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SYNERGY EFFECTS OF NATURAL FUNGAL INHIBITORS CALCULATED BY QUEUING MODEL

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Abstract. *Model is based on the fungal birth and death processes. Model is suited for Petri dish. Growth of fungal colony diameter in Petri dish is described with exponential function. The value of diameter is declared as integer variable. Integer variable with 1 mm increment is a discrete state of the system. Time in the system is continuously. Discrete states, continuous time and exponential growth are basis for the application of queuing systems in the Petri dish. Queuing system clearly separated the intensity of birth and death. Difference between the birth intensity and death intensity is declared as the fungal life cycle. Fungal life cycle variable is extra sensitive to the inhibitors effects. The procedures for parameters calculation are mathematically explained, as well as the significance of the obtained parameters. Application of the model is performed for F. verticilloides in control conditions and at 16% concentration of basil and clove essential oils. Life cycle minimum is the synergetic inhibition maximum. For F. verticilloides, synergetic inhibition maximum is at 42% of basil and 58% of clove in 16% essential oil concentration.*

Key words: *fungi, synergy, inhibition, essential oil, natural extract*

1. Introduction

Exponential probability distribution has exceptional constitutive characteristics such as maximum entropy, constant hazard function and it is memoryless. If the random evolution of a system is exponentially distributed, then this system is memoryless. In memoryless system, future state depends only on its present state, and not on any past states. The exponential distribution is the only distribution that

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has memoryless property. Also, exponential function with the base e = 2.718281, $f(x)=e^x$ has one unique feature. Function $f(x)=e^x$ and her arbitrary derivation are identical, $f(x)'=f(x)''=...=f(x)^{(n)}=e^x$. This feature is the basis of memoryless.

Mycelium growth (Kang et al., 2003, Vargas-Arispuro et al., 2005; Boyraz and Özcan, 2006, Judith et al., 2008, Villa et al., 2009), hifae growth (Larralde-Corona et al., 1997 ; Kampichler et al., 2004; Diéguez-Uribeondo et al., 2004), spore count (Wagner et al., 2001) and fungal germination under extreme conditions (Onofri et al., 2007) have exponential properties.

Alteration of the fungal colony diameter (Roller and Covill, 1999; Tzortzakis and Economakis, 2007; Taniwaki et al., 2009, Tang et al., 2009), fungal colonies in the presence of bacteria (Brule et al., 2001), the development of fungal biomass (Damar et al., 2006), the influence of various inhibitors (Collopy-Junior et al., 2006), essential nutritienats (Ramirez et al., 2004) and the impact of radiation on the fungal growth (Maity et al., 2008) can be described with exponential distribution.

Indirect evidence about exponential fungal dynamics we can find in the fungal degradation process (Kim et al., 2000; Schober and Trösch, 2000; Mal-Nam et al., 2000; Ruiz-Aguilar et al., 2002; Ishii et al., 2007, 2008; Wakaizumi et al., 2009; Tanaka et al., 2009, Elsherbiny et al., 2017).

Fungal growth occurs in the system of self-replicator species (Scheuring and Szathmáry, 2001; Chertov et al., 2004; Milne, 2008; Boswell, 2008). Self-replicator growth system is the basis of analogy between fungal growth and exponential function. Indirectly, through an exponential distribution, fungal systems are memoryless. Analogously, the fungal growth is the Markovian process.

Management of microbiological systems has significant economic, environmental and health aspects. The microbiological control of foods is particularly significant. In the case of fungi, control of growth by using inhibitors is based on compromise. Inhibition need to meet the requirements of microbiological quality and in the same time, to preserve the nutritional, health and organoleptic properties of food.

The intensity of fungal inhibition is commonly investigated with the agar plate method, based on the measurement of the colony diameter, in the presence of essential oil or herbal extract during the time. (Nielsen and Rios, 2000; Guynot et al., 2003; Suhr and Nielsen, 2003; Benkeblia, 2004; Pereira, et al., 2006; Sheng-Hsien et al., 2007; Lopez-Malo et al., 2007; Fung and Zheng, 2007; Tullio et al., 2007; Soylu et al., 2007; Viuda-Martos et al., 2007, 2008; Tzortzakis, 2009; Reddy et al., 2009; Tatsadjieu et al., 2009, Tanackov S. et al., 2014; Badea et al., 2016; Llana-Ruiz-Cabello et al., 2016 Tancinová et al., 2018, 2019).

Inhibitors can be synthetic and natural. Use of synthetic inhibitors is not always desirable, especially in food. Essential oils and plant extract are the main natural inhibitors. A special analytical challenge is the potential synergic effects in the application of inhibitors. Synergy inhibitors may improve the composition of the combinatorial selection of inhibitors with greater antifungal effect and more acceptable organoleptic characteristics.

