g \le m, 1 \le h \le m, 1 \le e \le s)$ the relative importance of the criteria g on the criterion h expressed by the expert e, m represents the number of criteria, while with the number of decision makers (DM) or experts.

Calculate the maximum of its own vector λ_{max}^e from B_e, then calculate the consistency index CI = (λ_{max}^e - n) / (n - 1).

Get out of the table (RI) depending on n and calculate the degree of consistency CR=CI/RI.

Subsequently, the group matrix of comparison $\tilde{B}$ is expressed as:

$$\tilde{B} = \begin{bmatrix} 1 & \tilde{x}_{12}^e & \cdots & \tilde{x}_{1m}^e \\ \tilde{x}_{21}^e & 1 & \cdots & \tilde{x}_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^e & \tilde{x}_{m2}^e & \cdots & 1 \end{bmatrix} \tag{12}$$

where is $\tilde{x}_{gh}$ $\{x_{gh}^1, x_{gh}^2, \dots, x_{gh}^s\}$, $\tilde{x}_{gh}$ the sequence of the relative importance of the criteria g on the criterion h.

Step 3: *In this step, a rough matrix of comparisons needs to be formed.*

All elements x_{gh}^e in $\tilde{B}$ must be translated into a rough number $RN(x_{gh}^e)$:

$$RN\ (x_{gh}^e) = [x_{gh}^{eL}, x_{gh}^{eU}] \tag{13}$$

where is x_{gh}^{eL} lower limit of rough numbers $RN\ (x_{gh}^e)$, while x_{gh}^{eU} the upper limit of the rough number.

Then a rough sequence $RN\ (\tilde{x}_{gh}^e)$ is presented as:

$$RN\ (\tilde{x}_{gh}) = \{[x_{gh}^{1L}, x_{gh}^{1U}], [x_{gh}^{2L}, x_{gh}^{2U}], \dots, [x_{gh}^{sL}, x_{gh}^{sU}]\} \tag{14}$$

After that, conversion to an average rough number is carried out $RN\ (x_{gh})$:

$$RN(x_{gh}^e) = [x_{gh}^{eL}, x_{gh}^{eU}] \tag{15}$$

$$x_{gh}^{L} = \frac{x_{gh}^{1L} + x_{gh}^{2L} + \cdots + x_{gh}^{sL}}{s} \quad (16)$$

$$x_{gh}^{U} = \frac{x_{gh}^{1U} + x_{gh}^{2U} + \cdots + x_{gh}^{sU}}{s} \quad (17)$$

where is x_{gh}^{L} lower limit of rough numbers $RN\ (x_{gh})$ and x_{gh}^{U} the upper limit of the rough number.

Then, the rough matrix of the comparison of M is expressed as:

$$M = \begin{bmatrix} [1,1] & [x_{12}^{L}, & x_{12}^{U}] & \cdots & [x_{1m}^{L}, x_{1m}^{U}] \\ [x_{21}^{L}, x_{21}^{U}] & & [1,1] & \cdots & [x_{2m}^{L}, x_{2m}^{U}] \\ \vdots & & \vdots & \ddots & \vdots \\ [x_{m1}^{L}, x_{m1}^{U}] & & [x_{m2}^{L}, x_{m2}^{U}] & \cdots & [1,1] \end{bmatrix} \quad (18)$$

Step 4: Calculating the rough weight w_g for each criterion using the following two equations:

$$w_g = \left[\sqrt[m]{\prod_{h=1}^{m} x_{gh}^{L}}, \quad \sqrt[m]{\prod_{h=1}^{m} x_{gh}^{U}} \right] \quad (19)$$

$$w'_g = W_g / \max(w_g^{U}) \quad (20)$$

where is w'_g normalized weight of the criterions.

3.3. Set of Criteria of Traffic Accessibility

Accessibility as a term should be regarded as the extent to which potential passengers, who have certain transportation needs, have access to the city area.

The SEU (2003) report determines that accessibility depends upon:

- Existence of transport services connecting people and content;
- Informing people about transport services;
- Physical and financial limitations of access to transportation services
- Remoteness of content and activities

Accessibility can be:

- Spatial—referring to the spatial arrangement of contents in relation to users who set the requirements for their use;
- Temporal—referring to the time when a certain service is offered during the day, week or a longer period of time in relation to the available time of users for this service.

The first phase involves the identification and classification of criteria. In this phase, it is recommendable to use information on the functioning of the analyzed systems. It was also necessary to classify criteria according to their type, sub-system they belong to, and the level of decision-making.

A certain number of set elements of the preliminary criteria were identified on the basis of physical, functional and other characteristics of the system, which was the subject of the study. The second part of the preliminary criteria was defined on the basis of scientific and practical research and the analysis of literature on the subject. The third part of the set of preliminary criteria was identified on the basis of earlier experience with similar projects worldwide. Combining these three approaches, the number of set elements of the preliminary criteria for the assessment of the impact of traffic accessibility was obtained. Respecting experience and recommendations mentioned above, it is suggested that the assessment of traffic accessibility is made based on 13 factors (sub-criteria) grouped in 4 groups of criteria (Table 1).

Table 1. Impact criteria of traffic accessibility on suburb development

Criteria	Sub-criteria
Transport	Network of PT lines Remoteness of the railway Characteristics of the settlement Possesion of a car in the household
Space	Built infrastructure Network of access roads Remoteness from the most significant contents
Quality of service	Comfort in a vehicle Travel time Transfer points
System quality	Timetable Transport costs Tariff system

The surveys method, as one of the most commonly used methods for data collection in surveys (whose optimal size is 5 ± 2 members), gathered data, information, attitudes and opinions about the relevance of the given criteria in the preliminary meeting. The questionnaire consists of two basic elements: an introduction to the survey and questionnaire (questions). Given that this is an evaluation of predetermined criteria where respondents should only give preference to the importance, respondents were personally given a closed questionnaire type, that is, the one with the offered responses in the form of intensity of importance (optimal 5 intensities). The second part of the questionnaire consisted of a question of a closed type, by which the participants in the survey evaluated the importance of the criteria by rounding out one of the grades of 1-5 (1-smallest importance, 5-major importance).

Decision makers at this level are relevant experts who have knowledge and experience and who are directly related to the topic that is being processed. All interviewees have a master's degree.

4. Results

When defining the set of criteria and sub-criteria for assessment of the impact of traffic accessibility on development of suburbs, an expert team from economy made up of 5 professionals in the field of Transport systems and Public transport of passengers was consulted in the city of Niš. The number of experts who took part in this research is limited due to the impossibility to involve a greater number of experts who live and work on the territory of the city of Nis. It was required that all experts from the area of research they are relevant in, be from the territory of the urban unit. The matrices of the comparison of the value of the estimation by the experts for the Fuzzy AHP analysis are given in Table 3.

Table 3. Compatibility matrix for a group of transport criteria

		A_1	A_2	A_3	A_4
A_1	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(1,1,1)	(3/2,2,5/2)	(3/2,2, 5/2)	(1/2,1,3/2)
	E_4	(1,1,1)	(3/2,2,5/2)	(1/2,1, 3/2)	(3/2,2,5/2)
	E_5	(1,1,1)	(3/2,2,5/2)	(3/2,2, 5/2)	(1,1,1)
A_2	E_1	(2/7,1/3, 2/5)	(1,1,1)	(2/7,1/3, 2/5)	(2/7,1/3, 2/5)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(2/5,1/2, 2/3)	(1,1,1)	(1,1,1)	(2/3, 1, 2)
	E_4	(2/5, 1/2, 2/3)	(1,1,1)	(2/3,1,2)	(1,1,1)
	E_5	(2/5,1/2, 2/3)	(1,1,1)	(2/5,1/2, 2/3)	(2/9,1/4, 2/7)
A_3	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(2/5,1/2, 2/3)	(1,1,1)	(1,1,1)	(2/3, 1, 2)
	E_4	(2/3,1,2)	(1/2,1,3/2)	(1,1,1)	(1/2,1,3/2)
	E_5	(2/5, 1/2, 2/3)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2, 2/3)
A_4	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(2/5,1/2, 2/3)	(2/5,1/2, 2/3)	(2/5,1/2, 2/3)	(1,1,1)
	E_3	(2/3,1,2)	(1/2,1,3/2)	(1/2,1, 3/2)	(1,1,1)
	E_4	(2/5,1/2, 2/3)	(1,1,1)	(2/3,1,2)	(1,1,1)
	E_5	(1,1,1)	(7/2,4,9/2)	(3/2,2, 5/2)	(1,1,1)

The relative fuzzy weights of each sub-criterion for the Transport group of criteria are shown in Table 4:

Table 4. Average and normalized weight criteria for the transport group of criteria

Sub-criteria	W'	W	Rank
Network of PT lines - A1	1	0.435	1
Remoteness of the railway - A2	0.070	0.031	4
Characteristics of the settlement - A3	0.610	0.265	3
Possesion of a car in the household - A4	0.619	0.269	2

Similarly, a comparative analysis of the obtained results was performed and they are presented in Table 5 and graphical way.

Table 5. Relative rank of significance of particular criteria based on comparison with Fuzzy AHP method

Criteria	Sub-criteria	W'	W
Transport	***Network of PT lines***	***1***	***0.435***
	Remoteness of the railway	0.070	0.031
	Characteristics of the settlement	0.610	0.265
	Possesion of a car in the household	0.619	0.269
Space	Built infrastructure	0.961	0.333
	Network of access roads	***1***	***0.347***
	Remoteness from the most significant contents	0.920	0.319
Quality of service	Comfort in a vehicle	0.502	0.206
	Travel time	***1***	***0.411***
	Transfer points	0.931	0.383
System quality	***Timetable***	***1***	***0.378***
	Transport costs	0.934	0.354
	Tariff system	0.708	0.268

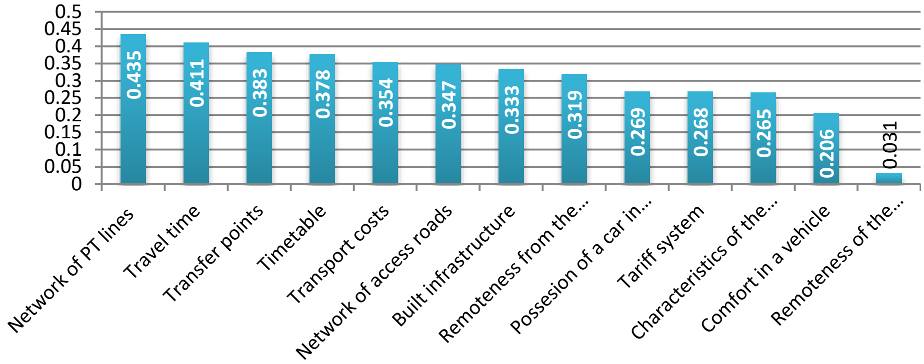


Figure 1. Relative weight of sub-criterion for all groups of criteria

If in general the relative weight of the sub-criterion were observed, the highest values are found in the sub-criteria of Network of PT lines, Travel time, Transfer points and Timetable. The smallest weights have the sub-criteria such as Comfort in a vehicle and Remoteness of the railway.

In the second case, using the Rough AHP method, after a comparison, a group matrix of comparisons in pairs was formed. A group matrix for the transport group of criteria looks like this:

$$\tilde{E}\begin{bmatrix} 1,1,1 & 2,4,1 & 4,4,3 & 2,5,4 \\ \frac{1}{2},\frac{1}{4},1 & 1,1,1 & 3,1,3 & 1,2,4 \\ \frac{1}{4},\frac{1}{4},\frac{1}{3} & \frac{1}{3},1,\frac{1}{3} & 1,1,1 & \frac{1}{3},2,2 \\ \frac{1}{2},\frac{1}{5},\frac{1}{4} & 1,\frac{1}{2},\frac{1}{4} & 3,\frac{1}{2},\frac{1}{2} & 1,1,1 \end{bmatrix}$$

Based on the group matrix, the rough weight of the sub criterion for the transport group of criteria is obtained:

$$w = \{[1.99, 2.67];\ [1.04, 1.61];\ [0.57, 0.80];\ [0.53, 0.89]\}$$
$$w' = \{[0.75, 1.00];\ [0.39, 0.60];\ [0.21, 0.30];\ [0.20, 0.33]\}$$

The values of the rough weight of all sub-criteria are given in Figure 2:

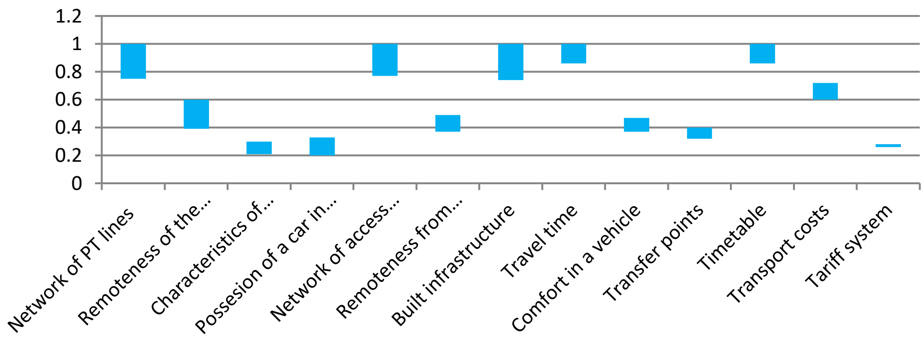


Figure 2. Rough weight of the sub-criteria using the rough AHP method

The greatest rough weights, in general, have the sub-criteria such as Built infrastructure, Network of PT lines and Network of access roads. Unlike the arrangement using the Fuzzy AHP method, the sub-criterion Remoteness of the railway using the rough AHP method is highly ranked and has a significant relative weight. The minimum value of relative weight is provided by the Tariff system and Transfer points.

4.1. Comparison Analysis of Results

After obtaining the results using the Fuzzy AHP method and the Rough AHP method, a comparison of the significance of the criteria can be made, and the results are presented graphically.

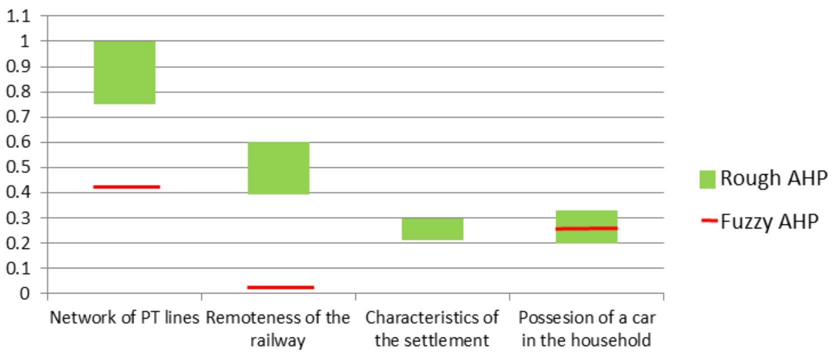


Figure 3. Sub-criteria values for the Transport group of criteria obtained using the Fuzzy AHP and Rough AHP methods

Figure 3 shows the comparative values of the weight of the sub-criterion for the Transport Criteria Group using the Fuzzy AHP and Rough AHP methods. Although there is a difference in the value between these two methods, the significance of the sub-criteria Network of PT lines is dominant in relation to others. Also, using Rough AHP method, the sub-criterion Remoteness of the railway showed greater significance than in the case when the analysis was performed using the Fuzzy AHP method.

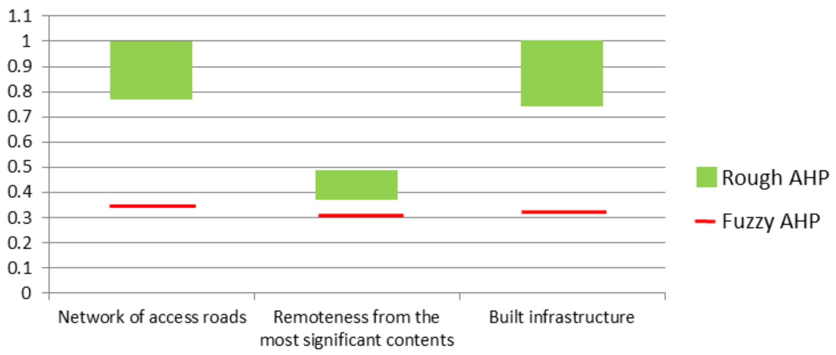


Figure 4. Sub-criteria values for a Spatial group of criteria obtained using the Fuzzy AHP and Rough AHP methods

Similarly, in Figure 4, the values of the sub-criterion for the Spatial Criteria group are shown using the methods indicated.

Subcriteria values using the Fuzzy AHP method are approximately similar, as can be seen in Figure 4. On the other hand, the Rough AHP method shows that the significance of the sub-criterion of Network of access roads and the Built infrastructure are approximately equal, but that the Built Infrastructure has a dominant significance.

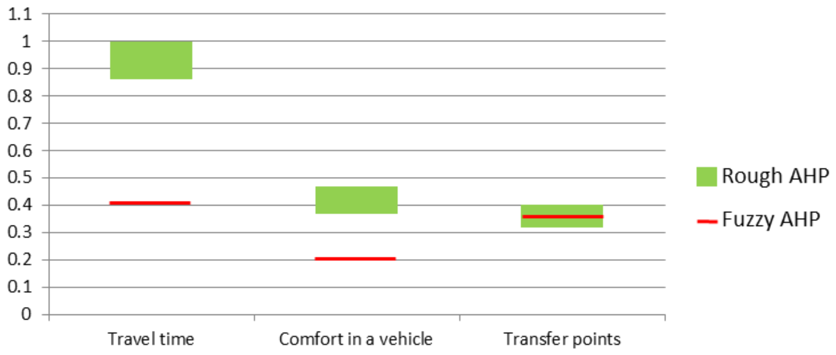


Figure 5. Sub-criteria values for the Quality of services criteria group obtained using Fuzzy AHP and Rough AHP methods

Figure 5 shows the values of the sub-criterion of the Quality of service group where we can see similar weights of the criteria of the Travel time and Comfort in a vehicle. Only the last sub-criterion (Transfer points) of the Fuzzy AHP method is more important than the Rough AHP method.

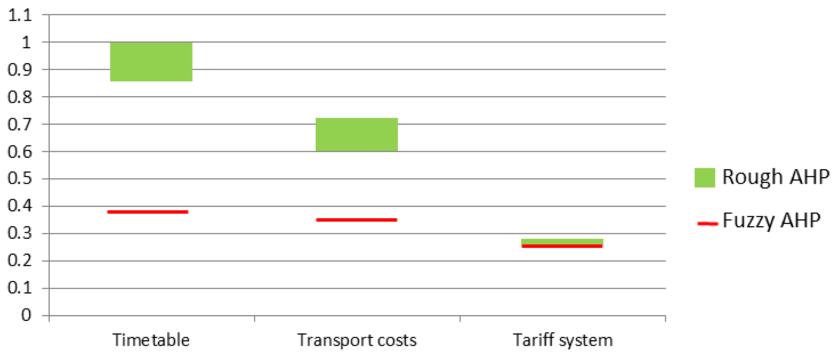


Figure 6. Sub-criteria values for the Quality of system criteria group obtained using Fuzzy AHP and Rough AHP methods

Using both methods, in Figure 6, it can be seen that the values of the weight of the significance of the sub-criterion of the Quality of system group are similarly distributed.