The inhibition intensity is determined by the comparative method a posteriori. This method is based on determining the initial birth rate without inhibition. In the presence of inhibitors, a reduced birth rate is obtained. The comparison (difference) of these two intensities represents the difference in the birth intensity, again. The intensity of dying due to inhibitory effects remains unknown. Individual inhibitor intensities can be estimated by standard procedure, but the synergistic effect of two or more inhibitors is difficult to describe by existing models.

Considering the growth of colonies as a stochastic system opens up the possibility of applying a queuing system (QS). The birth and death intensities in microbiology analysis are analogous to the intensities of clients arrivals and clients servicing from queueing systems. The capacity of QS models has been proven in many fields of research (Fazlollahtabar anf Gholizadeh, 2019a; Fazlollahtabar and Gholizadeh, 2019b; Tanackov I. et al, 2019a, Tanackov I. et al, 2019b)

2. Materials and methods

2.1. Experimental setup

For the antifungal activity testing, commercially available, food grade clove and basil extract was provided from ETOL "Tovarna arom in eteričnih olj" d.d., Celje, Slovenia.

As test microorganisms, the following fungal strain from the genus *Fusarium* was used: *F. verticillioides* (Sacc.) Nirenberg (syn. *F. moniliforme* Sheld.). The fungal culture were isolated from cakes and maintained on Potato Dextrose Agar (PDA) at 4°C as a part of the collection of the Laboratory for Food Microbiology at the Faculty of Technology, University of Novi Sad, Serbia.

The agar plate method was applied in the testing of the antifungal activity of extracts. The basic medium for the antifungal tests was PDA. The medium was divided into equal volumes (150 ml), poured into Erlenmeyer (250 ml) flasks and autoclaved at 121ºC for 15 min. Concentrations 0 i 0.16% (v/v) were tested self-contained extracts, and basil-clove combinations: 50%:50%; 75%:25% i 25%:75%. The extracts were added to medium after cooling to 45°C. The culture medium was then poured into sterile Petri dishes (ϕ9 cm), 12 ml into each plate.

To prepare the conidial suspension dispute we used the seven-day culture *F. verticillioides* grown on PDA. Suspension of fungi prepared in a medium which contained 0.5% Tween 80 and 0.2% agar dissolved in distilled water and were adjusted to provide initial spore count of 10^6 spores/mL by using a haemocytometer. For each extract dose and fungi species, including the controls were centrally inoculated by spreading 1 μl of spore suspension (10^3 spores/ml) using an inoculation needle. After inoculation, the Petri plates were closed with parafilm. The efficacy of the treatment was evaluated by daily measurement of the diameter of radial colony growth during 14 days of incubation at 25 ±2ºC (table 1.).

2.2. Markovian process in Petri dish

Exponential parameter (Whitt, 2018; Tanackov et al., 2019) of fungal growth ξ is a function of the intensity of birth λ and death μ, $\xi=f(\lambda,\mu)$, provided $\lambda\geq\mu$. In Petri dish queuing system, number of microorganisams determines the state of the system. Description with Markovian birth-death process is based on the exponential intensity of birth λ and death μ. If the initial state of the system is defined with zero microorganisms, then the initial intensity of death μ is also equal to zero. The system goes into a state one microorganism with intensity λ. Simultaneously with the transition to a state one microorganism, death process with intensity μ is started. In the same time with the transition to a state with one microorganism, process of death with intensity μ start. From the state with one microorganism, system exceeds to the state with two microorganisms by the same intensity of the birth, λ. If the system implemented another birth with intensity λ, and the first micro-organism has not finished the process of dying, the system exceeds in to the state two microorganisms. The dying process of the first microorganism is not complited and the second microorganism begins the process of dying. Therefore, the intensity of death in a state two microorganisms is equal 2μ. System with the same birth intensity exceeds in the next state, and with multiplicity intensity of death exceeds to a previous state. If the number of microorganisms is equal to k in the system, then all k microorganisms are in the process of dying. Therefore, the intensity of dying in system with k microorganisms is equal to $k\mu$. System with k microorganisms cannot realize $(k+1)\mu$ intensity of the death. This relationship between the intensity of birth λ and intensity of death μ, can be described with exponential development of fungal colonies in Petri dish (Fig. 1).

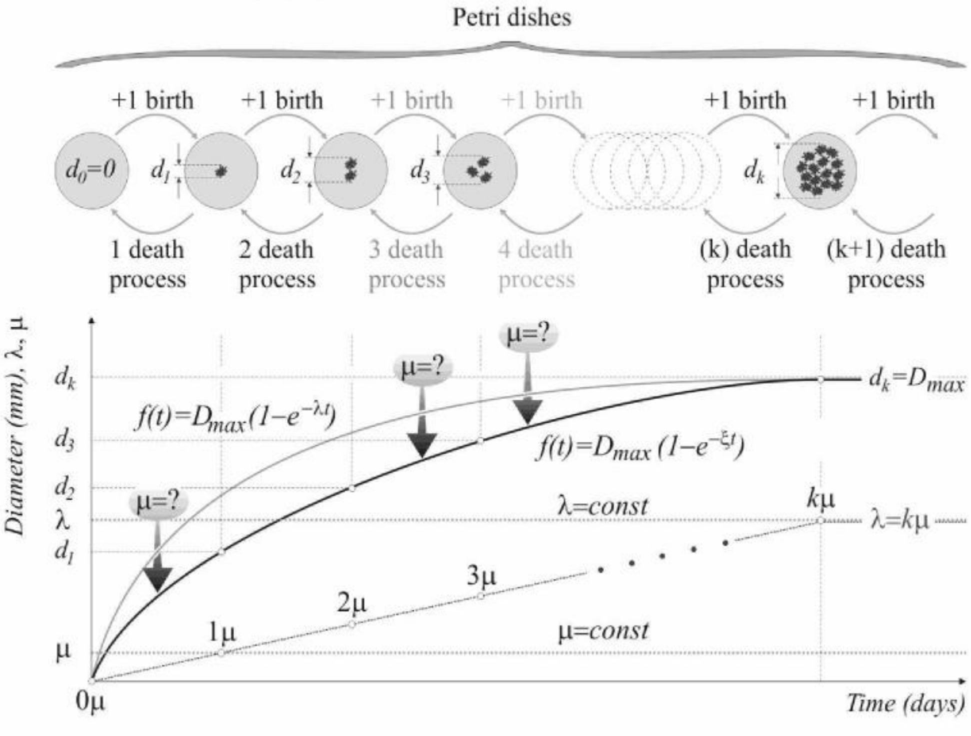

Figure 1. Fugal colony, exponential development

At asymptote diameter, the intensity of birth and k multiplicated death are identical, $\lambda=k\mu$. The value of the colony diameter is equal to asymptote value which is maximal colony diameter D_{max}. This point have a crucial importance for solving the explicit form of the function $\xi=f(\lambda,\mu)$. The solution to the intensity of dying is now available, initially in steady-state mode. If necessary, the intensity of dying can be considered as non-stationary in time, and additional possibilities are consideration of non-stationary intensity of dying in conditions of different temperatures, humidity, initial inoculation or other important microbiological parameters.

2.3. Petri dish Queuing system

Marcovian processes in the system are determined with the time and state of the system. Time in the system can be discretely and continuously. State of the system can be discrete and continuous, also.

Consecutive time intervals for fungal colony diameter measurements were determined by SI unit, time.

These intervals are discrete, usually 1 day. Measurement of fungal colony diameters in Petri dish, are recorded in the SI unit of length, in millimetres or centimetres. Development of fungal colonies declared this dimension as a variable. Diameters values are represent in the time series.

The time is independent variable, and the diameter is dependent variable. Due to the nature of the fungal colony development, the total number of fungi cannot be precisely determined. All elements of the fungal colony development are synthesized in the diameter.

Diameter is a generalized variable of the system. The state of the fungal colony is continuous variable.

Fungal colony diameter (d_0, d_1, d_2, d_3, ..., d_k), $f(t_i)=d_i$ time series in Petri dish, for discrete time intervals Δt, (t_0, t_1, t_2, t_3, ..., t_k), $t_{(i+1)} = t_i+\Delta t$, $k\in[0, 1, 2, \dots, n]$ have a form of exponential function:

$$f(t_k) = d_k = D_{max}(1-e^{-\xi t_k}) \quad k\in[0, 1, 2, \dots, n] \qquad (1)$$

A high approval of empirical and theoretical data is necessary condition for regular description of the fungal colony diameter with the exponential function. This agreement can be expressed with the correlation coefficient. The linear regression of empirical and theoretical data must be described with fulfil values of parameters $a\approx1$ and $b\approx0$, in addition to the high value of correlation coefficient $r\approx1$.

A fulfilment of these conditions gives a representative description of the empirical time series with exponential theoretical function. Discrete values of colony diameter can be obtained with integer function values from representative function.

$$s(t) = [f(t)] = INT\left[D_{max}(1-e^{-\xi t})\right] \qquad (2)$$

Approximation of $f(t)$ with the function $s(t)$ depends from the increment size. Smaller increment has a better approximation. For fungal colony diameter measuring in millimetres, integer increment 1 mm gives a satisfactory approximation. With discrete values of the colony diameter, are fulfilment conditions for the application of Markovian process with continuous time. Continuous time with discrete states of the system allows the Petri dish to formation Markovian queuing system (Fig. 2).