Comparative weighting criteria for both methods of multi-criteria decision making are given in Table 6:

Table 6. Weight values of all sub-criteria using Fuzzy AHP and Rough AHP methods

Criteria	Fuzzy AHP	Rank	Rough AHP	Rank
Network of PT lines	0.435	*1*	(0.75; 1.0)	*2*
Remoteness of the railway	0.031	*13*	(0.39; 0.60)	*4*
Characteristics of the settlement	0.265	*11*	(0.21; 0.30)	*11*
Possesion of a car in the household	0.269	*9*	(0.20; 0.33)	*7*
Network access roads	0.347	*6*	(0.77; 1.0)	*3*
Remoteness from the most significant contents	0.319	*8*	(0.37; 0.49)	*8*
Built infrastructure	0.333	*7*	(0.74; 1.0)	*1*
Travel time	0.411	*2*	(0.86; 1.0)	*5*
Comfort in a vehicle	0.206	*12*	(0.37; 0.47)	*10*
Transfer points	0.383	*3*	(0.32; 0.40)	*12*
Timetable	0.378	*4*	(0.86; 1.0)	*6*
Transport costs	0.354	*5*	(0.60; 0.72)	*9*
Tariff system	0.268	*10*	(0.26; 0.28)	*13*

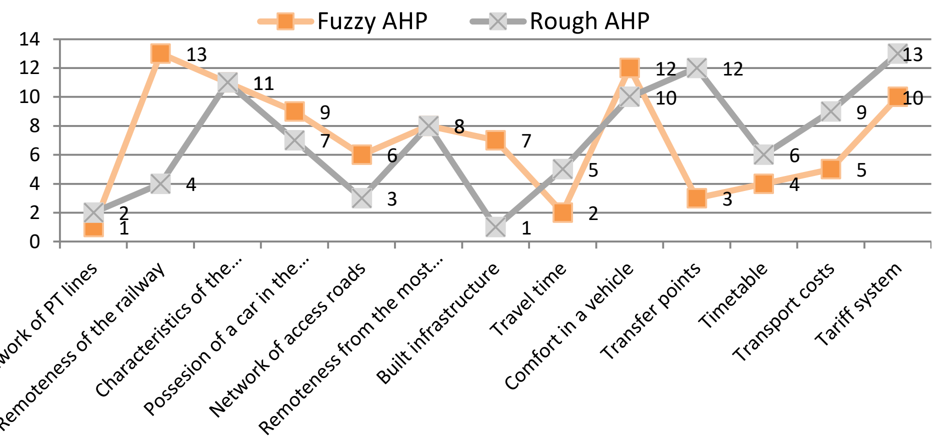


Figure 7. Ranking the sub-criterion using the Fuzzy AHP and the Rough AHP methods

Generally, according to the Fuzzy AHP method, Network of PT lines is in the first place, while the second place is occupied by Travel time (Figure 7). By using the Rough AHP method, the criterion of Built infrastructure was ranked first, followed by Network of PT lines. The sub-criterion Remoteness of the railway is at the last place based on the Fuzzy AHP method, while according to Rough AHP method, it is on the high fourth position. According to the same method, the Tariff system is last ranked.

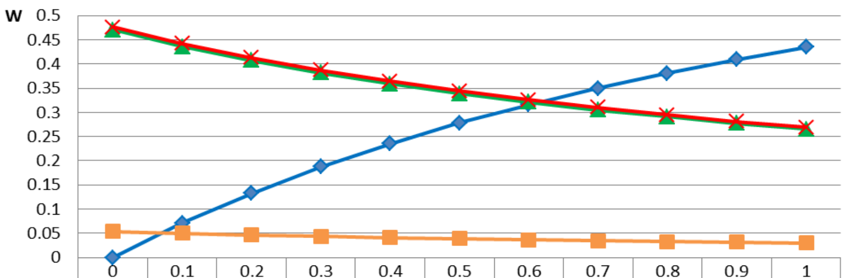
4.2. Analysis of the sensitivity of the criterion values

When choosing the relevant criteria, one of the important characteristics of the applied methods is the analysis of the sensitivity of the final solution, which allows the decision maker to examine different variants. The sensitivity analysis shows the relations of priority change as a function of the significance of the attributes (Batinić, 2013). Several methods are used to analyze the sensitivity of the solution:

- dynamic sensitivity analysis;
- gradient sensitivity analysis;
- performance sensitivity analysis;
- „head of the head“ analysis (one to one);
- two-dimensional analysis.

Dynamic sensitivity analysis shows that the change in the priorities of one criterion influences the change in the priorities of other criteria and the priorities of the alternatives within the observed criterion. The importance of implementing a dynamic sensitivity analysis is also the ability to determine the individual participation of the criteria in the priorities of the alternative. Changing the priorities of one criterion to change the priority of the criteria and alternatives, or finally the final ranking of alternatives as results can be more clearly followed in the gradient analysis graph. Performance sensitivity analysis summarizes the presentation of the criteria and alternatives for all criteria individually and collectively at the global level and at the criteria levels. The significance of the performance sensitivity analysis is that it is possible to determine the final solution, that is, the result - ranking for any node on the tree of the criteria within the associated level. An analysis of the sensitivity of the "head of the head" determines for which percentage the significance of the considered criterion in relation to the other is higher. To determine this percentage, a specific scale of the set of criteria for which the required value is determined is used. The graph of two-dimensional sensitivity shows how alternatives behave according to two criteria.

To ensure that the results obtained are valid and applicable in the real world, it is necessary to perform sensitivity analysis and check the stability of the final results. Changes in the weight values of the criteria are analyzed to determine how their significance affects the results.



	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.071	0.133	0.188	0.235	0.278	0.316	0.35	0.381	0.409	0.435
2	0.054	0.05	0.047	0.044	0.041	0.039	0.037	0.035	0.033	0.032	0.03
3	0.47	0.436	0.407	0.382	0.359	0.339	0.321	0.305	0.291	0.277	0.265
4	0.476	0.442	0.413	0.387	0.364	0.344	0.326	0.31	0.295	0.281	0.269

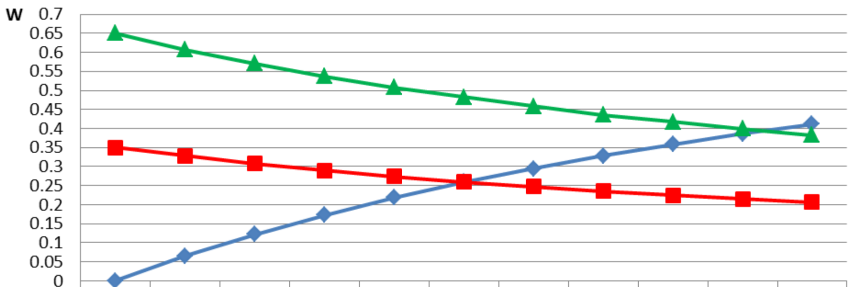
Figure 8. Results of the sensitivity analysis for the Transport Criteria Group

In Figure 8, the sensitivity of the significance of the criterion, which has the greatest value in relation to the other criteria, was analyzed. The dominant significance of the Network of PT lines has a weight vector of 0.65 in relation to the sub-criteria of the Characteristics of the Settlement and the Possession of a Car. The Remoteness of the railway has a slight dominance of up to 0.1. A small change in value (10-20%) would not affect the change in the significance of the sub-criterion.

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.05	0.096	0.138	0.175	0.21	0.242	0.271	0.298	0.324	0.347
2	0.489	0.465	0.442	0.422	0.403	0.387	0.371	0.357	0.343	0.331	0.319
3	0.511	0.485	0.462	0.441	0.421	0.404	0.387	0.372	0.358	0.345	0.333

Figure 9. Results of sensitivity analysis for the Space group of criteria

Sub-criteria The Built infrastructure and the Remoteness from the most significant contents have a dominant value of the weight of significance up to a value of 0.95 (Figure 9). This practically means that a small change in the value of the sub-criterion of the Network of access roads (10%) will cause a change in the weight of the significance and the dominance of the sub-criterion within the space group of criteria.

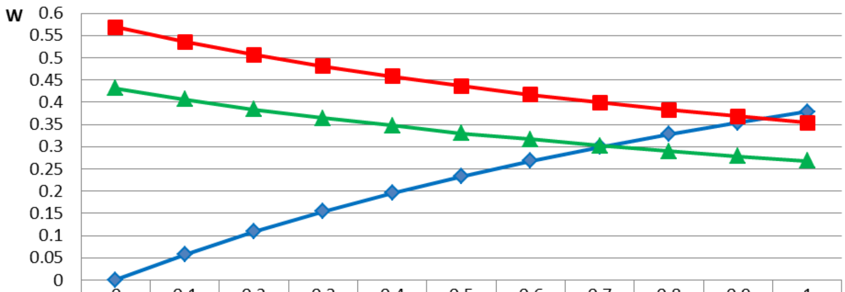


	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.065	0.122	0.173	0.218	0.259	0.295	0.328	0.358	0.386	0.411
2	0.35	0.328	0.308	0.29	0.274	0.26	0.247	0.235	0.225	0.215	0.206
3	0.65	0.607	0.57	0.537	0.508	0.482	0.458	0.436	0.417	0.399	0.383

Figure 10. Results of the sensitivity analysis for the Group of criteria Quality of service

In Figure 10, the sensitivity of the significance of the sub-criterion was analyzed. Travel time in relation to other criteria. The dominant significance for the Transfer points has the value of the weight vector 0.5, and in relation to the sub-criterion of the

Comfort in a vehicle of 0.95. With a change of less than 10%, the weight value of the sub-criterion changes and the sub-criterion Comfort in the vehicle becomes dominant.



	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.057	0.109	0.154	0.196	0.233	0.268	0.299	0.328	0.354	0.378
2	0.569	0.536	0.507	0.481	0.458	0.436	0.417	0.399	0.383	0.368	0.354
3	0.431	0.406	0.384	0.364	0.347	0.33	0.316	0.302	0.29	0.278	0.268

Figure 11. Results of the sensitivity analysis for the Group of criteria Quality of the system

Sub-criteria the Transport cost and the Tariff system have a dominant value of the weight of importance up to a value of 0.7 and 0.95 (Figure 11). This practically means that a change of less than 10% triggers a change in significance according to the sub-criterion of Transport cost, while the change of significance of 30% would trigger the dominance of the sub-criterion Tariff system.

5. Discussion

By reviewing the literature, scientific papers and research, as well as consulting with experts from relevant fields, a total of 13 criteria for assessing the impact of traffic accessibility in suburban settlements were identified. They are classified into four groups: transport, space, quality of service and system quality. Economic experts who are directly in touch with the analyzed problematics were involved in assessing the significance of certain criteria within each group of criteria.

In order to solve the problem of evaluating and selecting priority criteria from individual groups, one of the decision-making methods - the Fuzzy Analytical Hierarchical Process (FAHP) was used, since it is known from previous experiences and from literature that such problems should be addressed by methods of multi-criteria decision-making. Also, in defining the significance of the sub-criterion, in addition to the FAHP method, a coarse theory was applied, among which the Rough AHP method is most suitable for testing uncertainty when it is necessary to exclude subjectivism in the choice of the importance of the significance of criteria.

A multi-criterion analysis of four sets of criteria, using the FAHP method, has shown from each group those that are a priority for assessing the impact of traffic accessibility. Criteria that in the normalized ranks gained an advantage over other criteria from their group are:

1. From the Transport Criteria Group, the Network of PT lines has the highest relative weight;
2. From the Space group of criteria, the highest relative weight has the Network of access roads;

3. From the Group of criteria Quality of service, Travel time has the relative weight;
4. From the Group of criteria Quality of the system, the Timetable has the highest relative weight.

In the theory of rough numbers, the application of the Rough AHP method showed from each group those that are a priority for assessing the impact of traffic accessibility. Criteria that in the normalized ranks gained an advantage over other criteria from their group are:

1. From the Transport Criteria Group, the Network of PT lines has the highest relative weight;
2. From the Space group of criteria, the highest relative weight is possessed by the Built infrastructure;
3. From the Group of criteria Quality of service, the relative weight is possessed by the Travel time;
4. From the Group of criteria Quality of the system, the highest relative weight is possessed the Timetable.

By analyzing the obtained results of the applied methods, it was determined that there is only the difference in the Space group of criteria, where in the first method the dominant sub-criterion is the Network of PT lines, while in the second method the significance was assigned to the sub-criterion Built Infrastructure. Generally, according to the Fuzzy AHP method, Network of PT lines is in the first place, while the second place is occupied by Travel time (Figure 7). By using the Rough AHP method, the criterion of Built infrastructure was ranked first, followed by Network of PT lines. The sub-criterion Remoteness of the railway is at the last place based on the Fuzzy AHP method, while according to the Rough AHP method, it is on the high fourth position. According to the same method, the Tariff system is ranked at the last place.

By defining a greater number of different impact factors on traffic accessibility and by applying the method for multicriteria decision making, it was possible to select dominant criteria that represent the generators of development and sustainability of suburban areas, in a similar way as the accessibility criteria have been defined by Litman (2017). Ranković-Plazinić (2015) defined the types of rural settlements in relation to accessibility, which is a good predisposition for the implementation of some future models. This created an opportunity for assessment of criteria for traffic accessibility.

6. Conclusions

The context in which decisions, regarding the implementation of measures, are made should have strong ties with the impacts that will be assessed, the aims that should be reached and the target groups (users of public transport) that should be taken into consideration. Contribution of this paper is to make settlements competitive for life and to make them attractive for economic investments. Through definition and quantification of significant criteria for traffic accessibility, first steps were made towards the development of a future research.

In order to strengthen the bond between the parameters, it is necessary to have a broad knowledge of natural, social, economic and other characteristics. Also, for a similar research in the future, the research area would need to be broader, that is with less limitations than having them now. This means that the number of experts would need to be greater and their professional interests would need to encompass wider social and natural areas. The application of these results in real life is multifaceted and refers to the improvement of life quality, accessibility of different services, systematic development of settlements and a possible decrease in migration of residents from suburban areas.

This paper presents a new way of determining the importance of accessibility criteria, which involves the application of two methods of multi-criteria decision making Fuzzy AHP and Rough AHP. By applying these methods, with the help of relevant experts, the importance of each criterion is determined individually from the group of 13 criteria and the results are mutually compared. The sensitivity analysis showed the relationship of priority change as a function of the significance of the attributes, that is, the criteria.

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DEVELOPMENT OF THE METHODOLOGY FOR SELECTING THE OPTIMAL TYPE OF PEDESTRIAN CROSSING

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Abstract: *The World Health Organization in its agenda on sustainable development 2030 sets a goal to reduce the number of traffic-related accidents by 50%. According to the trend toward reducing the number of traffic-related accidents and the latest statistics report by SIA Bitola, we have found that this is a great challenge for our city and a very high goal which we could try to reach. Namely, we have started a pedestrian safety initiative by trying to provide infrastructural facilities and elements that are planned and designed according to the security principles and which correspond to the projected speed and road function as well as safe infrastructure for pedestrians, the elderly and persons with disabilities. The main objective of this paper is to develop a case study methodology regarding the selection of pedestrian crossing types on the case study location example. Namely, the VISSIM simulation model for the studied location has been introduced, and the general conclusions have been adopted based on the multi-criteria decision-making process analysis. The most important aim is directed towards obtaining pedestrian safety while bearing in mind the role of pedestrian safety within the current safety goals.*

Key Words: *Pedestrian Safety; Pedestrian Crossing, AHP, VISSIM Simulation*

1. Introduction

Pedestrians are the most vulnerable road users. In many countries, collisions with pedestrians are a leading cause of death and injury, and over half of all road deaths are caused by collisions between vehicles and pedestrians that occur in a number of situations, especially including walking while trying to cross the road. The process of pedestrian traffic is influenced by a number of factors, of which the urban

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environment and streetscape are very important (AASHTO, 2010, 2014). The severity of pedestrian crashes is strongly dependent on traffic speed whereas the risk of pedestrian injuries is increased by a number of factors related to the road environment, including high traffic speed, inadequate crossing facilities, lack of pedestrian crossing opportunities (gaps in passing traffic), number of lanes to cross, complexity and unpredictability of traffic movements, inadequate separation from traffic and poor crossing sight distance as well. In OECD countries, traffic accidents cause 41% of fatalities among 14-year-olds. In Spain, nine children aged between 6 and 14 died from a traffic-related accident while five of them were pedestrians (Road Safety Inspection Manual for School Zones, 2014). Moreover, according to Principle 2 of the Declaration of the Rights of the Child, "The child shall enjoy special protection, and shall be given opportunities and facilities, by law and by other means, to enable him/her to develop physically, mentally, morally, spiritually and socially in a healthy and normal manner and in conditions of freedom and dignity"(Geneva Declaration, 1959), the protection of the most vulnerable traffic group has to be one of the priorities of local authorities; hence it is one of the operational objectives of our recently launched pedestrian safety initiative "to provide safe school zones and routes."

2. Methodology

Since there is no unique methodology for selecting an appropriate pedestrian crossing facility, the process for its selection revolves around the question of why it is considered desirable to provide specific assistance for pedestrians at a particular location or what it is that the designer seeks to achieve. The second stage, which follows after the overall need has been identified, is to identify a set of facilities that may have a detrimental impact on the safety of all users. Typically, this choice of possible devices is based on the characteristics of the road on which the facility is to be installed and the basic choice sets are outlined in the tables, respectively. Making a decision regarding the selection of a pedestrian crossing type is based on several criteria in order to create a solution that is fair for all the participants.

The main objective of this paper is to develop a case study methodology regarding the selection of the most suitable pedestrian crossing type for the city of Bitola, Macedonia. The most important aim is directed towards obtaining pedestrian safety while bearing in mind the role of pedestrian safety within the current safety goals.

2.1. Geomorphological and transport position of Bitola

The City of Bitola, the second largest city in Macedonia (77,004 inhabitants, Census 2002), is located in its southwest part, on the edge of the Pelagonija valley. It is located at the foothills of the Baba Mountain with the peak Pelister (2601 m), near the Greek border, 13 km away (Ristov, 2015).

The city stretches from both sides of the river Dragor; to the north, it is surrounded by the Bairo hills, as part of the Cloud-Snow mass with the peak Kale (890m); to the south, it is surrounded by the hill Tumbe cafe (744m) as a branch of Neolica, i.e. Baba Mountain. To the east, Bitola is widely open to the Pelagonia valley, and towards the west it is open to the floodplains of the river Dragor, the Gavatian overbearing valley and the peak Pelister. Bitola is spread on a terrain that is sloped from west to east, from 720 m to 585 m, with an average altitude of 652 m. Regarding the traffic situation, it can be said that Bitola is relatively poorly connected. This unfavorable traffic connection had its beginnings in the early 20th century, when with the reshaping of the borders, a large number of traffic routes lost their meaning or completely disappeared. Hence the Bitola gravitational area was reduced and deformed (Dimitrov, 1998).