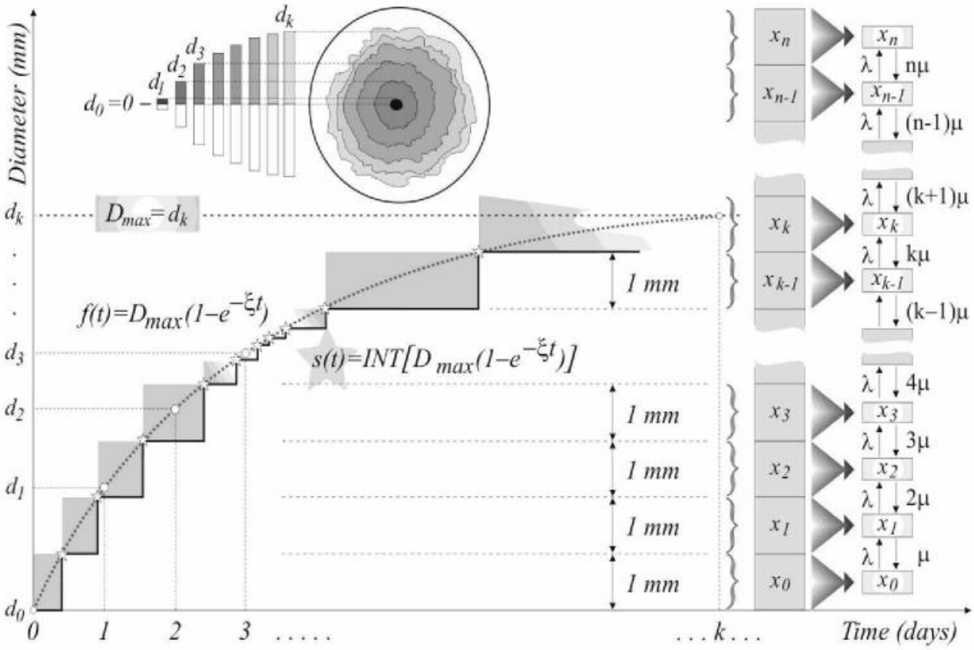

Figure 2. Petri dish Markovian queuing system

Explicit form of the function $\xi=f(\lambda,\mu)$ have two unknown variables, λ and μ. For the calculation of their values, it is necessary to define a system of two equations. The first equation is obtained from initial conditions. At the beginning of growth, at t=0, the intensity of death is equal to zero, μ=0. Intensity of birth λ is equal to:

$$D_{max}(1-e^{-\xi t})'_{t=0}=(D_{max}\xi e^{-\xi t})_{t=0}=\lambda \Leftrightarrow \lambda = D_{max}\xi \tag{3}$$

The second equation can be obtained from the development of state and calculation of the average number of clients in the Markovian system (Fig. 3).

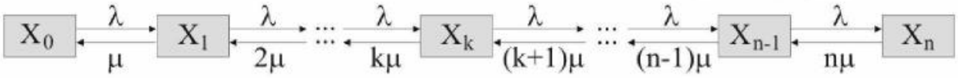

Figure 3. Development of Markovian's system mold colonies in Petri dishes

Differential equations of queuing states in the stationary mode, with constant values of birth and death intensity $\lambda(t)=\lambda=const$ and $\mu(t)=\mu=const$, are:

$$p_0(t)'=0=-\lambda p_0+\mu p_1 \Leftrightarrow p_1=\frac{\lambda}{\mu}p_0$$

$$p_1(t)'=0=\lambda p_0-\mu p_1-\lambda p_1+2\mu p_2 \Leftrightarrow 0=-\frac{\lambda^2}{\mu}p_0+\mu p_2 \Leftrightarrow p_2=\frac{1}{1\cdot 2}\left(\frac{\lambda}{\mu}\right)^2 p_0$$

$$p_2(t)'=0=\lambda p_1-2\mu p_1-\lambda p_1+3\mu p_2 \Leftrightarrow 0=-\frac{\lambda^3}{2\mu^2}p_0+3\mu p_2 \Leftrightarrow p_3=\frac{1}{1\cdot 2\cdot 3}\left(\frac{\lambda}{\mu}\right)^3 p_0$$

. . . . .

$$p_k(t)' = 0 = \lambda p_{k-1} - \mu p_k - \lambda p_k - \mu p_{k+1} \Leftrightarrow p_k = \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k p_0$$

. . . . .

$$p_n(t)' = 0 = +\lambda p_{n-1} - n\mu p_n \Leftrightarrow p_n = \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n p_0 \tag{4}$$

In the n previous equations we have $(n+1)$ unknown variables, $k \in [0, 1, 2, \ldots, n]$. Equation needed to solve this system of equations, we can obtaine from the basic requirements of probability states:

$$p_0 + p_1 + p_2 + \ldots + p_{n-1} + p_n = 1 \Leftrightarrow p_0 + \frac{\lambda}{\mu} p_0 + \ldots + \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k p_0 + \ldots + \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n p_0 = 1$$

From these $(n+1)$ equations, probability of state p_0 is:

$$p_0(1 + \frac{\lambda}{\mu_0} + \ldots + \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \ldots + \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n = p_0 \sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k = 1 \Leftrightarrow p_0 = \frac{1}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k} \tag{5}$$

Recurrent equation for calculating the probabilities of the queuing system states is obtained from (4) and (5):

$$p_k = \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k p_0 \Leftrightarrow p_k = \frac{\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k} \tag{6}$$

The average number of clients in the system is obtained from the (6):

$$\sum_{s=0}^{n} s \cdot p_s = \sum_{s=0}^{n} s \cdot \frac{\frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k} = \sum_{s=0}^{n} \frac{\frac{s}{s!}\left(\frac{\lambda}{\mu}\right)^s}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k} = \left(\frac{\lambda}{\mu}\right) \frac{\sum_{s=1}^{n} \frac{1}{(s-1)!}\left(\frac{\lambda}{\mu}\right)^{s-1}}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k} \tag{7}$$

The exponential function $e^{\frac{\lambda}{\mu}}$ may be written as a Taylor series:

$$\sum_{n=0}^{\infty} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} = \frac{\left(\frac{\lambda}{\mu}\right)^0}{0!} + \frac{\left(\frac{\lambda}{\mu}\right)^1}{1!} + \frac{\left(\frac{\lambda}{\mu}\right)^2}{2!} + \frac{\left(\frac{\lambda}{\mu}\right)^3}{3!} + \cdots = e^{\frac{\lambda}{\mu}} \Rightarrow$$

$$\lim_{n\to\infty} \frac{\sum_{s=1}^{\infty} \frac{1}{(s-1)!}\left(\frac{\lambda}{\mu}\right)^{s-1}}{\sum_{k=0}^{\infty} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^{k}} = \frac{e^{\frac{\lambda}{\mu}}}{e^{\frac{\lambda}{\mu}}} = 1$$

For a large enough n, we can adopt $\frac{\sum_{s=1}^{n} \frac{1}{(s-1)!}\left(\frac{\lambda}{\mu}\right)^{s-1}}{\sum_{k=0}^{n} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^{k}} \approx 1$

Average number of clients in the system is equal:

$$\sum_{s=0}^{n} s \cdot p_s = \frac{\lambda}{\mu} \tag{8}$$

In stationary mode of ergodic Marcovian queuing system, this value (8) is equal to the average diameter of the fungal colony d_{ave}. From birth intensity initial conditions and from average number of clients, the value of death intensity μ is:

$$d_{ave} = \frac{\lambda}{\mu} \Leftrightarrow d_{ave} = \frac{D_{\max}\xi}{\mu} \Leftrightarrow \mu = \frac{D_{\max}\xi}{d_{ave}} \tag{9}$$

Values D_{max}, ξ and d_{ave} we can calculated from experimental measurements of Petri dish. D_{max} is the parameter of the fungal colony asymptote. ξ is the parameter of the exponential function. ξ is calculated by the heuristic search of the colony diameter time series d_0, d_1, d_2, d_3, ... , d_k,

Parameter d_{ave} is equal to:

$$d_{ave} = \frac{1}{k}\sum_{i=0}^{k} d_i = \frac{d_0 + d_1 + d_2 + \ldots + d_k}{k} \tag{10}$$

In a long time of measurement, average diameter d_{ave} converge to asymptote of fungal colony D_{max}.

$$\lim_{k\to\infty} d_{ave} = \lim_{k\to\infty} \frac{d_0 + d_1 + d_2 + \ldots + d_k}{k} = D_{\max} \tag{11}$$

Also, the intensity of death converges to the growth rate.

$$\lim_{k\to\infty} \mu = \lim_{k\to\infty} \frac{D_{\max}\xi}{\frac{d_0 + d_1 + d_2 + \ldots + d_k}{k}} = \lim_{k\to\infty} \frac{D_{\max}\xi}{D_{\max}} = \xi \tag{12}$$

Therefore, entry in to the deep asymptotic region should be limited. The introduction of another diameter d_{k+1} from time series in to the d_{ave} calculation (11), should be stopped because of small differences between successive diameter, $d_k \approx d_{k+1}$. Significance of this difference, $p = (1-q)$ can be directly set and calculated from the integral equation (13):

$$\int_{t_k}^{t_{k+1}} D_{\max}(1-e^{-\xi t})dt = D_{\max}\xi e^{-\xi t}\Big|_{t_k}^{t_{k+1}} = D_{\max}\xi(e^{-\xi t_{k+1}} - e^{-\xi t_{k+1}}) \le q \quad (13)$$

Adding and subtracting the value of 1, we relate the diameter and significance (14):

$$-D_{\max}\xi(1-1+e^{-\xi t_{k+1}} - e^{-\xi t_k}) = -D_{\max}\xi(1-e^{-\xi t_k} - (1-e^{-\xi t_{k+1}})) \le q \quad (14)$$

Successive diameters are $d_k = D_{max}(1-e^{\xi t_k})$ i $d_{k+1} = D_{max}(1-e^{\xi t_{k+1}})$, and limit of the diameter difference d_{end} is equal to (15) :

$$-D_{\max}\xi(d_k - d_{k+1}) \le q \Leftrightarrow (d_{k+1} - d_k) \le \frac{q}{D_{\max}\xi} = d_{end} \quad (15)$$

Equation (14) provides reliable intensity of birth λ and death μ, with the required significance p.