2.2. Problem identification

According to the standing classification of city street intersections (GUPCB, 1999; SIA, 2016) Vasko Karangeleski St. is classified as the main street. After the appropriate analysis, "mobility versus accessibility", it is determined that this street does not meet the criteria for that classification (Administrative Office of the Primary School Elpida Karamandi Bitola, 2018). Furthermore, according to the data from the report of SIA Bitola for 2003-2016, a total of 38 pedestrians were injured on the said street (13 of whom were severely injured while 25 suffered minor injuries). From this data it can be concluded that there were no injured pedestrians only in 2010 and 2013 while in 2003, 2007 and 2016 an increased number of injured pedestrians was noted (Administrative service at the Pedagogical Faculty Bitola, 2018).The traffic situation particularly deteriorated after the constriction of the primary school Elpida Karamandi, the kindergarten Majski Cvet, the Day Centre for Persons with Disabilities and the Faculty of Pedagogy since a large number of children and students who live east off the street were forced to cross Vasko Karangeleski St. on a daily basis. Today, this street is crossed by 228 pupils (World Bank, 2012; WHO, 2016) who live to the east of the street as well as 380 students who are enrolled as full-time students in the academic year 2017/2018 (Adriazola-Steil et al., 2015). The crossing of the street is made difficult due to the fact that the children, most of whom are still very young, have to cross four lanes at once and deal with the lack of traffic culture by the drivers who fail to follow the rules of pedestrian crossings.

2.3. Pedestrian safety initiative

Following the identification of the problem and the initiative launched by the parents of the children who attend the school, a campaign was organized, in cooperation with the Municipal Council on Road Traffic Safety, professors in the Traffic and Transport Department at the Faculty of Technical Sciences Bitola and non-government organizations in Bitola, to raise awareness among the drivers about the pedestrians' need for safe crossing of streets as well as an initiative to the relevant institutions to help find a suitable solution for the pedestrians on Vasko Karangeleski St. The proposals of the parents and the NGOs are related to the placement of vertical signalization (call buttons), which would be operational during the arrival and departure times of the students in the school; they would enable a relatively fast flow of vehicles on the main street as well as help to avoid any unnecessary stops when there are no pedestrians, as is the case with conventional traffic lights.

In order to acquire information regarding citizens' opinion over pedestrian safety on the analyzed location, we used a questionnaire of six questions and an online survey that involved 770 citizens (Figures 1-3). Namely, gender equality was a key factor since 56.8% of the surveyed were women while 43.2% were men. In terms of age, most of the surveyed were between 31 and 40 (32.6%) and 21 and 30 years of age (25.7%). When asked "How safe is it to cross the street at the pedestrian crossing?” 40.3% answered that it is not safe at all whereas 57.1% answered that it is partially safe.

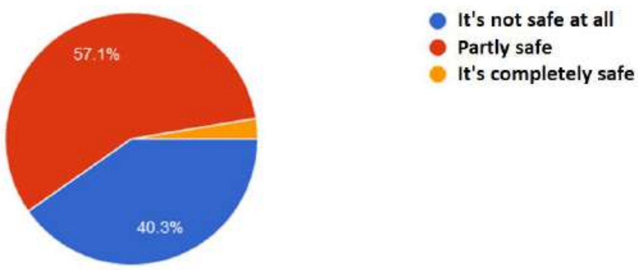

Figure 1. Graphical presentation of pedestrian crossing safety

When determining the main cause for the lack of safety at the pedestrian crossing, the lack of traffic culture among drivers and unmarked pedestrian crossings are listed as the two main reasons. These are followed by illegally parked vehicles in front of pedestrian crossings, its illumination, and ultimately the lack of traffic police and traffic signalization. What is quite evident from the answers of citizens is that despite the fact that the number one reason for the lack of pedestrian safety on pedestrian crossings dominates, all of the given causes contribute to some degree to the reduction of pedestrian safety.

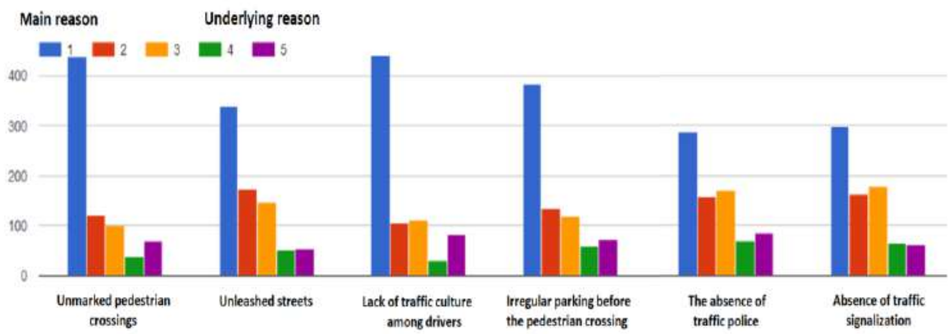

Figure 2. Graphical presentation of pedestrian insecurity while crossing

When asked "Do you think that the four lanes of the street can be safely crossed by a primary school pupil?" a high percentage of 75.8% answered that it would be impossible.

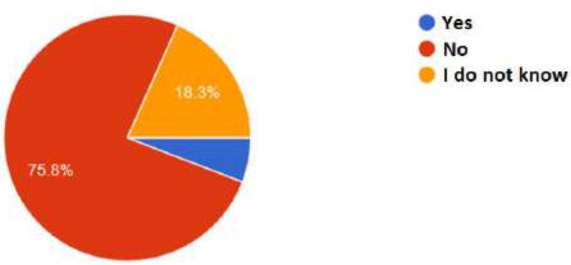

Figure 3. Graphical presentation of meaning regarding pedestrian crossing length

When asked "Do you think that the placement of light signalization (call button) on Vasko Karangeleski St. will increase the safety of the students who use the pedestrian crossing?" almost 86% of the surveyed answered yes, which speaks to the need of regulating traffic on this location.

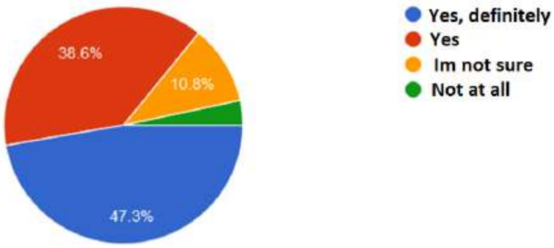

Figure 3. Graphical presentation of meaning regarding signalized pedestrian crossing design

3. Multi-Criteria Decision-Making approach

We have decided to use a multi-criteria decision-making analysis based on the AHP (Analytic Hierarchy Process) approach which synthesizes the aspects of different opinions by weighing up many subjective factors and which studies the unique common result (Saaty& Tran, 2007). The level of consistency allows us to form an adjustment of judgments. At the end of the process we have answered how to best make a decision in a complex and subjective situation with more than a few realistic options. Namely, for the application of the AHP method we set the goal, i.e. three alternatives, adequate number of criteria and subcriteria for precise ranking of the alternative, as in (Table 1). Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion (Figure 4).

Table 1. Competing alternatives and criteria

	A1 - signalized pedestrian crossing	A2 - pedestrian crossing with refuge median island	A3 – pedestrian overpass
K1- Safety Criterion	Subcriterion: driving speed (N,1.1) Subcriterion: Traffic flow (N,1.2) Subcriterion: Length of the pedestrian crossing (road width) (N,1.3)		
K2- Price Criterion	Subcriterion: Cost of design (N,2.1) Subcriterion: Cost of construction (N,2.2) Subcriterion: Cost of maintenance (N,2.3)		
K3- Environment & Comfort Criterion	Subcriterion: Noise and environmental impact (N,3.1) Subcriterion: Comfort(N,3.2) Subcriterion: Access for the disabled (N,3.3)		

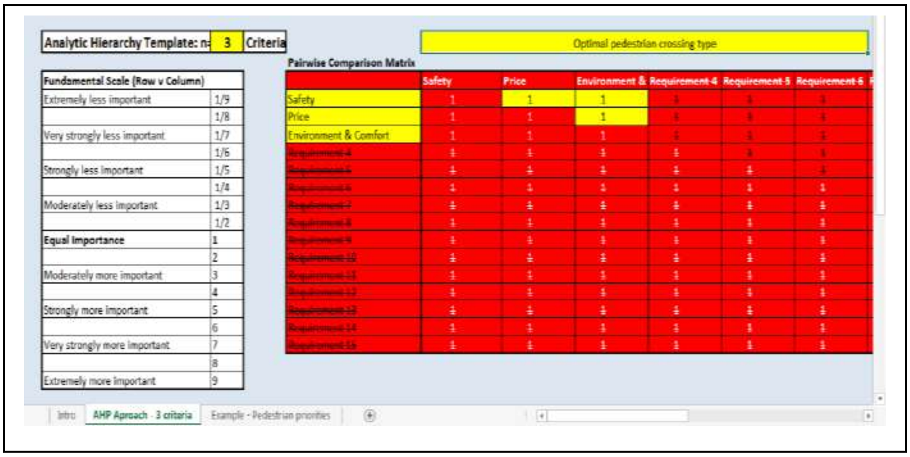

Figure 4. Adopted AHP excel software tool for pedestrian crossing type selection

3.1. Establishment of structural hierarchy

3.1.1. Signalized pedestrian crossings as an alternative

It consists of signal displays, line markings and lighting. In general, fixed-time signals are the rule in urban areas for reasons of regularity, network organization, predictability, and reducing unnecessary delays. In certain, less-trafficked areas, actuated signals (call buttons, loop detectors) may be appropriate; however, these must be programmed to minimize delay, which will increase compliance. The pedestrian crossing signals at midblock crossing locations are widely used in most developed countries. They can be classified into four types: Fixed time pedestrian actuated crossing, Pelican crossing, Puffin crossing and Toucan crossing.

Fixed time pedestrian actuated crossing (Figure 5) is a stand-alone pedestrian actuated (or automatic) signal control. Pedestrians can call green phase by pushing the button, though, traffic must be able to see pedestrian crossing points in time to stop for them. Advance warning signs should be used if visibility is poor. Parking should be removed from near pedestrian crossings to provide adequate sight distance.

Figure 5. VISSIM microscopic simulation for location under study

Figure 6. Design of Puffin pedestrian crossing for location under study

3.1.2. Pedestrian crossing with Median Island as an alternative

Crossing a busy road with fast flowing traffic can be very difficult. Pedestrian median islands (Figure 7) can help pedestrians to cross such roads safely by allowing them to cross in two stages and deal with one direction of traffic flow at a time. They can be used where there is a demand for pedestrians to cross the road but where the number of pedestrians is not high enough to warrant a signalized pedestrian crossing. Median islands can be part of no-signalized pedestrian crossing and are usually used on wide, multi-lane roads, with the function of narrowing the lanes for vehicular traffic. They must be clearly visible to traffic both day and night.

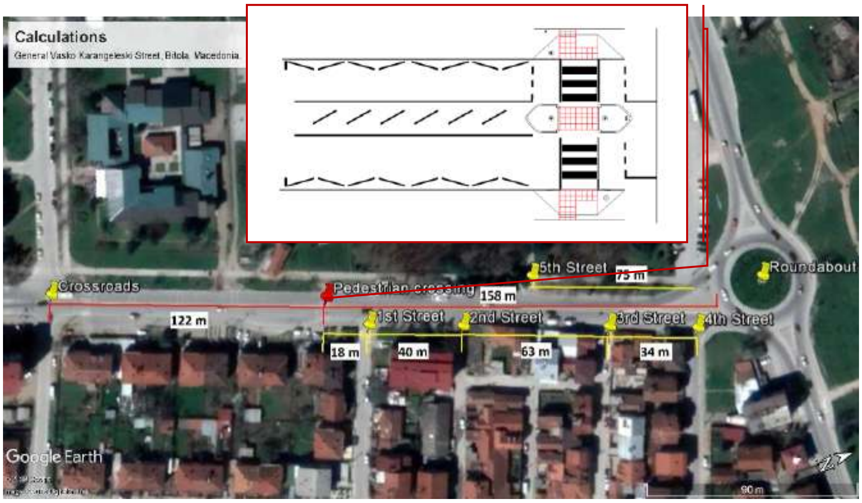

Figure 7. Design of pedestrian crossing type with Median Island for location under study

3.1.3. Pedestrian overpass as an alternative

One effective way of preventing crashes between vehicles and pedestrians is placing them at different levels, or 'grade separating' them. In urban situations where the pedestrian crossing signals would cause congestion or crashes (due to high traffic speeds), a grade separated pedestrian crossing, such as an overpass or an underpass, may be used. Outside of urban areas, in situations where there is pedestrian demand in high speed environments, this treatment may also be applied. Grade separated pedestrian crossings reduce pedestrian crashes but they also have some disadvantages: they are costly, pedestrians may avoid them if there are a lot of steps to climb up or down. What is more, if they are not well-lit and patrolled, they may pose a personal security risk. Pedestrians tend only to use crossing facilities located at, or very near, to where they want to cross the road. Where a lot of cycling traffic is present, a pedestrian underpass or overpass can be used by cyclists as well as pedestrians, but this will require shallow approach ramps and therefore additional land.

3.1.4. Decision hierarchy criteria and sub-criteria

Safety (K1) is a condition in which a pedestrian can normally cross at a pedestrian crossing in the process neither disturbed nor degraded due to various threats and dangers, adapted according to (SIA, 2016).

Driving speed (N1.1) has been identified as a key risk factor in road traffic injuries, influencing both the risk of a road crash as well as the severity of the injuries that result from crashes (World Bank, 2012). Excess speed is defined as exceeding the speed limit. At inappropriate speed, the pedestrian cannot properly estimate the moment at which the vehicle will reach the pedestrian crossing, i.e. the point of intersection between the paths of the vehicle and the pedestrian while the motorist is not able to stop the vehicle on time. The greater the difference in the speed between the pedestrian and the vehicle, the greater the danger to the pedestrian.

If traffic flow (N1.2) saturation results in situations in which the time gap between the approaches of two succeeding vehicles is shorter than the time required to cross the road, the method of stopping the vehicle has to be applied in order to perform the crossing. If traffic is of a higher intensity resulting in even scarcer occurrences of suitable intervals to cross the road, the pedestrians lose patience and recklessly step onto the roadway. The consequences of such actions may be catastrophic and in such situations zebra crossings do not usually match the needs and signalized crossing needs to be constructed. Should traffic lights cause very long queues of vehicles, and pedestrian waiting time exceeds the limit of patient waiting, then the pedestrian crossings are grade-separated, by constructing overpasses.

The length of the pedestrian crossing (N1.3) is in correlation with traffic safety. The crossing time using a longer pedestrian crossing means a longer stay of the pedestrian on the roadway and a higher risk of getting injured. On a multi-lane road the vehicles moving along the right kerb often obscure the view of vehicles that move along the farther lane. This phenomenon is especially noted in cases when small children want to cross the street and the motorists fail to notice them on time. This problem is especially emphasized in the vicinity of schools.

Price (K2) is the value that is put to a product or service and is the result of a complex set of calculations, research and understanding and risk taking ability. A pricing strategy takes into account segments, ability to pay, market conditions, competitor actions, trade margins and input costs, amongst others. It is targeted at the defined customers and against competitors. In forming the criteria of prices for pedestrian facilities, costs of design (N2.1), construction (N2.2), and maintenance (N2.3), have been taken into consideration and studied as separate subcriteria.

Bearing in mind that there are no exact numerical indicators the criterion environment & comfort (K3) serves as an additional assistance to the decision-makers.

Exposure to noise (N3.1), in everyday urban life is considered to be an environmental stressor. A specific outcome of reactions to environmental stress is a fast pace of life that also includes a faster pedestrian walking speed. On zebra crossings and signalized crossings pedestrians are exposed at a high noise level whereas in underpasses and overpasses they are much better protected. The closer the vehicles are to the pedestrian crossing and the larger their number, the greater the influence of noise. It is most expressed at the peak hours when the greatest number of vehicles and pedestrians is on the road.

The sub-criterion aesthetic and environment (N3.2) considers the negative impacts of pedestrian crossing construction on the environment, changes of the streetscape, unpleasant experiences as well as a feeling of personal protection.

The concept of accessible design for disabled persons (N3.3) ensures both direct access, i.e. unassisted, and indirect access, that is compatibility with a person's assistive technology (for example, computer screen readers). This intends to make everything accessible to all people regardless of their having any disability or not.

4. Conclusions

The crossing opportunities available to pedestrians on the studied location are below the desired level of service. Historical records of crashes in the vicinity of the location are a serious factor that indicates the need for providing crossing assistance. The methodology of selecting a pedestrian crossing proposed by this research is comprehensive. For this purpose an adopted AHP excel software tool has been developed and a VISSIM microscopic simulation was used to model the alternatives under a range of likely pedestrian volumes and a range of likely vehicle volumes. The process of alternatives evaluation by calculating the weight values of criteria and alternatives has been performed by comparing the pairs of criteria, based on the questionnaire results for different target groups of citizens, professionals, disabled and healthy persons. Namely, professionals give weights to the traffic safety and priority to the overpasses. Regarding environment and price the best alternative is Median Islands. Both healthy and persons with disabilities equally value signalized pedestrian crossing.

Analysis results are in correlation with the design principles showing that on undivided four lane main street (two lanes per direction), without allowed side parking, at a speed limit of 50 km/h, and with the distance of 150-200 meters to the next intersection light signals or median islands are recommended. Bearing in mind the traffic culture of drivers, we assume that the introduction of signalized mid-block crossing with pedestrian-actuated control and fixed-time operation is the optimal type for the location under study.

The methodology and the results from various research allow tests to be administered on possible scenarios in order to decide on the best type of pedestrian crossing. However, we must take into account all the specific features of the location so as to introduce the best conditions, both in terms of space and maintenance plan, as well as suitable traffic signalization.

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RANKING DANGEROUS SECTIONS OF THE ROAD USING THE MCDM MODEL

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Abstract: *Traffic accidents are a matter of great concern in traffic safety since they unexpectedly and sometimes unavoidably cause fatal and non-fatal injuries, or material damage. The causes of traffic accidents can vary but they can always be linked to one of the four basic factors: human, vehicle, road and environment. However, there are some places where traffic accidents happen more frequently than in others. The decision-making process concerning dangerous road sections using the Multi-criteria decision-making (MCDM) model involves the definition of quantitative and qualitative traffic safety criteria. The model used in the paper consists of five quantitative and two qualitative traffic safety criteria. Based on those criteria the ranking of the prospected sections is carried out. By analyzing the total number of traffic accidents, by their categories and by analyzing the current state of the traffic infrastructure and Annual Average Daily Traffic (AADT), seven traffic safety criteria are defined and, in the first phase of the model, are rated and ranked by their importance. By using the Full Consistency Method (FUCOM), weighted coefficients of the defined criteria are determined followed by ranking of dangerous road sections using the Weighted Aggregate Sum Product Assessment method (WASPAS). The obtained results show which of the offered alternatives is best ranked, that is, which section of the road is the safest one.*

Key Words: *Dangerous Sections, Traffic Safety, Multi-criteria Decision-making, FUCOM, WASPAS*

1. Introduction

Undoubtedly, decision-making is one of the most important aspects of shaping the future of traffic safety, especially in situations where human lives and material goods are endangered, as in the case of traffic accidents. The multi-criteria decision-making (MCDM) methods are gaining importance as potential tools for analyzing and solving

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complex real-time problems due to their inherent ability to evaluate different alternatives with respect to various criteria (Chakraborty et al., 2015). The multi-criteria decision-making methods can be used as an adequate tool for making valid decisions when it comes to traffic safety. Approximately 1.35 million people die each year as a result of road traffic accidents. Variations in death rates observed across regions and countries also correspond to differences in the types of road users most affected. Only in the European Union, over 1.1 million traffic accidents have killed more than 30,000 people while 1.5 million people have been injured (World Health Organization, 2018). Based on WHO data (2018), estimated road traffic death rate in Bosnia and Herzegovina is 17.7 (per 100 000 population).

For the system management, it is necessary (Lipovac, 2008):

- to know the existing state of affairs,
- to define the desired condition, and,
- to choose those management measures that would bring the existing situation closer to the desired one.

In the field of traffic safety, the concept of management can be defined similarly; so, in order to manage the safety of traffic, it is necessary to know the existing situation, define the desired state of affairs and take measures to bring the existing state to the desired one. In defining the present state of affairs, it is necessary to observe the basic trends in the development of the phenomenon, which includes the prognosis of the occurrence based on the existing condition (for example, the forecast of the number of traffic accident and their consequences, assuming that the current trend continues). This means that nothing is done in terms of solving traffic safety problems, so that the current trend continues. However, this is only the first step in defining the current state. It should be followed by the research based on the definition of the supposed desired state as well as the selection of those management measures that would bring the current state closer to the desired one.

Because of that, traffic safety includes several models that can be used for defining the current state of affairs (Lipovac, 2008):

- Descriptive model,
- Prediction model,
- Risk factor model,
- Models that show the consequences of traffic accidents, and,
- Models that rely on monitoring the traffic safety indicators.

The descriptive model is trying to describe the state of affairs and traffic safety problems by using three dimensions: exposure, accident risk and consequences of traffic accidents. Basic data about road traffic accidents and injuries are collected every day in most countries. Police officers write reports on accidents, insurance companies document their clients' accidents while health workers keep medical records on the road traffic injuries they have treated. The main purpose of documenting this information is usually to assist an agency in carrying out its specific function like investigation, law enforcement and provision of health care. However, this information can also be used for ranking dangerous sections of the road by using the MCDM model.

The motorization rate in Bosnia and Herzegovina has been growing gradually in the last couple of years and so has the number of road accidents. The consequence of such trend is the absence of the road safety system due to the lack of systemic and continual road safety management (Lipovac et al., 2015). Ranked road sections in terms of risk, together with ranked weights of factors considered as causes of accidents for each section, are highly effectual information for road safety implementing planning (Jantakat et al., 2014). That is why it is important to determine the dangerous road sections, which can help us to make a better decision when it comes to improving traffic safety.

Basic sources about traffic accidents and their consequences are police, hospital and insurance company reports. So, the first step in the descriptive model is to describe the current state of affairs and determine the importance of the traffic safety problems based on that data.

In this paper, the description of the current state of affairs is given by data on the total number of traffic accidents - by their categories, data on the current state of the traffic infrastructure and AADT for observed locations. In order to determine the significance of the problem, dangerous road sections on the territory of the municipality of Derventa will be ranked by using the MCDM model. Hence the main goal of this paper is to make a decision about the road section which is estimated as the most dangerous of all the observed ones. That will show the significance of the problem when it comes to traffic safety.

The paper is structured in several sections. Section 1 (*Introduction*) shows the importance of describing the current state of affairs when it comes to traffic safety. Next Section (*Literature review*) consists of three parts: a review of the use of the Multi-Criteria Decision-Making model, a review of the use of the FUCOM method in different research fields and a review of the use of the WASPAS method of evaluating different alternatives. Section 3 (*Methods*) consists of two parts; the first one describes in detail three steps of the FUCOM method while the second one describes the WASPAS method by its steps. It is on the basis of these steps that the dangerous sections of the road on the territory of the Municipality of Derventa will be ranked. The main section of the paper is Section 4 (*Case study*), which includes forming a multi-criteria model as well as applying the FUCOM and the WASPAS methods to the concrete case. The end of this Section is reserved for the sensitivity analysis, based on what we can do in the model behavior testing. The last section of the paper (*Conclusion*) represents a brief summary of the things described in the paper as well as an explanation showing us which of the observed locations is ranked best.

2. Literature review

The research and development of the MCDM methods increased during the 80s and early 90s but it seems that the exponential growth of this process continued (Köksalan et al., 2011). The MCDM methods can be applied effectively to determining the value and utility degree of various areas and to establishing the priority order for their implementation (Turskis, 2008). Triantaphyllou and Mann (1995) said that the MCDM plays an important role in real-life problems as there are a large number of everyday decisions to be made which include a huge number of the criteria. According to Chen et al. (2015), the MCDM is an effective, systemic and quantitative way of solving vital real-life problems with a large number of alternatives and several (opposing) criteria. According to Drezner (1995) the study of location selection has a long and extensive history spanning many general research fields including operations research (or management science), industrial engineering, geography, economics, computer science, mathematics, marketing, electrical engineering, urban planning, etc. According to Kahraman et al. (2011) evaluation of specific sites in the selected community is commonly termed microanalysis. Many authors (Roberts and Goodwin, 2002; Solymosi and Dompi, 1985; Cook, 2006; Weber and Borcherding, 1993) agree that the values of criteria weights are significantly conditioned by the methods of their determination. But there is no agreement as to which of the methods is the best one for determining criteria weights. According to Stević et al. (2018) the main problem of the multi-criteria decision-making (MCDM) is that of choosing an appropriate method for determining criteria weights, as a very important stage, which complicates the decision-making process. If we take the fact that the weights of criteria can significantly influence the outcome of the decision, it is clear that attention must be paid to the objectivity factors of criteria weights.

Real problems do not usually have the criteria of the same degree of significance. It is, therefore, necessary that the significance factors of particular criteria should be defined by using appropriate weight coefficients for the criteria, so that their sum is one. Therefore, the new FUCOM method for determining the weight coefficients of criteria is proposed (Pamučar et al., 2018). The FUCOM method enables the precise determination of the values of the weight coefficients of all of the criteria at a certain level of the hierarchy. In comparison with similar subjective models (the AHP and the BWM methods) for determining the weight the coefficients of the criteria, the FUCOM only requires the (n-1) pairwise comparison of the criteria (Pamučar et al., 2018).

A FUCOM method is applied to determining the weights of the criteria for the selection of the Automatically Guided Vehicles (AGVs) as one important type of material handling equipment in warehouses. The multi-criteria model included several criteria and AGVs solutions, based on which the selection of AGVsis done. That caused reduction of labor costs, increased reliability and productivity, reduction of the damage of goods, safety improvement, managing and control of the complete system, etc. (Zavadskas et al., 2018).

Solving different problems can be done by using the FUCOM with some other method. The advantages of the new methodology, Delphi-FUCOM-SERVQUAL methodology, are reflected in providing precise treatment of input and output parameters, and obtaining results that are more objective (Prentkovskis et al., 2018). According to Nunić (2018), solving the problem of the selection of the PVC carpentry manufacturer by using the FUCOM-MABAC model has included all the relevant criteria which are of influence upon the final decision. The objective was to obtain the most suitable offer, that is, the one which involves high quality, which is the lowest possible price, a short time for delivery and montage, a possibility of deferred payment, a longer warranty period with the manufacturer's reliability but it is not necessary to ignore other relevant facts that may have an impact on the formation of a final decision. According to Pamučar et al. (2018) the FUCOM method was used for evaluation of the level crossing, as a point of the crossing of road and rail traffic in the same level. The presented FUCOM-MAIRCA model allows consideration of subjectivity in the process of group decision-making through linguistic evaluation of the evaluation criteria.

The results obtained using the WASPAS method show that the use of method and techniques in the field of MCDM can help decision-makers to successfully evaluate defined alternatives (Tešić et al 2018). Chakraborty and Zavadskas (2014) used the WASPAS approach for solving decision-making problems related to manufacturing, and the findings of this paper were accurate; the proposed method had accurate ranking capability for solving decision-making problems related to manufacturing. According to Zavadskas et al. (2012), the WASPAS method approach enables attaining high accuracy measurement.

The use of the WASPAS technique for assessment and selection of appropriate solutions for occupational safety (Dėjus and Antuchevičienė, 2012) has revealed that typical solutions for occupational safety are used in the field of road construction; however, they are intended for protecting third persons from accessing dangerous zones next to a construction site rather than for ensuring health and safety of workers.

According to Stević et al. (2018) the expanded form of WASPAS method, which includes rough numbers, was used to make decisions that are more precise because an initial matrix has more accurate values, which eliminates subjectivity and reduces uncertainty in a decision-making process. That is why the complete Rough BMW-Rough WASPAS model is used for the location selection for the construction of a roundabout which is one of the essential factors for increasing mobility in the towns.

3. Methods

3.1 Full Consistency Method (FUCOM)

The FUCOM method was developed by Pamučar et al. (2018) for determining the weights of criteria. According to the author, this new method is better than AHP (Analytical Hierarchy Process) and BWM (Best Worst Method).

The FUCOM provides a possibility to validate the model by calculating the error size for obtained weight vectors, by determining the degree of consistency. On the other hand, in other models for determining the weights of criteria, the BWM (Rezaei, 2015) and the AHP (Saaty, 1980) models, redundancy in pairwise comparison appears which makes them less susceptible to errors in judgment, while the methodological procedure of the FUCOM eliminates that problem.

In the following section, the procedure for obtaining weight coefficients of criteria by applying the FUCOM is presented:

Step 1 In this step, the criteria from the predefined set of the evaluation criteria $C=\{C_1,C_2,...,C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance:

$$C_{j(1)} > C_{j(2)} > \ldots > C_{j(k)} \tag{1}$$

Step 2 In this step, comparison of the ranked criteria is carried out and comparative priority $(\varphi_{k/(k+1)}) = \dfrac{C_k}{C_{k+1}}$, $k=1,2,...,n$, with k representing the rank of the criteria) of the evaluation criteria, is determined.

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right) \tag{2}$$

Step 3 In this step, the final values of the weight coefficients of evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the following two conditions:

(a) The ratio of the weight coefficients is equal to the comparative priority among observed criteria $(\varphi_{k/(k+1)})$ defined in Step 2, i.e. the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(b) In addition to condition (2), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. t $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

Then $\varphi_{k/(k+1)} = \dfrac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \dfrac{w_{k+1}}{w_{k+2}}$ $\dfrac{w_k}{w_{k+1}} \otimes \dfrac{w_{k+1}}{w_{k+2}} = \dfrac{w_k}{w_{k+2}}$ are obtained.

Thus, another condition that the final values of the weight coefficients of the evaluation criteria should meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \le \chi,\ \forall j \\
&\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \ge 0,\ \forall j
\end{aligned} \tag{5}$$

By solving model (5), we obtain the final values of evaluation criteria $\left(w_1, w_2, ..., w_n\right)^T$ and the degree of consistency (χ) of the results obtained.

3.2. Weighted aggregate sum product assessment method (WASPAS)

The Weighted aggregate sum product assessment method (WASPAS) (Zavadskaset al., 2012) is one of the best known and often applied multiple criteria decision-making methods for evaluating a number of alternatives in terms of a number given criteria. In general, suppose that a given MCDM problem is defined on *m* alternatives and *n* decision criteria. Next, suppose that w_j denotes the relative significance of the criterion and x_{ij} is the performance value of alternative *i* when it is evaluated in terms of criterion *j*.

WASPAS methods consist of the following steps:

Step 1 Formatting of initial decision matrix (X). The first step is to evaluate *m* alternatives by *n* criteria. Alternatives are shown to the vectors:

$$A_i = \left(x_{i1}, x_{i2}, ..., x_{in}\right)$$

Where x_{ij} is value of i-th alternatives according to the j-th criterion.

$\left(i = 1, 2, 3, ..., m;\ j = 1, 2, 3, ..., n\right)$.

$$X = \begin{array}{c} \\ A_1 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & ... & C_n \end{array} \\ \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \end{array} \tag{6}$$

Step 2 In this step it is necessary to normalize the initial matrix using the following equations:

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{7}$$

for $C_{1,} C_2, \ldots, C_n \in B.$

$$n_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{8}$$

for $C_{1,} C_2, \ldots, C_n \in B.$

Step 3 Weighing the normalized matrix is done in such a way that the previous (normalized) matrix is multiplied by the weight coefficients:

$$V_n = \left[v_{ij} \right]_{m \times n} \tag{9}$$

$$V_{ij} = w_j \times n_{ij}, i = 1, 2, \ldots, m, j \tag{10}$$

Step 4 Summarizing all obtained values of the alternatives (summation in rows):

$$Q_i = \left[q_{ij} \right]_{1 \times m} \tag{11}$$

$$q_{ij} = \sum\nolimits_{j=1}^{n} v_{ij} \tag{12}$$

Step 5 Determination of the weighted product model by using the following equations:

$$P_i = \left[p_{ij} \right]_{1 \times m} \tag{13}$$

$$p_{ij} = \prod\nolimits_{j=1}^{n} (v_{ij})^{wj} \tag{14}$$

Step 6 Determination of the relative values of alternative A_i:

$$A_i = \left[a_{ij} \right]_{1 \times m} \tag{15}$$

$$A_{ij} = \lambda \times Q_i + (1 - \lambda) \times P_i \tag{16}$$

Coefficient λ can be crisp value; and it can be any value from 0, 0.1, 0.2, ... , 1.0.

Step 7 Ranking of alternatives. The highest value of the alternative is the best ranked while the smallest value reflects the worst alternative.

4. Case study

4.1 Forming a Multi-Criteria Model

Three locations (Fig. 1) that are located in the Municipality of Derventa, of which one is connection between the town of Derventa and the town of Brod (Lužani), one that connects the town of Derventa and the town of Prnjavor (Lug), and one that passes by the town (Kninska Street), are evaluated based on a total of seven criteria presented in Table 1.

Fig. 1 Observed locations in the Municipality of Derventa

The first location is located in the Municipality of Derventa, and it represents the main road M14.1 The second location is an exit from the town of Derventa onto the M16.1 main road towards Prnjavor, while the third location is an exit from the town of Derventa onto the M14.1 towards Brod.

Table 1 Criteria in a multi-criteria model and their interpretation

Criterion	Criterion Description
C_1	Total number of traffic accidents with killed persons (quantitative data for last 6 years)
C_2	Total number of traffic accidents with seriously injured persons (quantitative data for last 6 years)
C_3	Total number of traffic accidents with slightly injured persons (quantitative data for last 6 years)
C_4	Total number of traffic accidents with property damage only (quantitative data for last 6 years)
C_5	Geometric design of road (qualitative data about curves, road width, upgrade, downgrade, etc.)
C_6	AADT (besides annual average daily traffic, quantitative data about the structure of traffic flow, car flow)
C_7	Traffic elements (qualitative data about condition of pavement, roadway, road markings (horizontal and vertical signalization)

Table 1 shows both the criteria and the detailed interpretation of their meaning. The criteria used in this study are traffic safety criteria, commonly used in Croatia and Serbia (Stević et al., 2018). Criteria number 1,2,3,4 and 6 represent quantitative data, while criteria number 5 and 7 represent qualitative data. When it comes to the number of traffic accidents, all data are obtained from Derventa Police Station. All data about number of accidents are shown in Fig. 2.

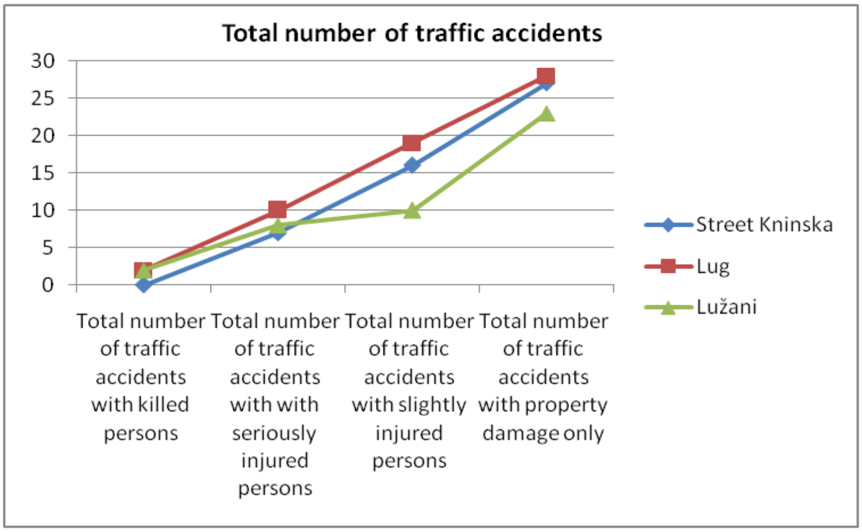

Fig. 2 Total number of traffic accidents for last 6 years

As the Fig. 2 shows, two traffic accidents with killed persons happened in location Lug and Lužani, while in the Kninska Street location no traffic accidents with killed persons happened. The highest number of accidents with seriously and slightly injured persons took place at the Lug location while the smallest number of traffic accidents with seriously injured persons happened on Kninska Street location. The smallest number of traffic accidents with property damage only took place at location No. 3, Lužani, while the highest number took place at the Lug location.

AADT data for three locations are shown in Fig. 3.

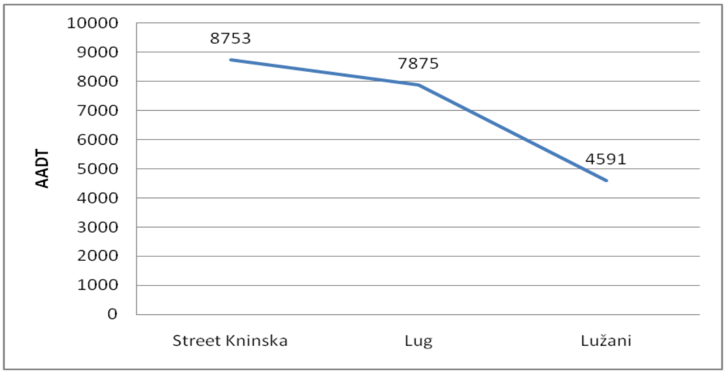

Fig. 3 AADT data for observed locations

Criterion number 6, AADT data about observed locations is based on the basis of data from the Roads of the Republic of Srpska's. AADT for first location is 8753 vehicle/day, for second location is 7875 vehicle/day, and for third location is 4591 vehicle/day.

4.2 Determining criteria weights the using FUCOM method

Step 1 Ranking the criteria based on their importance:

$$C_1 > C_2 > C_3 > C_4 > C_6 > C_7 = C_5$$

Table 2 The importance of criteria (FUCOM method)

Criterion	C_1	C_2	C_3	C_4	C_6	C_7	C_5
w_{cj}	1	1.8	2	2.5	2.6	3.4	3.4

Table 2 presents the importance of criteria used in the multi-criteria decision-making model, where we can see that the most important criterion is criterion 1, the total number of traffic accidents with killed persons. After that, the most important criteria are the total number of traffic accidents with seriously and slightly injured persons, separately. Then follows criterion 4 referring to the total number of traffic accidents with property damage only. The next criterion by importance is criterion 6, AADT. Criteria 5 and 7 have the same importance.