2.4. Results

The calculation of all relevant parameters is given in table 2. Calculated limit difference d_{end} for significance p=0.95 satisfies all the requirements of measuring up to 14 days. Empirical results of measuring diameter and theoretical exponential functions linear regression parameters a and b were $a \approx 1$ and $b \approx 0$, in control conditions and 16% concentration for all compositions of basil and clove essential oils. The correlation coefficient is high $r^2 \ge 0.99$, for all conditions, also. Calculation of the parameters ξ i D_{max} is valid. Parameter d_{ave} is obtained from (11) as the average diameter of fungal colonies. Birth intensity λ is obtained form (3), and death intensity μ is obtained from (9)

3. Discusion

In this example, approximated diameter converges to value 120.154 mm for 50% basil and 50% clove in 16% essential oil concentration. This value is larger than the approximated diameter for control conditions, 117.176 mm. From diameter comparation, synergetic stimulation off fungal growth is deduced by classic approach. However, the diameter does not express explicit morphological changes. Morphological changes are contained in the parameter of the life cycle.

The life cycle of fungi represent the subtraction between birth intensity and death intensity. Subtraction between birth intensity in control conditions $\lambda_{control}$=9,608 mm/day and the death intensity in control conditions $\mu_{control}$=2,058 mm/day is the life cycle of fungi *F. verticilloides* in control conditions $\Delta_{control}$=7,594 mm/day. Life cycle control value is constant for all range of concentration and arbitrary inhibitors relation. Intensity of birth and death values, λ_{clove}^{basil} i μ_{clove}^{basil} respectively, at 16% concentration for different relations basil and clove, do not have a constant value. These values are functions of relations between basil and clove. The calculations of the *F. verticilloides* life cycles in control condition and basil-clove synergetic conditions are given in table 3.

Graphic presentation of the results in table 3 is given in Fig. 4.

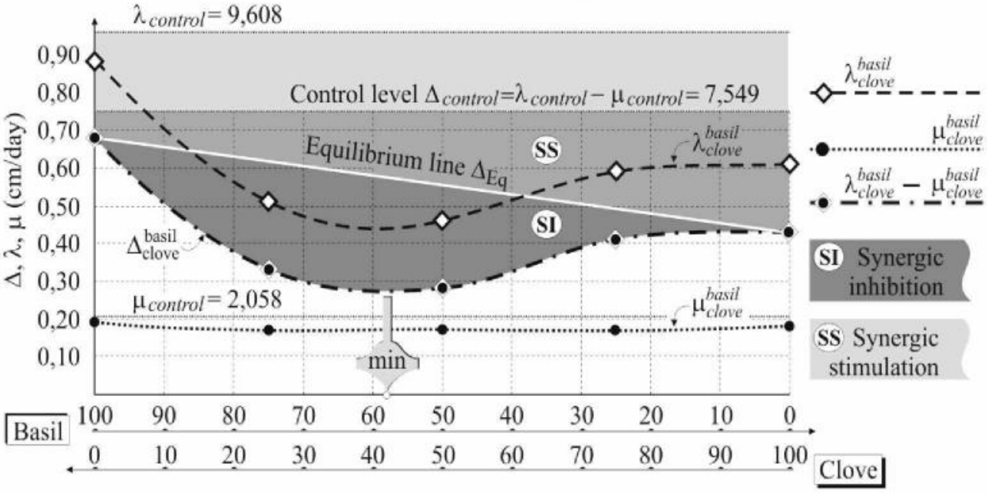

Figure 4. *F. verticilloides* life cycle dynamic

From Fig. 4 is the apparent dynamics of birth and death process for the *F. verticilloides*. Birth process intensity λ_{clove}^{basil} on the 16% concentration has pronounced variations of value. Birth intensity at 100% basil in 16% essential oil concentration (8.850 mm/day) have higher birth intensity from 100% clove in 16% essential oil concentration (6,197 mm/day). With the increasing participation of clove in 16% essential oil concentration, come to a sudden fall of the birth intensity. Minimum intensity birth is about 60% basil and 40% clove participation. With further increase participation of clove, comes an increase in the intensity of birth. Stabilization of about 75% of clove participation, remains constant until the end of the domain.

The intensity of the death μ_{clove}^{basil} at 16% concentration has not pronounced variations. Death intensity have μ_{clove}^{basil} are less than the death intensity in control conditions. Lacking the expected death intensity increase. However, reducing the intensity of growth directly reduces the quantity of the system, and thus the intensity of dying.