Step 2 Comparison of the ranked criteria is carried out and the comparative priority of the evaluation criteria is determined. Comparative priority of the evaluation criteria is obtained by equation (3):

$$\varphi_{C_1/C_2} = 1.8 \ \varphi_{C_2/C_3} = 1.11 \ \varphi_{C_3/C_4} = 1.25 \ \varphi_{C_4/C_6} = 1.04 \ \varphi_{C_6/C_7} = 1.31 \ \varphi_{C_7/C_5} = 1$$

Step 3 The final values of the weight coefficients are calculated by equation (4):

$$\frac{w_1}{w_3} = 2 \ \frac{w_2}{w_4} = 1.39 \ \frac{w_3}{w_6} = 1.30 \ \frac{w_4}{w_7} = 1.36 \ \frac{w_6}{w_5} = 1.31$$

Regarding the defined limitations, on the basis of expression (5), a finite model for determining the weight coefficients meeting the condition of maximum consistency can be defined.

$$\min \lambda$$
$$s.t. \begin{cases} \left|\frac{w_1}{w_2} - 1.8\right| \le \lambda; \left|\frac{w_2}{w_3} - 1.11\right| \le \lambda; \left|\frac{w_3}{w_4} - 1.25\right| \le \lambda; \left|\frac{w_4}{w_6} - 1.04\right| \le \lambda; \left|\frac{w_6}{w_7} - 1.31\right| \le \lambda; \left|\frac{w_7}{w_5} - 1\right| \le \lambda; \\ \left|\frac{w_1}{w_3} - 2\right| \le \lambda; \left|\frac{w_2}{w_4} - 1.39\right| \le \lambda; \left|\frac{w_3}{w_6} - 1.3\right| \le \lambda; \left|\frac{w_4}{w_7} - 1.36\right| \le \lambda; \left|\frac{w_6}{w_5} - 1.31\right| \le \lambda; \\ \sum_{j=1}^{m} w_j = 1, w_j \ge 0, \forall_j \end{cases}$$

Final results for weight coefficients were obtained using the LINGO 17 program, and it follows:

$$w_1 = 0.292 \ w_2 = 0.162 \ w_3 = 0.146 \ w_4 = 0.117 \ w_5 = 0.086 \ w_6 = 0.112$$
$$w_7 = 0.086$$

After the completed calculation, it can be concluded that the most important criterion is the total number of traffic accidents with killed persons, whose weight coefficient is $w_1 = 0.292$. Deviation from full consistency (DFC) was obtained as 0.00.

4.3 Ranking dangerous sections road using WASPAS method

Step 1 Formatting of initial decision matrix (*X*).

The data shown in Figs. 2 and 3 are used to form the initial decision matrix (Table 4), in the first step of the WASPAS method. All criteria have been evaluated by using Linguistic scale, presented in Table 3. All criteria were evaluated by obtained data, depending on their type, max/min type.

Table 3 Linguistic scale for evaluating qualitative criteria (Stević et al., 2017)

Linguistic scale	For Criteria Max Type	For Criteria Min Type
Very poor (VP)	1	9
Poor (P)	3	7
Medium (M)	5	5
Good (G)	7	3
Very good (VG)	9	1

Criterion 5 (geometric design of road in location number one and location number three) was evaluated by linguistic scale, and it is poor (P). Geometric design of road in location number two was evaluated by previous scale, and it is good (G). Kninska Street, the first location, is the main road M14.1.The beginning of the hall is a crossroad, at an angle of 90 degrees. Most of the hall is a straight line, along which there are four mild curves, and one bridge. The main road is characterized by a large number of percussion holes, damaged carriageway and very poor roadblock status, making it the lowest scoring on the scale. The second location, Lug, represents the M16.1 main road, from Derventa towards Prnjavor. This layout of the main road M16.1 is a route along which there are no curves. The condition of the carriageway is rated as good, with curbside and protective equipment alongside the road. The location of Lužani is rated at grade 3 because of the fact that on this section of main road M14.1 from Derventa towards Brod, there is a major damage on road. Except for that, the grade "poor" was given because there are two sharp curves on this part of the road, one of which is steep.

Criterion number seven, traffic elements, was evaluated by linguistic scale, as poor (P) for location one, and medium (M) for location number two and three. Location number one is rated poor (P) because of no placed vertical signaling at all the necessary locations along the layout. Edge lines as well as dividing lines in certain places are not sufficiently noticeable, especially in night conditions. Location number two and three are rated as medium (M) because there are adequate vertical signaling on these sections of the road. All traffic signs are in a good condition. Horizontal signaling is well known, visible in day and night conditions.

Table 4 Initial decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1	5	5	7	3	5	3
L_2	5	7	7	7	7	5	5
L_3	5	5	3	5	3	7	5
	min	min	min	min	max	min	max
	1	5	3	5	7	5	5

Step 2 Normalization of the initial matrix using Eqs. (7), (8). Normalization of the initial matrix (Table 5) has been done according to the type of criteria. If it is maximum, we use equation (7), and if it is minimum we use equation (8). The first example represents the minimum criteria, and the second example represents the maximum criteria.

$$n_{21} = \frac{1}{5} = 0.200$$

$$n_{15} = \frac{3}{7} = 0.429$$

Table 5 Normalization of the initial decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1.000	1.000	0.600	0.714	0.429	1.000	0.600
L_2	0.200	0.714	0.429	0.714	1.000	1.000	1.000
L_3	0.200	1.000	1.000	1.000	0.429	0.714	1.000

Step 3 Weighting of the normalized matrix is done in such a way that the previous (normalized) matrix is multiplied by the weight coefficients, by using equation (10). Table 6 represents the normalized matrix with weight coefficients which is used to form weighted normalized matrix.

Table 6 Normalized initial matrix with weight coefficients

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1.000	1.000	0.600	0.714	0.429	1.000	0.600
L_2	0.200	0.714	0.429	0.714	1.000	1.000	1.000
L_3	0.200	1.000	1.000	1.000	0.429	0.714	1.000
w_{cj}	0.292	0.162	0.146	0.117	0.086	0.112	0.086

$$V_{11} = 0.292 \times 1.000 = 0.292$$

After using equation (10), like in the previous example, the normalized initial matrix is weighted (Table 7).

Table 7 Weighted normalized matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	0.292	0.162	0.088	0.084	0.037	0.112	0.052
L_2	0.058	0.116	0.063	0.084	0.086	0.112	0.086
L_3	0.058	0.162	0.146	0.117	0.037	0.080	0.086

Step 4 Summarizing all obtained values of the alternatives by using equation (11), (12) (summation in rows):

$$S_1 = 0.292 + 0.162 + 0.088 + 0.084 + 0.037 + 0.112 + 0.052 = 0.826$$

This step implies that every row in Table 7 must be summarized. By summing up every row, we form the next table, Table 8.

Table 8 Summation in rows

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	S_i
L_1	0.292	0.162	0.088	0.084	0.037	0.112	0.052	0.826
L_2	0.058	0.116	0.063	0.084	0.086	0.112	0.086	0.604
L_3	0.058	0.162	0.146	0.117	0.037	0.080	0.086	0.686

Step 5 Determination of the weighted product model by using Eqs. (13), (14):

$$P_1 = 1.000^{0,292} \times 1.000^{0,162} \times 0.600^{0,146} \times 0.714^{0,117} \times 0.429^{0,086} \times 1.000^{0,112} \times 0.600^{0,086} = 0.794$$

Weighted product model (Table 9) is formed by using Eqs. (13) and (14) as in the previous example. The weighted product model is used to determinate the relative values of the alternatives.

Table 9 Weighted product model

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	P_i
L_1	1.000	1.000	0.928	0.961	0.930	1.000	0.957	0.794
L_2	0.625	0.947	0.884	0.961	1.000	1.000	1.000	0.503
L_3	0.625	1.000	1.000	1.000	0.930	0.963	1.000	0.560

Step 6 Determination of the relative values of alternative A_i:

$$A_1 = 0.5 \times 0.828 + (1 - 0.5) \times 0.794 = 0.810$$

$$A_2 = 0.5 \times 0.604 + (1 - 0.5) \times 0.503 = 0.554$$

$$A_3 = 0.5 \times 0.686 + (1 - 0.5) \times 0.560 = 0.623$$

Step 7 Ranking of alternatives. The final step of the WASPAS method means ranking of alternatives by their values. By using the FUCOM method for determining the weight coefficients and the WASPAS method for ranking the locations, we have obtained that the best alternative is Location number 1 (Kninska Street). After location 1, the best ranked alternative is location 3; that is why location 2 represents the most dangerous location of the road in terms of traffic safety. All data about values of the alternatives is shown in Table 10.

Table 10 Ranking of alternatives

	Q_i	P_i	A_i
L_1	**0.826**	**0.794**	**0.810**
L_2	0.604	0.503	0.554
L_3	0.686	0.560	0.623

$$L_1 > L_3 > L_2$$

4.4 Sensitivity analysis

The results of the multi-criteria models can significantly be influenced by the values of degree of consistency λ. The value of λ goes from 0, 0.1, 0.2, ..., 1. That is why the analysis of the influence of values of λ on the results of the research is done. Therefore, in this part of the paper the sensitivity analysis of the ranks of alternatives to changes in value of λ is carried out. The sensitivity analysis is performed through ten situations. In every situation, values of λ is different, starting from 0,0.1,0.2, ...,1. The obtained ranges are shown in Fig. 4.

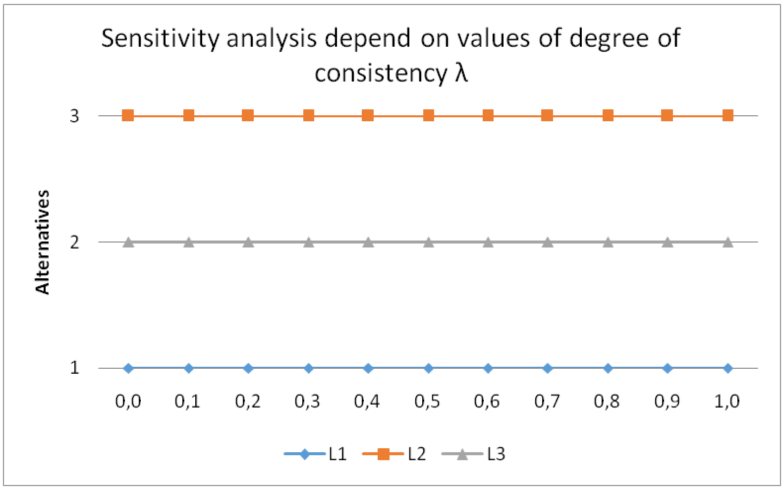

Fig. 4 Sensitivity analysis

After sensitivity analysis is done, the obtained results show that there is no difference in ranking dangerous sections of the road in the territory of the Municipality of Derventa. For all changes value of λ the ranking results are the same:

$$L_1 > L_3 > L_2$$

Location number 1 is the best ranked alternative. Location number 2 is the most dangerous sections of the road, and it is ranked as the third alternative.

5. Conclusion

This research study presents the use of the multi-criteria FUCOM-WASPAS model for ranking dangerous sections of the road in the Municipality of Derventa. The FUCOM-WASPAS model used in the study encompasses seven traffic safety criteria that are evaluated by the Linguistic scale presented in the paper. By applying the FUCOM-WASPAS model three different sections of the road were ranked. The results obtained were verified through the sensitivity analysis carried out on the basis of different values of degree of consistency λ. In every case, location Kninska Street was best ranked alternative, while the location Lug is ranked as the most dangerous section of the road, from all observed locations at the Municipality of Derventa.

In order to manage the safety of traffic, it is necessary to know the existing situation, which can include ranking dangerous sections of the road. The process of ranking the road sections would help us determine the locations having the priorities when it comes to making decisions about improvements in traffic safety. When we find out which section is the most dangerous section of the road, it is easier to take the management and every other measure to improve safety of traffic starting from the most dangerous section. Also, ranking of the road sections gives data to the traffic participants that would serve them as the basis for choosing a safer way to their finish line.

In addition, the model presented in this paper introduces new methodological principles for evaluating the dangerous sections of the road, which at the same time contributes to the improvement of theoretical basis of multi-criteria decision making in general. Future research related to this paper may imply the improvement of the proposed methodology by defining universal criteria for ranking dangerous sections of the road and the possibility of developing new approaches in the area of multi-criteria decision-making.

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MULTI-CRITERIA FUCOM – FUZZY MABAC MODEL FOR THE SELECTION OF LOCATION FOR CONSTRUCTION OF SINGLE-SPAN BAILEY BRIDGE

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Abstract: *Selecting the most favorable location for construction of single-span Bailey bridge is ideal for applying multi-criteria decision making. In that regard, it has been developed a model for selecting the most favorable location. The first part of the model is based on the full consistency method (FUCOM), and it is used for the evaluation of weight coefficients of criteria. The second part of the model presents the fuzzification of the Multi-Attributive Border Approximation Area Comparison (MABAC) method, which is used in the evaluation of alternatives. Additionally, in the paper are presented basic criteria, based on which the selection is to be made*

Key words: *FUCOM, fuzzy MABAC method, single-span Bailey bridge, selection of location.*

1. Introduction – problem description

The set for launching Bailey bridge consists of a number of elements used to make single-span and multi-span bridges (bridges on standing supports) which are designed for overcoming dry and water barriers. These bridges are mounted on the banks, and after mounting their construction are launched over dry or water barrier (Slavkovic et al., 2013). They can be easily adapted to different length or capacity requirements. Their main disadvantage is large mass of the parts of the set, which can significantly slow down the mounting of the bridge itself. These sets are included in the engineering units of the Serbian Army. The bridges made of this material can be found throughout Serbia, and in some places they represent significant link between the two banks.

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The selection of location for mounting a single-span Bailey bridge is ideal field for the application of multi-criteria decision making methods. Potential locations where such bridges could be placed usually have significant differences that more or less affect the speed of assembly and human and material resources necessary during the construction process (Gordic et al., 2013). By correct selection of location for such bridge can be prevented potential problems in the process of its construction and later use.

In this paper, the selection of location for the construction of a single-span Bailey bridge is carried out using the FUCOM - fuzzy MABAC method. Weight coefficients of criteria are calculated using the FUCOM method, while for ranking alternatives is used fuzzy MABAC method.

Both methods are very young and have not been largely applied so far. The FUCOM method was developed in 2018 by Pamučar et al. (2018). In the same year Prentkovskis et al. (2018) used this method as a part of the model for Improving Service Quality Measurement. Crisp MABAC method was announced for the first time in 2015 by Pamučar and Ćirović (2015). As a new method, it has been noted by the researchers quickly, and now there are many papers using this method in problem consideration, independently or as a part of a hybrid model (Božanić et al., 2016a; Peng & Yang, 2016; Chatterjee et al., 2017; Hondro, 2018; Majchrzycka & Poniszewska, 2018; Ji et al., 2018; Peng & Dai, 2018). In some papers, the method is used in fuzzy environment (Roy et al., 2016; Xue et al., 2016; Sun et al., 2017; Hu et al., 2019; Yu et al., 2017), and it has also appeared combined with rough numbers (Sharma et al., 2018; Roy et al. 2017).

2. Methods

Considering that the hybrid FUCOM – fuzzy MABAC model consists of two methods, in the following section of the paper these two methods will be described in detail.

2.1. FUCOM

This method is a new MCDM method proposed in (Pamučar et al., 2018). In the following section, the procedure for obtaining the weight coefficients of criteria by using FUCOM is presented.

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria $C=\{C_1,C_2,...,C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{1}$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of “>” between these criteria in the expression (1)

Step 2. In the second step, a comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k=1,2,...,n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of the evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vector of the comparative priorities of the evaluation criteria are obtained, as in the expression: (2)

$$\Phi=\left(\varphi_{1/2},\varphi_{2/3},\ldots,\varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k+1)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, decision-makers define the comparative priority $\varphi_{k/(k+1)}$ among the observed criteria.

b) Based on a predefined scale for the comparison of criteria, decision-makers compare the criteria and thus determine the significance of each individual criterion in the expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of the criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}}=1$), a conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of using integer, decimal values or the values from the predefined scale for the pairwise comparison of the criteria.

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria $\left(w_1,w_2,\ldots,w_n\right)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions: (1) that the ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

$$\frac{w_k}{w_{k+1}}=\varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (3), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)}\otimes\varphi_{(k+1)/(k+2)}=\varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)}=\frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)}=\frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}}\otimes\frac{w_{k+1}}{w_{k+2}}=\frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}}=\varphi_{k/(k+1)}\otimes\varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}}=\varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}}=\varphi_{k/(k+1)}\otimes\varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi=0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of the weight coefficients $(w_1, w_2, ..., w_n)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of the value χ. In that manner the requirement for maximum consistency is satisfied.

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$
\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \chi,\ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \ge 0,\ \forall j
\end{aligned}
\tag{5}
$$

2. 2. Fuzzy MABAC method

The MABAC method is developed by (Pamučar & Ćirović, 2015). It is developed as the method providing crisp values. In this paper is carried out its fuzzification. The fuzzyfication is performed using triangular fuzzy numbers. A general form of triangular fuzzy number is given in the Figure 1.

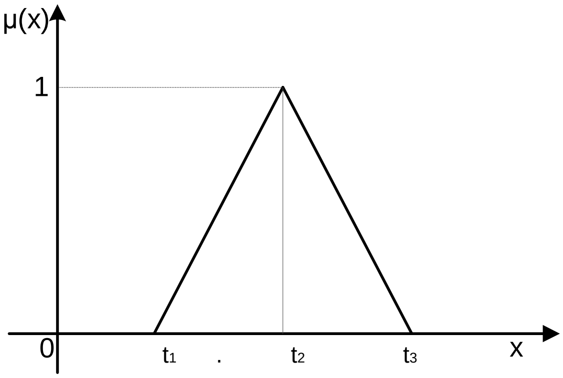

Figure 1. Triangular fuzzy number

Triangular fuzzy numbers have the form $\tilde{T} = (t_1, t_2, t_3)$. Value t_1 represents the left distribution of the confidence interval of fuzzy number T, t_2 is where the fuzzy number membership function has the maximum value - equal to 1, and t_3 represents the right distribution of the confidence interval of fuzzy number $\tilde{T}$ (Pamučar, 2011).

The fuzzyfication of the MABAC method is taken from (Božanić et al., 2018), and its mathematical formulation is presented in seven steps.

Step 1. Forming of the initial decision matrix ($\tilde{X}$). In the first step the evaluation of m alternatives by n criteria is performed. The alternatives are shown by vectors $A_i = \left(\tilde{x}_{i1}, \tilde{x}_{i2} ..., \tilde{x}_{in}\right)$, where x_{ij} is the value of the i alternative by j criterion (i = 1,2, ... m; j = 1,2, ..., n).

$$\tilde{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{1m} & \tilde{x}_{2m} & \dots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{6}$$

where m denotes the number of the alternatives, and n denotes total number of criteria.

Step 2. Normalization of the initial matrix elements ($\tilde{X}$).

$$\tilde{N} = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \dots & \tilde{t}_{1n} \\ \tilde{t}_{11} & \tilde{t}_{22} & & \tilde{t}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{t}_{1m} & \tilde{t}_{2m} & \dots & \tilde{t}_{mn} \end{bmatrix} \end{array} \tag{7}$$

The elements of the normalized matrix ($\tilde{N}$) are obtained by using the expressions:

For benefit-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{8}$$

For cost-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{9}$$

where x_{ij}, x_i^+ and x_i^- represent the elements of the initial decision matrix ($\tilde{X}$), whereby x_i^+ and x_i^- are defined as follows:

$x_i^+ = \max(x_{1r}, x_{2r}, \dots, x_{mr})$ and represent the maximum values of the right distribution of fuzzy numbers of the observed criterion by alternatives.

$x_i^- = \min(x_{1l}, x_{2l}, \dots, x_{ml})$ and represents minimum values of the left distribution of fuzzy numbers of the observed criterion by alternatives

Step 3. Calculation of the weighted matrix ($\tilde{V}$) elements

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \dots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \dots & \tilde{v}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & \dots & \tilde{v}_{mn} \end{bmatrix} \tag{10}$$

The elements of the weighted matrix ($\tilde{V}$) are calculated on the basis of the expression (11)

$$\tilde{v}_{ij} = w_i \bullet \tilde{t}_{ij} + w_i \tag{11}$$

where $\tilde{t}_{ij}$ represent the elements of the normalized matrix ($\tilde{N}$), w_i represents the weighted coefficients of the criterion.

Step 4. Determination of the approximate border area matrix ($\tilde{G}$). The border approximate area for every criterion is determined by the expression (12):

$$\tilde{g}_i = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{12}$$

where $\tilde{v}_{ij}$ represent the elements of the weighted matrix ($\tilde{V}$), m represents total number of alternatives.

After calculating the value of $\tilde{g}_i$ by criteria, a matrix of border approximate areas $\tilde{G}$ is developed in the form n x 1 (n represents total number of criteria by which the selection of the offered alternatives is performed).

$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \tilde{G} = & \left[\begin{array}{cccc} \tilde{g}_1 & \tilde{g}_2 & \cdots & \tilde{g}_n \end{array} \right] \end{array} \tag{13}$$

Step 5. Calculation of the matrix elements of alternatives distance from the border approximate area ($\tilde{Q}$)

$$\tilde{Q} = \begin{bmatrix} \tilde{q}_{11} & \tilde{q}_{12} & \cdots & \tilde{q}_{1n} \\ \tilde{q}_{21} & \tilde{q}_{22} & & \tilde{q}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{q}_{m1} & \tilde{q}_{m2} & \cdots & \tilde{q}_{mn} \end{bmatrix} \tag{14}$$

The distance of the alternatives from the border approximate area ($\tilde{q}_{ij}$) is defined as the difference between the weighted matrix elements ($\tilde{V}$) and the values of the border approximate areas ($\tilde{G}$).

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{15}$$

The values of alternative $\tilde{A}_i$ may belong to the border approximate area ($\tilde{G}$), to the upper approximate area ($\tilde{G}^+$), or to the lower approximate area ($\tilde{G}^-$), i.e., $\tilde{A}_i \in \left\{ \tilde{G} \vee \tilde{G}^+ \vee \tilde{G}^- \right\}$. The upper approximate area ($\tilde{G}^+$) represents the area in which the ideal alternative is found (A^+), while the lower approximate area ($\tilde{G}^-$) represents the area where the anti-ideal alternative is found (A^-), as presented in the Figure 2.

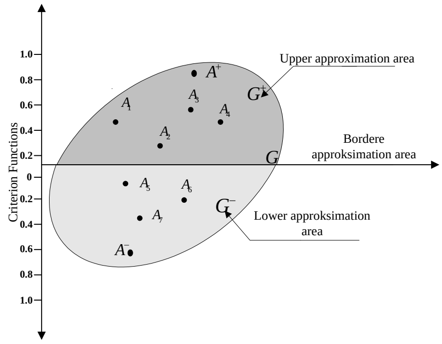

Figure 2. Display of upper ($\tilde{G}^{+}$), lower ($\tilde{G}^{-}$) and border ($\tilde{G}$) approximate area (Pamučar & Ćirović, 2015)

The membership of alternative $\tilde{A}_i$ to the approximate area ($\tilde{G}$, $\tilde{G}^{+}$ or $\tilde{G}^{-}$) is determined by the expression

$$\tilde{A}_i \in \begin{cases} \tilde{G}^{+} \text{ if } \tilde{q}_{ij} > 0 \\ \tilde{G} \text{ if } \tilde{q}_{ij} = 0 \\ \tilde{G}^{-} \text{ if } \tilde{q}_{ij} < 0 \end{cases} \tag{16}$$

For alternative $\tilde{A}_i$ to be chosen as the best from the set, it is necessary for it to belong, by as many as possible criteria, to the upper approximate area ($\tilde{G}^{+}$). The higher the value $\tilde{q}_i \in \tilde{G}^{+}$ indicates that the alternative is closer to the ideal alternative, while the lower the value $\tilde{q}_i \in \tilde{G}^{-}$ indicates that the alternative is closer to the anti-ideal alternative.

Step 6. Ranking of alternatives. The calculation of the values of the criteria functions by alternatives is obtained as the sum of the distance of alternatives from the border approximate areas ($\tilde{q}_i$). By summing up the matrix $\tilde{Q}$ elements per rows, the final values of the criteria function of alternatives are obtained

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij},\ j = 1, 2, \ldots, n,\ i = 1, 2, \ldots, m \tag{17}$$

where n represents the number of criteria, and m is the number of alternatives.

Step 7. Final ranking of alternatives. By defuzzification of the obtained values $\tilde{S}_i$, the final rank of alternatives is obtained. The defuzzification can be performed with the next expressions (Seiford, 1996):

$$\text{defazzy } S = \left[(t_3 - t_1) + (t_2 - t_1) \right] 3^{-1} + t_1 \tag{18}$$

$$\text{defazzy } S = \left[\lambda t_3 + t_2 + (1-\lambda) t_1 \right] 2^{-1} \tag{19}$$

3. Description of criteria and calculation of weight coefficients

The criteria for selecting the most favorable location for a single-span Bailey bridge are defined based on the analysis of the available literature. The analysis sets out seven key criteria that have the greatest influence on the selection, and they are the following (Kočić, 2017):

C1- Access roads
C2- Scope of work on site arrangement
C3- Properties of banks
C4- Width of water barrier
C5- Masking conditions
C6- Scope of works on joining access roads with the crossing point
C7- Protection of units

The concept of access roads (C1) refers to the number and quality of the roads by which the resources are brought to the location for construction and launching of the bridge over the water barrier, or close to it. These are the roads with adequate surface which does not require significant repairs and reconstructions. Through this criterion several elements are considered: capacity, number and width of access roads, as well as the position of roads in relation to the barrier (administrative or lateral) (Pamučar et al., 2011).

The scope of work on site arrangement (C2) represents the workload required for the site arrangement. In other words, it refers to the works necessary for arranging a place of work, where the space for storage of the parts of the set is arranged, parking of motor vehicles, place for stuff operation, space for rest, material disposal, and space for assembly and launching of the bridge (Božanić, 2017).

Properties of the banks (C3) refer to the soil composition of the bank, height of the bank, slope of the bank, forestation, artificial barriers, and the like.

The width of water barrier (C4) is defined as the distance from one bank to the other, measured by the surface of water (Pifat, 1980).

Masking conditions (C5) include measures and procedures undertaken to hide the activities and arrangement of the forces, assets and objects from the enemy, in order to lead the enemy to wrong conclusions, to make wrong decisions and apply wrong actions (Rkman, 1984).

Scope of works on joining access roads with the crossing point (C6) refers to the roads that ensure moving the unit from the nearest access road to the crossing point over the water barrier.

Unit protection (C7) is an integral and essential part of every operation. This criterion includes the assessment of the measures that must be taken to ensure required level of unit protection.

The set of criteria from C1 to C7 consists of two subsets:

The "C +" is a set of criteria of the benefit type, which means that the higher value of criteria is more favorable (the criteria C1, C3, C5 and C7), and

the"C -" is a set of criteria of the cost type, which means that the lower value of criteria is more favorable (the criteria C2, C4 and C6).

The criterion C4 is presented as numerical, while the other criteria are presented as linguistic.

The weight coefficients of criteria are obtained by applying the FUCOM method. The evaluation of the weight coefficients is performed by 9 decision makers (DM) – experts in the field of the subject matter. For all decison makers is carried out the evaluation of competence.

In the first step, the decision makers ranked the criteria. After several rounds of harmonization, three groups of ranks of criteria appeared, which are as follows:

- DM1, DM2, DM6, DM7, DM8 and DM9: C1>C2>C3>C4>C5>C6,>C7,
- DM3 and DM5: C1>C2>C5>C4>C3>C6,>C7
- DM4: C2>C1>C3>C4>C5>C6,>C7.

In the second step, the decision makers compared in pairs the ranked criteria from the step 1. The comparison is made according to the first-ranked criterion, based on the scale $\left[1,7\right]$. This is how the importance of the criteria is obtained ($\varpi_{C_{j(k)}}$) for all the criteria ranked in the step 1 (Table 1).

Table 1. Importance of criteria

DM1							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2	2.5	3	3.1	4	5.5
DM2							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2.5	3	3.5	4	5	5
. . .				. . .			
DM9							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2	2.1	3	4	4.5	6

Finally, in the third step and based on the comparison performed by DM, applying the expressions 3-5 are obtained the values presented in the Table 2.

Table 2. Weight coefficient of criteria by every DM individually

DM1							
Criteria	C1	C2	C3	C4	C5	C6	C7
w_j	0.335	0.167	0.134	0.112	0.108	0.084	0.061
DM2							
Criteria	C1	C2	C3	C4	C5	C6	C7
w_j	0.375	0.150	0.125	0.107	0.094	0.075	0.075
. . .				. . .			
DM9							
Criteria	C1	C3	C2	C4	C5	C6	C7
w_j	0.339	0.170	0.162	0.113	0.085	0.075	0.057

Having been obtained the weight coefficients of criteria by every DM, it is performed the calculation of the aggregated weight coefficient. Such calculation was carried out by subsequent synthesis of individual decisions by the method of averaging using geometric mean (*Geometric Mean Method – GMM*) applying the expression (Zoranović & Srđević, 2003):

$$A_i^G = \prod_{k=1}^{K} \left[a_i(k) \right]^{b_k} \tag{20}$$

where:

A_i^G – aggregated value of the weight coefficient,

$a_i(k)$ – value of the weight coefficient for every k-th DM where k=1,...K,

b_k – additionally normalized competence coefficient of the k-th DM;

Final, aggregated values of the weight coefficients are presented in the Table 3.

Table 3. Final weight coefficient of criteria

Criteria	Weight coefficient of criteria
C1	0.311
C2	0.198
C3	0.137
C4	0.112
C5	0.098
C6	0.079
C7	0.065

4. Model testing

The testing of the model, respectively, fuzzy MABAC method is performed with six alternatives. Before the very beginning of the testing, fuzzy linguistic descriptors had been defined which were used to describe linguistic criteria

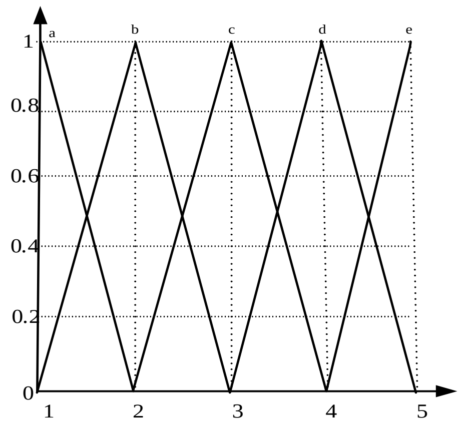

Figure 3. Graphic display of fuzzy linguistic descriptors (Božanić et al., 2016b)

Every criterion can be described with five values:

C1, C3, C5 and C7: a=very bad (VB), b=bad (B), c=medium (M), d=good (G) and e=excellent (E).

C2 and C6: a=very small (VS), b=small (S), c=medium (M), d=large (L), e=very large (VL).

The initial decision making matrix is shown in the Table 4.

Table 4. Initial decision making matrix

	C1	C2	C3	C4	C5	C6	C7
A1	M	L	E	(45,50,56)	M	VS	VB
A2	G	S	M	(39,44,47)	VB	VL	G
A3	VB	VL	G	(47,51,56)	E	S	M
A4	B	M	VB	(46,48,51)	G	VS	VB
A5	M	L	B	(38,42,45)	E	L	G
A6	E	M	G	(45,47,51)	G	S	B

The quantification of linguistic descriptors is shown in the Table 5.

Table 5. Quantification of linguistic descriptors

	C1	C2	C3	C4	C5	C6	C7
A1	(2,3,4)	(3,4,5)	(4,4,5)	(45,50,56)	(2,3,4)	(1,1,2)	(1,1,2)
A2	(3,4,5)	(1,2,3)	(2,3,4)	(39,44,47)	(1,1,2)	(4,4,5)	(3,4,5)
A3	(1,1,2)	(4,4,5)	(3,4,5)	(47,51,56)	(4,4,5)	(1,2,3)	(2,3,4)
A4	(1,2,3)	(2,3,4)	(1,1,2)	(46,48,51)	(3,4,5)	(1,1,2)	(1,1,2)
A5	(2,3,4)	(3,4,5)	(1,2,3)	(38,42,45)	(4,4,5)	(3,4,5)	(3,4,5)
A6	(4,4,5)	(2,3,4)	(3,4,5)	(45,47,51)	(3,4,5)	(1,2,3)	(1,2,3)

Applying steps 1 to 7 of the fuzzy MABAC method, final values for every alternative are obtained, which allow ranking alternatives and selecting the most favorable location for the construction of a Bailey bridge. The Table 6 shows final results by alternatives

Table 6. Ranking of alternatives

	Fuzzy MABAC method		Crisp MABAC method	
	Si	Rank	Si	Rank
A1	0.027	3	0.022	4
A2	0.127	2	0.175	2
A3	-0.110	6	-0.174	6
A4	-0.079	5	-0.077	5
A5	0.021	4	0.073	3
A6	0.168	1	0.219	1

As can be noted in the Table 6, the rank of criteria slightly differs when applying crisp and fuzzified MABAC method. The main difference is in the ranking of alternatives A1 and A5. It is also noted that the obtained values by alternatives are not the same, but that does not have a significant influence to the rank of criteria.

5. Sensitivity analysis

In this section is presented sensitivity analysis, as a logical sequence of the development of the multi-criteria decision-making model.The sensitivity assessment was done by changing the weight coefficients of the criteria, using seven different scenarios, where in each scenario the second criterion was favorable (Pamučar et. al. 2017). The display of weight coefficients according to the scenarios is given in Table 7.

Table 7. Weight coefficient in different scenario

Criteria	S-0	S-1	S-2	S-3	S-4	S-5	S-6	S-7
C1	0.311	0.4	0.1	0.1	0.1	0.1	0.1	0.1
C2	0.198	0.1	0.4	0.1	0.1	0.1	0.1	0.1
C3	0.137	0.1	0.1	0.4	0.1	0.1	0.1	0.1
C4	0.112	0.1	0.1	0.1	0.4	0.1	0.1	0.1
C5	0.098	0.1	0.1	0.1	0.1	0.4	0.1	0.1
C6	0.079	0.1	0.1	0.1	0.1	0.1	0.4	0.1
C7	0.065	0.1	0.1	0.1	0.1	0.1	0.1	0.4

The values obtained by applying different scenarios are given in Table 8.

Table 8. Ranking of alternatives by applying different scenarios

Alter. index	S-1		S-2		S-3		S-4		S-5		S-6		S-7	
	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank
A1	0.024	4	-0.020	5	0.149	1	-0.034	4	-0.021	5	0.131	1	-0.071	5
A2	0.113	2	0.143	1	0.038	4	0.097	2	-0.132	6	-0.105	6	0.143	2
A3	-0.114	6	-0.084	6	0.086	2	-0.064	6	0.091	3	0.067	3	0.040	3
A4	-0.098	5	0.007	3	-0.148	6	-0.048	5	0.007	4	0.084	2	-0.118	6
A5	0.048	3	0.003	4	-0.027	5	0.134	1	0.128	1	-0.046	5	0.152	1
A6	0.189	1	0.094	2	0.064	3	0.051	3	0.094	2	0.046	4	0.019	4

Based on sensitivity analysis of the results from the Table 8, it can be observed that the model in the midst of change of weight coefficients provides also the change of ranks of the given alternatives. It is interesting to note, though, that the first-ranked alternative A6, no matter the scenario, not once was ranked as the fifth or the sixth, and the alternative A3 which was ranked as the last, not in one scenario appeared as the first one.

For the mathematical determination of the correlation of ranks, the values of Spirman's coefficient were used:

$$S = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2 - 1)} \tag{21}$$

where is:

- S - the value of the Spirman coefficient,
- Di - the difference in the rank of the given element in the vector w and the rank of the correspondent element in the reference vector,

– n - number of ranked elements.

The rank of each criterion - the alternative is determined based on the weight coefficient vector w=(w_1, w_2, ..., w_n).

Spirman's coefficient takes values from the interval [-1,1]. When the ranks of the elements completely coincide, the Spirman coefficient is 1 ("ideal positive correlation"). When the ranks are completely opposite, the Spirman coefficient is -1 ("ideal negative correlation"), that is, when S = 0 the ranks are unregulated.

Table 9. Spirman's coefficient values

	S-0	S-1	S-2	S-3	S-4	S-5	S-6	S-7
S-0	1	0.964	0.821	0.464	0.750	0.286	0.143	0.429
S-1		1	0.857	0.321	0.857	0.429	0.000	0.571
S-2			1	0.071	0.714	0.214	0.000	0.429
S-3				1	0.214	0.250	0.607	0.607
S-4					1	0.500	-0.071	0.786
S-5						1	0.286	0.696
S-6							1	-0.143
S-7								1

As observed from the table of Spearman's coefficient values, it ranges from -0.143 to 0.964. The differences in the ranks of alternatives point out the sensitivity of the model to changes of weight coefficients. On the other hand, low Spearman’s coefficient in certain scenarios indicates the necessity of careful evaluation of alternatives by criteria, because potential errors could reflect on the final rank of alternatives. What is important is that the values of Spearman’s coefficient, in relation to the S-0 strategy (according to calculated weight coefficients) are fairly high compared to all the other strategies.

6. Conclusions

The introduction of the model into the decision-making processes has proved to be very useful. In the specific case, deciding based on the application of the model has created the conditions for persons with less experience to make a decision. Also, this kind of decision making helps decision makers to perceive complete picture of the impact of all the conditions in which a Bailey bridge is constructed. On the other hand, deciding without applying the model creates the possibility of ignoring or neglecting a part of criteria during decision making.

The application of the fuzzified MABAC method is shown throughout the paper. It can be observed that the outputs in the application of crisp and fuzzified MABAC methods are not identical, which leaves space for further research. Certainly, fuzzified MABAC method provides greater scope for considering uncertainty, which is common in linguistic descriptors.