Birth intensity minimum is at 50% basil and 50% clove. Death intensity minimum is at 25% basil and 70% clove. Approximate function of the life cycle $\Delta_{clove}^{basil} = \lambda_{clove}^{basil} - \mu_{clove}^{basil}$, has a minimum at 42% basil and 58% clove. *F. verticilloides* life cycle minimum is the maximum basil-clove synergetic inhibition (Fig. 4.).

Equilibrium line Δ_{Eq} gets points through 100% of the selected concentrations of two inhibitors. Equilibrium line is a set of values that is linearly proportional to the inhibitor participation in a 16% essential oil concentration. The synergetic stimulation zone (SS) is above from Equilibrium line

The synergetic inhibitona zone (SI) is below from Equilibrium line. Area from Equilibrium line to the life cycle control level line is the synergic stimulation area. The values of the life cycle can vary about Equilibrium line. In such variations, values above the Equilibrium line are synergistic stimulation, even though they are less from the control level value. Synergetic inhibition values are below the Equilibrium line. In the shown case, for 16% concentration of essential oil relationships Basil and Clove, all values of the life cycle are under Equilibrium line. Selection of essential oils have a distinct inhibiting effect of synergy in the whole area, with a pronounced minimum of 42% basil and 58% clove.

Standard models based on the difference in growth intensity between non-inhibited and inhibited sample, cannot directly express the maximum synergistic effect of the two inhibitors. The formation of the two-dimensional function of the action of two inhibitors using standard models requires an incomparably larger number of experiments with different concentrations, and one post-process application of some heuristic model. The results show that the QS model is more accurate, reliable and less expensive for research.

4. Conclisuions

Queuing model has a high sensitivity. The basis of sensitivity is in intensity differentiation. These intensities are obtained from growth rate. At the same time, it is necessary to percieve a clear distinction between growth rate and life cycle. Growth rate is a feature of the of birth and death process. The life cycle is a feature of the birth and death intensitys.

The queuing model has limitations. In the case of higher concetrations, application of inhibitors may delay the start of fungal growth. During the asymptotic inhibition, birth intensity is equal to zero.

Changes in diameter does not correspond to exponential function. This period lasts until the beginning of delayed growth. Start of growth changes the value of the birth intensity. Existence of two values for the same intensity is a feature of nonstationary queing system. Solving the nonstationary queuing system can not be done by the proposed mathematical procedure. Therefore, the model gives solutions only in the case of small concentrations of inhibitors. These concentrations must be less then MIC (minimal inhibitory concentracion). The model can be applied to the analysis of bacterial inhibition, as well as the simultaneous application of three or more inhibitors.

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SELECTION OF COMMERCIALLY AVAILABLE ALTERNATIVE PASSENGER VEHICLE IN AUTOMOTIVE ENVIRONMENT

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Abstract. *There has been a paradigm shift in the automobile industry due to e-mobility which reduces green-house gas emission and air pollution. In this context, selection of the most feasible automotive passenger vehicle is a complex decision-making problem due to the use of different power source, technology, specification and price. In this paper, five alternative vehicles based on fuel cell, hybrid electric, battery electric, plug in hybrid electric and compressed natural gas bi-fuel are evaluated using an integrated criteria importance through inter-criteria correlation (CRITIC) - Combined Compromise Solution (CoCoSo) method. CRITIC method is used to obtain the weights of the vehicle selection criteria, whereas, CoCoSo method is employed to rank the vehicles considering different technical and operational criteria such as greenhouse gas emission, fuel economy, vehicle range, accelerating time, annual fuel cost and vehicle base model cost. It is found that battery electric vehicle out performs all other considered alternatives. The validity of the results is verified by comparing with other well popular MCDM methods. Further, a sensitivity analysis is conducted by changing the criteria weights to establish the stability of the model.*

Key words: *Alternate passenger vehicle selection, CoCoSo, CRITIC, sensitivity analysis*

1. Introduction

Alternate fuel vehicles are those which can be fueled in part or full by electricity, hydrogen, biodiesel, compressed natural gas (CNG), liquefied petroleum gas (LPG)