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METHODS FOR ASSIGNING WEIGHTS TO DECISION MAKERS IN GROUP AHP DECISION-MAKING

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Abstract: *The method known as the analytical hierarchy process (AHP), a theoretical and methodological concept of multi-criteria analysis, is increasingly used in solving various decision-making problems. AHP is an excellent support to both the individual and group decision-making process, however, the involvement of a greater number of decision makers complicates the process and requires a different approach to when an individual decides alone. The synthesis of individual decisions within a group can be done in various ways, but the problem is how to deal with different levels of consistency when there are a number of decision makers. Thus, this paper presents some of the methods for defining the individual weights of decision makers in group AHP decision making.*

Key words*: weights; decision makers; analytical hierarchy process; group decision making.*

1. Introduction

Decision making is as old as humanity itself. People have always made decisions (without even being aware of it), since decision making is, in fact, an integral part of everyday life. However, as life has become increasingly complex over time, it has also become necessary to master new knowledge in order to make the right decisions.

In order to support the work of individual or group decision makers with complex sets of diverse information that cross over at the psychological, technical and other levels during the decision-making process, various mathematical and computer tools have been developed to support the decision-making process. One of these tools is AHP.

Considering that the AHP is based on individual (subjective) opinion of a decision maker (DM) about decision-making issue, it is always better to make a decision in

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group context, as this reduces the risk of wrong assessment, as the problem is approached from different perspectives based on different knowledge and experience of decision makers, and finally, the decision made has greater legitimacy to be realized.

The objective of the research presented in this paper is to indicate the difference in significance of individual decision makers in group AHP synthesis. Basic assumption is founded on the attitude that individuality brings participants' subjectivity (education, knowledge, concentration, desire, etc.) into decision-making process, so a quality methodological procedure is necessary that would objectivise final (group) decision. Knowing the possibilities to define weights of decision makers directly contributes to the transparency of group decision.

The paper with introduction and conclusion consists of four parts. In the second part of the paper titled Analytical hierarchical process, mathematical basis of the AHP is presented. In the third section of the paper, a case study is used to present some of the methods for assigning individual weights to decision makers in group AHP. In the Conclusion - the fourth section of this paper, are pointed out key contributions of the conducted research and the directions for future research.

2. Analytical Hierarchy Process (AHP)

The Analytical Hierarchical Process (Saaty, 1980) is a method of multi-criteria analysis that is widely used in the world to support individual and group decision making (Eskobar et al., 2004; Vaidya & Kumar, 2006; Altuzarra et al., 2007; Ho, 2008; Arnette et al., 2010; Subramanian & Ramanathan, 2012; Bernasconi et al., 2014). The method is both "analytic" and "hierarchical" because a decision maker decomposes complex problem of decision-making into several decision-making elements between which he establishes hierarchy relation. The word "process" in the name of the method suggests that after the formation of the initial hierarchy of a decision making issue are allowed its iterative modifications (Saaty, 1999). The hierarchy of the decision making issue has several levels, with the goal at the top of the hierarchy; the following level contains the criteria, while the alternatives are at the bottom. Such hierarchical setting refers to standard decision-making problem, but there are also cases where the hierarchy has four and more levels, respectively, when there are sub-criteria between criteria and alternatives. Also, there are decision making issues in which the hierarchy has two levels, and then only alternatives are below the goal.

After setting the hierarchy, the decision maker compares pairs of elements at a given level of hierarchy with respect to all the elements at the higher level (superiors), in order to determine their mutual importance. In standard AHP, the elements are compared by providing linguistic (semantic) evaluations of mutual importance in relation to the elements at the higher level of the hierarchy using basic scale in the Table 1 (Saaty, 1980).

In addition to Saaty's scale, other scales can also be used, such as Lootsma's (Lootsma, 1988; Lootsma, 1990; Lootsma et al., 1990), Ma & Zheng's (Ma & Zheng, 1991), balanced, etc., but the Saaty 's scale is used mostly. Linear part of the Saaty's scale consists of integers [1,9], and non-linear part of its reciprocal values [1,1/9].

When a DM at the given level of hierarchy evaluates n elements of the decision-making process as compared to the superior element according to the scale shown in the Table 1, its semantic ratings according to the definitions in the left column are expressed as numerical values from the right column and recorded in a square matrix A.

Table 1. Saaty 's relative importance scale

Definition	Numerical value
Absolute dominance of the element i over the element j	9
Very strong dominance of the element i over the element j	7
Strong dominance of the element i over the element j	5
Weak dominance of the element i over the element j	3
The same importance of the elements i and j	1
Weak dominance of the element j over the element i	1/3
Strong dominance of the element j over the element i	1/5
Very strong dominance of the element j over the element i	1/7
Absolute dominance of the element j over the element i	1/9
(Intervalues)	(2,4,6,8)

The matrix is positive and reciprocal (symmetrical in relation to the main diagonal). In other words, the elements from the top of triangle of the matrix are reciprocal to the elements from the bottom of triangle, and the elements on the main diagonal are equal to 1 ($a_{ij} = 1/a_{ij}$, for every i and j; $a_{ii} = 1$ for every i), as shown in the relation 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

If using standard Saaty 's scale, then every a_{ij} can have one of 17 values from a discrete interval [1/9,9]. Determining weights of the compared elements based on numerical values of the matrix A is called prioritization. Prioritization shows a process of determining of priority vectors $w = (w_1, \ldots, w_n)^T$ from the matrix A, where every $w_i > 0$ and it's true $\sum_{i=1}^{n} w_i = 1$. There are several matrix and optimization methods of prioritization (Table 2), but the most commonly used methods are eigenvalue method, logarithmic least square method and the method of additive normalization (Blagojević, 2015).

Table 2. Prioritization methods and their authors

Prioritization methods	Authors of the method
Eigenvector method – EV	Saaty (1980)
Additive normalization method – AN	Saaty (1980)
Weighted least squares method – WLS	Chu et al. (1979)
Logarithmic least squares method – LLS	Crawford & Williams (1985)
Logarithmic goal programming method – LGP	Bryson (1995)
Fuzzy preference programming method – FPP	Mikhailov (2000)

Due to its simplicity and frequent use, as the example shown in this paper is used the method of additive normalization (AN). To obtain a priority vector w it is enough to divide each element from the given column of the matrix A with the sum of the elements of this column (normalization), then to sum up the elements in each row and finally to divide each resulting sum with the rank of the matrix A. This procedure is described by the relations 2 and 3:

$$a_{ij}' = \sum_{i=1}^{n} a_{ij}, ij = 1, 2, \ldots, n \tag{2}$$

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}'}{n}, i = 1, 2, \ldots, n \tag{3}$$

Based on the evaluation, by selected prioritization method are determined local weights of decision-making elements, and by synthesis, that is, additive synthesis, at the end are determined weights of alternatives at the lowest level in relation to the element at the highest level (goal), thus completing individual deciding using the AHP. The additive synthesis is presented with the relation 4:

$$u_i = \sum_j w_j d_{ij} \tag{4}$$

where in:

- u_i – final (global) priority of the alternative i;
- w_j – weight of the criterion j;
- d_{ij} – local weight of the alternative i in relation to the criterion j;

In addition to the prioritization method, one of essential characteristics of the AHP is that at all levels of the hierarchy consistency of the decision makers' evaluation is checked. For testing consistency, Saaty (1977) proposed consistency ratio (CR) used in the AN prioritization method. Calculating the consistency ratio consists of two steps. In the first step, the consistency index (CI) is calculated using the relation 5:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

where in:

- n – the rank of the matrix;
- λ_{max} – the maximum eigenvalue of the comparison matrix;

In the second step, the consistency ratio (CR) is calculated as the relationship of the consistency index (CI) and the random index (RI):

$$CR = \frac{CI}{RI} \tag{6}$$

The random index (RI) depends on the rank of the matrix and its values are obtained in random generation of 500 matrices (Table 3).

Table 3. Random index values depending on the matrix rank

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

If the consistency ratio (CR) is lower or equal to 0, 10 the result indicates that the decision maker was consistent and there is no need for the re-evaluation (Jandrić Srđević, 2000). If the consistency ratio (CR) is higher than 0.10, the decision maker should repeat (or modify) his evaluation in order to improve consistency.

Important feature of the AHP is sensitivity analysis of the final solution. The sensitivity analysis is carried out in order to see the extent to which the changes in the input data reflect the changes in the obtained results (Nikolić & Borović, 1996). In order to conclude whether the ranking list of the alternatives is sufficiently stable in relation to acceptable changes in input data, it is recommended to check the priority of alternatives for different combinations of input data. This analysis is very easily performed using software packages (softwares) to support decision making. One of the most commonly used is Expert Choice, which offers five sensitivity analysis options: Dynamic, Performance, Gradient, Head to head and 2D . The analysis can be done based on the goal or any other element in the hierarchy. Sensitivity analysis based on the goal node shows the sensitivity of alternatives to all elements in the hierarchical tree structure.

The stability of the results is performed using dynamic sensitivity analysis (option Dynamic). If the rank of the alternatives remains unchanged when alternating the importance of the main criteria by 5% in all combinations, the result is considered to be stable (Hot, 2014) . The AHP algorithm implementation is shown in the Figure 1.

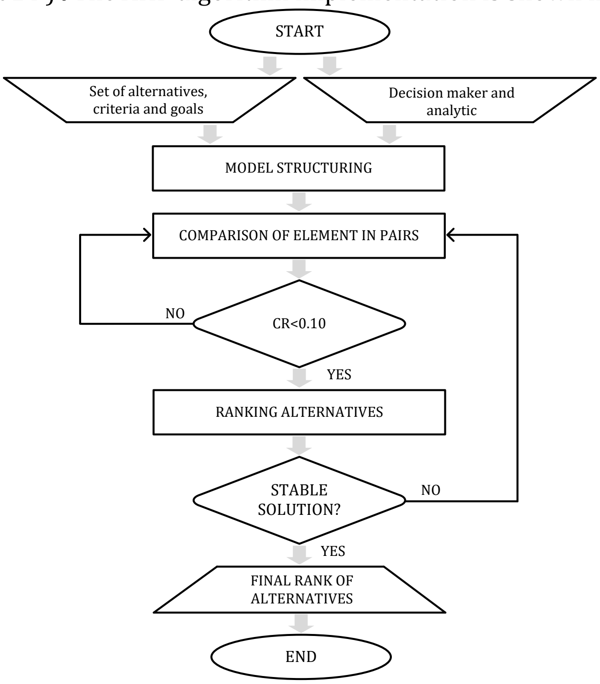

Figure 1. The AHP algorithm (Hot, 2014)

In the AHP there are several ways to consolidate individual decisions in group equivalents (Blagojević, 2015):

- Aggregation of Individual Priorities - AIP;
- Aggregation of Individual Judgments – AIJ;
- Consensus Model Convergence – CCM;
- Geometric Cardinal Consensus model – GCCM;

However, the synthesis of individual results of the AHP application and making group decision requires prior determination of individual weights of decision makers. This is a specific problem, which is especially difficult if there is no institutional framework defining this issue. Therefore, in this paper several possibilities of determining the criteria for defining weights of individual members of the group are presented.

3. Possibilities of defining individual weights of group members

According to the described methodology for the implementation of the AHP, it is discussed the hierarchy of decision making problems taken from (Lukovac, 2016), Figure 2, which consists of three levels.

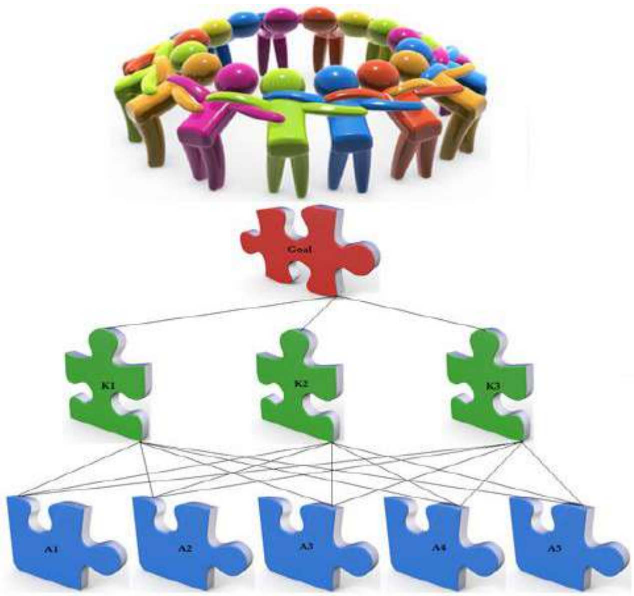

Figure 2. Hierarchy of decision making problems (Lukovac, 2016)

The goal is to "rank" the persons who can be included as assessors in the process of assessing the performance of drivers, and it is at the top of the hierarchy.

The ranking criteria are at the following – intermediate level, which include:

- Knowledge of the work to be evaluated (K1);
- The best possible insight into the work to be evaluated (K2);
- Objectivity, impartiality, in the evaluation process (K3);

Alternatives (participants in evaluating assessors) represent the subjects of ranking and they are at the lowest level of the hierarchy, which are:

- Superior (A1);

– Dispatcher (A2);
– Colleague (A3);
– Client (A4);
– Self-assessment (A5);

The expert group consisted of twenty decision makers (DMs) to which the assessment of the performances of direct executors - the drivers, was one of the obligations arising from the functional duty they performed. The decision makers compared the elements presented in a hierarchy in pairs using Expert Choice 2000 software, which automatically calculates the reciprocal values, so consequently only the elements in the so-called upper triangles of the comparison matrices are evaluated. The comparison matrices of the decision makers are presented in Tables 4 to 10.

Table 4. The comparison matrices of DM 1to DM 3

DM 1						DM 2						DM 3					
Goal						Goal						Goal					
	K1	K2	K3				K1	K2	K3				K1	K2	K3		
K1	1	1	1			K1	1	1	1			K1	1	1/2	1/2		
K2		1	1			K2		1	1			K2		1	1		
K3			1			K3			1			K3			1		
K1						K1						K1					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	2	5	3	A1	1	1	1	6	3	A1	1	2	1	6	2
A2		1	2	5	3	A2		1	1	6	3	A2		1	2	6	3
A3			1	3	2	A3			1	5	1	A3			1	4	1
A4				1	1	A4				1	1/4	A4				1	1/3
A5					1	A5					1	A5					1
K2						K2						K2					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	4	6	4	A1	1	1	4	6	4	A1	1	3	5	6	3
A2		1	4	6	4	A2		1	4	6	4	A2		1	2	5	2
A3			1	5	3	A3			1	5	3	A3			1	5	3
A4				1	1	A4				1	1	A4				1	1/2
A5					1	A5					1	A5					1
K3						K3						K3					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	3	5	7	A1	1	1	4	6	9	A1	1	2	5	7	9
A2		1	3	5	7	A2		1	4	6	9	A2		1	2	6	8
A3			1	3	5	A3			1	3	6	A3			1	4	7
A4				1	3	A4				1	6	A4				1	5
A5					1	A5					1	A5					1

Table 5. The comparison matrices of DM 4 to DM 6

DM 4					
Goal					
	К1	К2	К3		
К1	1	1	1		
К2		1	1		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	2	3	5	3
A2		1	2	6	2
A3			1	4	1
A4				1	½
A5					1
К2					
	A1	A2	A3	A4	A5
A1	1	2	4	6	3
A2		1	2	4	2
A3			1	4	3
A4				1	1
A5					1
К3					
	A1	A2	A3	A4	A5
A1	1	1	3	4	7
A2		1	3	4	7
A3			1	4	7
A4				1	4
A5					1

DM 4					
Goal					
	К1	К2	К3		
К1	1	1	1/2		
К2		1	1/2		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	2	2	9	2
A2		1	1	9	1
A3			1	9	2
A4				1	1/7
A5					1
К2					
	A1	A2	A3	A4	A5
A1	1	3	3	5	3
A2		1	3	5	3
A3			1	3	2
A4				1	1/2
A5					1
К3					
	A1	A2	A3	A4	A5
A1	1	2	4	6	9
A2		1	2	5	7
A3			1	3	6
A4				1	1/2
A5					1

DM 6					
Goal					
	К1	К2	К3		
К1	1	1	1		
К2		1	1		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	1	3	7	3
A2		1	2	8	2
A3			1	6	1
A4				1	1/2
A5					1
К2					
	A1	A2	A3	A4	A5
A1	1	1	2	5	1
A2		1	2	5	3
A3			1	6	3
A4				1	1/2
A5					1
К3					
	A1	A2	A3	A4	A5
A1	1	2	3	5	9
A2		1	3	5	8
A3			1	5	7
A4				1	4
A5					1

Table 6. The comparison matrices of DM 7 to DM 9

DM 7					
Goal					
	К1	К2	К3		
К1	1	1/2	½		
К2		1	1		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	1	3	7	3
A2		1	3	7	3
A3			1	7	1
A4				1	1/7
A5					1

DM 8					
Goal					
	К1	К2	К3		
К1	1	1	1		
К2		1	1		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	1	2	5	2
A2		1	2	5	2
A3			1	5	1
A4				1	1/3
A5					1

DM 9					
Goal					
	К1	К2	К3		
К1	1	1/2	1/2		
К2		1	1		
К3			1		
К1					
	A1	A2	A3	A4	A5
A1	1	1	1	5	1
A2		1	1	5	1
A3			1	5	1
A4				1	1/5
A5					1

K2						K2						K2					
	A1	A 2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1/2	2	7	2	A1	1	1	2	6	3	A1	1	1	2	5	2
A2		1	3	7	3	A2		1	2	6	3	A2		1	2	5	2
A3			1	3	2	A3			1	5	2	A3			1	4	1
A4				1	1/3	A4				1	1	A4				1	1
A5					1	A5					1	A5					1
K3						K3						K3					
	A1	A 2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	4	6	7	A1	1	1	1	5	7	A1	1	1	2	5	9
A2		1	4	6	7	A2		1	1	5	7	A2		1	2	5	9
A3			1	3	7	A3			1	5	7	A3			1	4	7
A4				1	3	A4				1	4	A4				1	4
A5					1	A5					1	A5					1

Table 7. The comparison matrices of DM 10 toDM 12

DM 10						DM 11						DM 12					
Goal						Goal						Goal					
	K1		K2		K3		K1		K2		K3		K1		K2		K3
K1	1		1		1	K1	1		1		1	K1	1		1		1
K2			1		1	K2			1		1	K2			1		1
K3					1	K3					1	K3					1
K1						K1						K1					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	1	4	1	A1	1	1	2	5	3	A1	1	2	2	7	4
A2		1	1	4	1	A2		1	2	5	3	A2		1	2	7	3
A3			1	4	1	A3			1	5	1	A3			1	5	1
A4				1	½	A4				1	1/4	A4				1	1/3
A5					1	A5					1	A5					1
K2						K2						K2					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	2	6	3	A1	1	1	2	5	3	A1	1	1	2	3	3
A2		1	2	6	3	A2		1	2	5	3	A2		1	2	3	3
A3			1	5	1	A3			1	3	1	A3			1	3	1
A4				1	1	A4				1	1/2	A4				1	1/3
A5					1	A5					1	A5					1
K3						K3						K3					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	2	3	4	8	A1	1	1	3	3	7	A1	1	1	2	3	7
A2		1	**3**	4	8	A2		1	3	3	7	A2		1	2	3	7
A3			1	4	8	A3			1	3	7	A3			1	3	7
A4				1	2	A4				1	3	A4				1	3
A5					1	A5					1	A5					1

Table 8. The comparison matrices of DM 13 to DM 15

Goal

DM 13				DM 14				DM 15			
	K1	K2	K3		K1	K2	K3		K1	K2	K3
K1	1	1	1	K1	1	1	1	K1	1	1	1
K2		1	1	K2		1	1	K2		1	1
K3			1	K3			1	K3			1

K1

DM 13						DM 14						DM 15					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	1	4	1	A1	1	1	1	3	2	A1	1	1	2	6	3
A2		1	1	4	1	A2		1	1	3	2	A2		1	2	6	3
A3			1	4	1	A3			1	3	1	A3			1	6	4
A4				1	½	A4				1	1/3	A4				1	1/3
A5					1	A5					1	A5					1

K2

DM 13						DM 14						DM 15					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	2	5	3	A1	1	1	2	4	3	A1	1	1	2	3	3
A2		1	2	5	3	A2		1	2	4	3	A2		1	2	3	3
A3			1	5	3	A3			1	3	1	A3			1	5	2
A4				1	½	A4				1	1/3	A4				1	1/3
A5					1	A5					1	A5					1

K3

DM 13						DM 14						DM 15					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	2	3	5	A1	1	1	2	4	6	A1	1	1	2	4	6
A2		1	2	3	5	A2		1	2	4	6	A2		1	2	4	6
A3			1	3	5	A3			1	3	5	A3			1	3	5
A4				1	3	A4				1	3	A4				1	3
A5					1	A5					1	A5					1

Table 9. The comparison matrices of DM 16 to DM 18

Goal

DM 16				DM 17				DM 18			
	K1	K2	K3		K1	K2	K3		K1	K2	K3
K1	1	1	1	K1	1	1/2	1/2	K1	1	1	1
K2		1	1	K2		1	1	K2		1	1
K3			1	K3			1	K3			1

K1

DM 16						DM 17						DM 18					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	1	6	2	A1	1	1	1	5	2	A1	1	2	3	7	4
A2		1	1	6	2	A2		1	1	5	2	A2		1	2	6	3
A3			1	6	2	A3			1	5	2	A3			1	5	2
A4				1	¼	A4				1	1/3	A4				1	1/3
A5					1	A5					1	A5					1

K2					
	A1	A2	A3	A4	A5
A1	1	1	2	4	3
A2		1	2	4	3
A3			1	4	2
A4				1	1/3
A5					1
K3					
	A1	A2	A3	A4	A5
A1	1	2	4	6	8
A2		1	3	5	7
A3			1	4	8
A4				1	3
A5					1

K2					
	A1	A2	A3	A4	A5
A1	1	1	2	5	4
A2		1	2	5	4
A3			1	4	2
A4				1	1/3
A5					1
K3					
	A1	A2	A3	A4	A5
A1	1	1	2	4	8
A2		1	2	4	8
A3			1	3	7
A4				1	4
A5					1

K2					
	A1	A2	A3	A4	A5
A1	1	1	2	3	4
A2		1	2	3	4
A3			1	3	2
A4				1	1/3
A5					1
K3					
	A1	A2	A3	A4	A5
A1	1	1	3	4	6
A2		1	3	4	6
A3			1	2	5
A4				1	3
A5					1

Table 10. The comparison matrices of DM 19 to DM 20

DM 19						DM 20					
Goal						Goal					
	K1	K2	K3				K1	K2	K3		
K1	1	1	1			K1	1	1	1		
K2		1	1			K2		1	1		
K3			1			K3			1		
K1						K1					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	1	1	2	6	3	A1	1	2	2	6	3
A2		1	2	5	3	A2		1	1	4	3
A3			1	4	2	A3			1	4	2
A4				1	1/3	A4				1	1/3
A5					1	A5					1
K2						K2					
	A 1	A 2	A 3	A 4	A5		A 1	A 2	A 3	A 4	A5
A1	1	2	3	7	4	A1	1	1	3	8	5
A2		1	2	4	3	A2		1	3	8	5
A3			1	3	1	A3			1	7	2
A4				1	1/3	A4				1	1/3
A5					1	A5					1
K3						K3					
	A 1	A 2	A 3	A 4	A5		A 1	A 2	A 3	A 4	A5
A1	1	3	4	6	7	A1	1	2	3	5	7
A2		1	3	4	6	A2		1	3	4	6
A3			1	3	6	A3			1	3	5
A4				1	3	A4				1	3
A5					1	A5					1

Table 11 presents the vectors of the priority alternatives for each decision maker, obtained by means of relations (1)–(6) based on data from the comparison matrices (Tables 4 to 10).

Table 11. Vectors of alternatives priorities by decision makers

Decision maker	Alternatives					*CR*
	Superior	Dispatcher	Colleague	Client	Self-assessment	
DM 1	0.351	0.351	0.165	0.066	0.068	0.02
DM 2	0.341	0.341	0.177	0.056	0.085	0.04
DM 3	0.433	0.257	0.171	0.055	0.083	0.05
DM 4	0.390	0.287	0.172	0.068	0.082	0.03
DM 5	0.424	0.253	0.181	0.045	0.098	0.03
DM 6	0.341	0.313	0.193	0.054	0.099	0.04
DM 7	0.327	0.381	0.150	0.051	0.090	0.03
DM 8	0.309	0.309	0.225	0.063	0.094	0.01
DM 9	0.303	0.303	0.203	0.067	0.127	0.02
DM 10	0.309	0.284	0.206	0.067	0.134	0.03
DM 11	0.330	0.330	0.170	0.068	0.101	0.02
DM 12	0.340	0.307	0.181	0.073	0.099	0.02
DM 13	0.286	0.286	0.224	0.076	0.128	0.01
DM 14	0.301	0.301	0.198	0.076	0.124	0.01
DM 15	0.317	0.317	0.213	0.066	0.088	0.02
DM 16	0.329	0.292	0.218	0.054	0.107	0.02
DM 17	0.319	0.319	0.211	0.067	0.084	0.01
DM 18	0.360	0.316	0.168	0.071	0.085	0.02
DM 19	0.405	0.284	0.16	0.057	0.094	0.02
DM 20	0.388	0.301	0.177	0.054	0.079	0.02

As during the implementation of dynamic alteration in sensitivity analysis of all important criteria by 5% in all combinations (optional Dynamic in Expert Choice software), there was no change in ranking of alternatives, the final results of the conducted individual AHP can be considered stable.

Since all DMs performed all the evaluations, the information base is complete, and thus is fulfilled one of the conditions for starting group syntheses of individual priority vectors from the Table 11. However, the synthesis of the individual results of the AHP application into a group decision requires prior defining of individual weights of DMs. By means of the case study, five methods for assigning individual weights to decision makers are considered (Lukovac, 2016).

"The first method" is to assign equal weights to all DMs and then synthesize a group decision (Srđević et al. 2004). This approach, however, does not treat individual DM consistency and is subject to manipulation and other irregularities. For example, if a DM had personal motive (relative-friendly relations, possibility of corruption, etc.), his ratings could be adjusted and/or inconsistent (to better rank the desired candidates) and would not have suffered any consequences in relation to his inconsistency (weights would remain the same as at other DMs).

According to this approach, in the specific case the weight (α_k) of all DM would be 0. 05 ($\alpha_k = 1/20$).

"The second method" is to assign to DMs the weights based on the values of Spearman's correlation coefficient which shows the compatibility of the individual

DM with the reference group decision where also his decision was taken into account (Srđević et al., 2009). Spearman's correlation coefficient (S) is calculated according to the relation 7.

$$S = 1 - \frac{6\sum_{i=1}^{n} D_a^2}{n(n^2-1)} \tag{7}$$

D_a is the difference between U_a and V_a, where U_a and V_a are the ranks for the alternative a by reference list and by list compared to the reference, and n is the number of alternatives. In a group context, the relation 7 is applied to each of the combinations (group list, the list for kth member of the group, that is, the Spearman's coefficient is calculated according to the number of the members of the group). Spearman's coefficient value may vary between theoretical values of – 1 and 1. When the value approaches to 1, the indication is that the ranks are the same or similar, and when the value approaches to zero and – 1, the ranks are reverse, or negatively correlated.

In this case, the highest weight obtains the DM whose decision was the closest to the group decision (the DM having the highest value of Spearman's coefficient), while the smallest weight obtains the DM whose decision was the furthest from the group decision. All DMs are scaled according to the value of Spearman's coefficient.

For the purpose of calculating the weights of DMs under this possibility, in the considered case, the first thing to be done is making group decision. Two basic and most commonly used ways for obtaining group decision in the AHP are the AIP and the AIJ (Ramanathan & Ganesh, 1994; Forman & Peniwati, 1998).

For consolidating individual decisions into the group one, in this case, the AIP method is used, which is characteristic for two aggregations:

(a) Weight Arithmetic Mean Weight Method – WAMM. It is provided the alternative A_i and its weight value (priority) $w_i^{(k)}$ for the k-th decision-maker. If all members of the group (g) are assigned appropriate weights α_k, the weight arithmetic mean is:

$$w_i^{(g)} = \sum_{k=1}^{m} w_i^{(k)} \alpha_k \tag{8}$$

where in:

– $w_i^{(g)}$ final (composite) priority of the alternative A_i.

– m number of decision makers (group members);

Assuming, individual weights α_k of the members of the group were previously additionally normalized, i.e., $\sum_{k=1}^{m} \alpha_k = 1$.

(b) Geometric Mean Method – GMM. In this method, the aggregation consists in applying the following expression:

$$w_i^{(g)} = \prod_{k=1}^{m} \left(w_i^{(k)} \right)^{\alpha_k} \tag{9}$$

The weights of group members (α_k) are also previously additionally normalized.

In the Table 12 are shown the results of the AIP synthesis of the individual DM priority vectors from the Table 11 in the case where DMs are assigned equal weights ($\alpha_k = 0.05$).

Table 12. The AIP synthesis for $\alpha_k = 0.05$

AIP	Superior	Dispatcher	Colleague	Client	Self-assessment
WAMM	0.345	0.307	0.188	0.063	0.097
GMM	0.345	0.307	0.188	0.063	0.097

From the Table 12 it can be seen that the identical values of group vector are obtained of alternatives priorities for both aggregations of the AIP synthesis (WAMM and GMM). With the synthesis carried out it is fulfilled the condition for calculating Spearman's correlation coefficient for every DM, respectively, for comparing individual DM decisions with a reference, group decision. In the Table 13 are shown the weights (α_k) assigned to the DM based on the obtained Spearman's coefficient of DM based on the correlation 7.

Table 13. DM weights based on S value

Decision maker	**S**	$\boldsymbol{\alpha_k}$
DM 1	0.975	0.050
DM 2	0.975	0.050
DM 3	1	0.051
DM 4	1	0.051
DM 5	1	0.051
DM 6	1	0.051
DM 7	0.9	0.046
DM 8	0.975	0.050
DM 9	0.975	0.050
DM 10	1	0.051
DM 11	0.975	0.050
DM 12	1	0.051
DM 13	0.975	0.050
DM 14	0.975	0.050
DM 15	0.975	0.050
DM 16	1	0.051
DM 17	0.975	0.050
DM 18	1	0.051
DM 19	1	0.051
DM 20	1	0.051

"The third method" is to determine the weights of the DMs based on their competency for solving given decision making problem (Lukovac, 2016). According to this approach, the competency coefficient for each DM is calculated. The obtained competence coefficients are later additionally normalized and assigned as weights of DMs. In the Table 14 are shown the weights (α_k) assigned to the DMs by the value calculated according to their competence ration according to the approach developed in (Lukovac, 2016).

Table 14. DM weights based on K value

Decision maker	**K**	α_k
DM 1	0.6706	0.054
DM 2	0.5624	0.046
DM 3	0.561	0.046
DM 4	0.5833	0.048
DM 5	0.5621	0.046
DM 6	0.5619	0.046
DM 7	0.5598	0.046
DM 8	0.6918	0.056
DM 9	0.7195	0.058
DM 10	0.5686	0.046
DM 11	0.6141	0.050
DM 12	0.6319	0.051
DM 13	0.6946	0.056
DM 14	0.6738	0.055
DM 15	0.6341	0.051
DM 16	0.6018	0.049
DM 17	0.6754	0.054
DM 18	0.5888	0.048
DM 19	0.6242	0.051
DM 20	0.5673	0.046

"The fourth method" is to assign to DMs weights obtained by normalizing reciprocal values of their consistency ratios (CR) (Srđević, 2008), Table 15.

Table 15. DM weights based on CR value

Decision maker	CR	1/CR	α_k
DM 1	0.02	50	0.047
DM 2	0.04	25	0.024
DM 3	0.05	20	0.019
DM 4	0.03	33.3333	0.032
DM 5	0.03	33.3333	0.032
DM 6	0.04	25	0.024
DM 7	0.03	33.3333	0.032
DM 8	0.01	100	0.095
DM 9	0.02	50	0.047
DM 10	0.03	33.3333	0.032
DM 11	0.02	50	0.047
DM 12	0.02	50	0.047
DM 13	0.01	100	0.095
DM 14	0.01	100	0.095
DM 15	0.02	50	0.047
DM 16	0.02	50	0.047
DM 17	0.01	100	0.095
DM 18	0.02	50	0.047
DM 19	0.02	50	0.047
DM 20	0.02	50	0.047

"The fifth method" is that the weights of the DMs are determined by the consistency ratio (CR) and total Euclidean distance (ED), explained in (Srđević et al., 2009). This possibility was developed in (Blagojević et al. , 2010) as a method consisting of the following steps:

1. For every DM, CR and ED are calculated from all comparison matrices;
2. All CR values for every DM are summed separately, and then the same procedure is repeated for ED values;
3. The reciprocal values of the CR and ED values are calculated for every DM;
4. Additive normalization is performed (the reciprocal value of a sum for one DM is divided by a sum of reciprocal values of the sums of all DMs), especially for CR and ED ;
5. For every DM, the mean value of the normalized values of CR and ED is calculated and it is adopted as its weight in the group AHP decision, respectively, $\alpha_k = (\text{NormCr} + \text{NormED}) / 2$.

Based on the data from the comparison matrices shown in (Lukovac, 2016), for the considered AHP example, in the Tables 16 – 19 the calculation of the weights of DMs based on CR and ED is described.

Table 16. Consistency and total Euclidean distance DM 1-DM 5

	DM 1		**DM 2**		**DM 3**		**DM 4**		**DM 5**	
	CR	ED	CR	ED	CR	ED	CR	ED	CR	ED
Goal	0	0	0	0	0	0	0	0	0	0
K1	0.008	1.109	0.032	2.026	0.044	1.867	0.023	2.896	0.022	4.364
K2	0.056	3.775	0.099	6.483	0.074	4.897	0.054	3.048	0.050	3.226
K3	0.031	3.532	0.079	6.979	0.086	8.032	0.065	4.885	0.063	4.955
Σ	0.096	8.416	0.210	15.488	0.204	14.796	0.142	10.829	0.135	12.546
1/Σ	10.43	0.12	4.75	0.06	4.90	0.07	7.02	0.09	7.41	0.08
Norm	0.046	0.052	0.021	0.028	0.022	0.030	0.031	0.041	0.033	0.035
α_k	0.049		0.025		0.026		0.036		0.034	

Table 17. Consistency and total Euclidean distance DM 6-DM 10

	DM 6		**DM 7**		**DM 8**		**DM 9**		**DM 10**	
	CR	ED	CR	ED	CR	ED	CR	ED	CR	ED
Goal	0	0	0	0	0	0	0	0	0	0
K1	0.029	3.098	0.046	5.800	0.012	2.025	0.000	0.000	0.013	1.514
K2	0.054	2.910	0.021	2.565	0.023	2.206	0.039	2.339	0.042	2.634
K3	0.076	5.836	0.064	5.757	0.032	3.441	0.026	3.638	0.059	4.867
Σ	0.158	11.844	0.130	14.122	0.067	7.672	0.065	5.977	0.114	9.015
1/Σ	6.32	0.08	7.71	0.07	14.93	0.13	15.42	0.17	8.78	0.11
Norm	0.028	0.037	0.034	0.031	0.066	0.057	0.068	0.074	0.039	0.049
α_k	0.032		0.033		0.062		0.071		0.044	

Table 18. Consistency and total Euclidean distance DM 11-DM 15

	DM 11		DM 12		DM 13		DM 14		DM 15	
	CR	ED	CR	ED	CR	ED	CR	ED	CR	ED
Goal	0	0	0	0	0	0	0	0	0	0
K1	0.026	3.057	0.024	3.049	0.013	1.514	0.018	1.284	0.034	2.836
K2	0.006	0.910	0.034	2.403	0.018	1.985	0.018	1.964	0.052	3.248
K3	0.047	3.900	0.019	2.601	0.027	2.469	0.020	2.482	0.020	2.482
Σ	0.079	7.866	0.078	8.053	0.059	5.968	0.055	5.730	0.106	8.567
1/Σ	12.63	0.13	12.88	0.12	16.95	0.17	18.02	0.17	9.43	0.12
Norm	0.056	0.056	0.057	0.055	0.075	0.074	0.079	0.077	0.041	0.051
α_k	0.056		0.056		0.074		0.078		0.046	

Table 19. Consistency and total Euclidean distance DM 16-DM 20

	DM 16		DM 17		DM 18		DM 19		DM 20	
	CR	ED	CR	ED	CR	ED	CR	ED	CR	ED
Goal	0	0	0	0	0	0	0	0	0	0
K1	0.002	0.874	0.001	0.456	0.019	3.260	0.011	1.724	0.017	1.906
K2	0.024	2.291	0.020	2.450	0.051	2.961	0.015	2.050	0.026	4.422
K3	0.069	6.330	0.020	3.294	0.021	3.172	0.070	5.971	0.045	4.003
Σ	0.096	9.495	0.041	6.200	0.092	9.393	0.096	9.745	0.087	10.331
1/Σ	10.45	0.11	24.33	0.16	10.91	0.11	10.41	0.10	11.43	0.10
Norm	0.046	0.046	0.107	0.071	0.048	0.047	0.046	0.045	0.050	0.043
α_k	0.046		0.089		0.047		0.046		0.046	

4. Conclusions

Decision making, especially at the strategic level, requires more participants in the decision-making process (experts), who have different preferences depending on institutional placements, interests, skills, education and the like. In order to maximally objectify group context, in the procedure of synthesis of individual decisions , in this paper, using specific case, several possibilities for grading individual preferences of decision makers in group AHP synthesis are presented.

It is important to emphasize also the difference between the terms "joint" and "group" decision. In the first case it is implied the consensus, and in the second not necessarily. Group context treated in this paper fits to another case, no harmonization is performed, no consultation among participants, and the results of individual evaluations are consolidated later.

Further research should be directed towards analyzing the AHP synthesis results for the shown possibilities of assigning weights to decision makers. The subject of the research should also be directed towards the consensus of decision makers and the so-called joint decision.

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