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and ethanol as compared to the conventional petrol and diesel-based vehicles. The most commonly used alternate vehicles are battery-electric, hybrids, plug-in hybrids and fuel cell vehicles in addition to vehicles based on ethanol, biodiesel, biogas and hydrogen. The total environmental impact of the vehicle fleet is likely to decrease if conventional vehicles are replaced by alternate fuel vehicles. The alternate electric vehicle (EV) technology reduces emission, increases energy efficiency, does not have any energy consumption at static condition and also boosts with low ambient noise. Fuel cells, similar to EVs, also have no tailpipe emission, no corrosion to the engine and it is also quiet in operation. Hybrid EVs (HEVs) and plug-in HEVs (PHEVs) use a combination of internal combustion engines (ICE) along with an electric motor and reduce fuel consumption and green-house gases (GHGs). Bi-fuel vehicle is another type of alternate vehicle which recues the tailpipe emission than petrol and diesel engines. According to a report (IEA 2019) that in 2018, more than 5.1 million the electric car was sold globally, out of these more than 66% of electric cars were battery EVs (BEVs). Market share of electric car has been steadily increasing from 50% (2012) to 68% (2018). China, Europe and United States are the world's largest electric car market. The report also indicated that by the end of 2018, global stock of electric busses was 4,60,000 while the same for two wheelers was 260 million. In 2018, sales of light-commercial vehicles were around 2,50,000 units and medium electric truck reached in the range of 1000-2000 units. In the same year, global EV stock aided publicly accessible 5.2 million light-duty vehicle chargers and 1,57,000 fast chargers for buses. It is also observed that, in 2018, EVs used about 58 terawatt-hours of electricity and produced 41 million tonnes of carbon-dioxide equivalent (CO_2e) on the road, that mean EVs saved 36 million tonnes of CO_2e as compared to an equivalent internal combustion engine vehicle.

In EV 2030 scenario, global EV sales are expected to be around 23 million (excluding two/three-wheelers) and would cut demand for fuel-based vehicles. BEVs and PHEVs are presently using electricity for battery charging. The current global average carbon intensity of electricity generation (518 gms of CO_2e /kWh) emits huge amount of GHG if the power generation mix is controlled by a high carbon source. CO_2 emissions at EVs are significantly reduced as the power generation is controlled by a low carbon power source. But in some countries, like India where the electric power is mainly produced by coal, therefore, hybrid vehicles emit lower GHG than the EVs. Further, the emission reduction potential of EVs over their entire life cycle can further be raised if electricity generation can be made decarbonized. Future concept in automobile sector now has been drastically changed. Therefore, the future demand for automobile sectors are renewable or alternate energy-based vehicles which can reduce emission from tailpipe and equivalent CO_2 emission from different sources. Therefore, appropriate selection of the alternate fuel car is now one of the most challenging areas and considered as a multi-attribute decision-making (MADM) process for stake holders like customers and governmental agencies due to the presence of several mutually conflicting attributes/criteria.

It has been observed that very less research works have yet been carried out in MADM domain focusing on the selection of the most feasible alternate fuel cars. Biswas & Das (2018a) applied entropy and multi-attributive border approximation area comparison (MABAC) methods for hybrid vehicle selection problems. Car model cost, fuel economy, tank size, tail pipe emission and passenger volume were considered as the predominant selection criteria. Further, Biswas & Das (2018b) adopted fuzzy-analytic hierarchy process (AHP) and MABAC method for commercially available electric vehicle selection for a case study of United States. Various technical and operational attributes like fuel economy, base model pricing, quick accelerating time, battery range and top speed were considered. Biswas & Saha (2019) proposed a novel MADM approach for evaluating commercially available scooters and considered kerb weight, mileage, top speed, fuel tank capacity and price as the influential criteria.

In this paper, an endeavor is attempted to integrate two vastly used MADM methods, namely criteria importance through inter-criteria correlation (CRITIC) and Combined Compromise Solution (CoCoSo) for the evaluation and ranking of five alternative environment friendly vehicles. The CRITIC method is used to determine the weight coefficients associated with each vehicle selection criterion. Ranking of the vehicles is achieved using the CoCoSo method. Five different types of passenger vehicles such as Toyota Mirai (fuel cell vehicle), Tesla Model 3 (BEV), Toyota Prius eco (HEV), Honda clarity plug in (PHEV) and Chevrolet Impala Bi-Fuel (CNG vehicle) are considered as the alternatives. Fuel economy, range in mile, annual fuel cost (in $), accelerating time from 0 to 60 mile per hour, vehicle cost (in $) and tail pipe emission in gram/mile are considered as the attributes based on the data available in manufacturers' websites and catalogues. Finally, a sensitivity analysis is also performed to check the effect of changing criteria weights on the ranking performance of the integrated model.

The paper is organized as follows: after the introduction and literature review, section 2 presents the mathematical formulation of CRITIC and CoCoSo methods. Section 3 presents an application of the hybrid method for ranking of cars. A sensitivity analysis for the novel method is presented in Section 4. Section 5 presents the discussion and concluding remarks and directions for future research is presented in section 6.

2. Methodology

This section presents the mathematical formulations of CRITIC and CoCoSo methods which are subsequently applied for the evaluation of the alternate passenger cars.

2.1. CRITIC Method

CRITIC method was originally developed by Diakoulaki et al. (1995) for estimating criteria weights in MADM environment. Here correlation analysis is used to distinguish between different criteria (Yılmaz & Harmancıoglu, 2010). This method is basically based on analytical testing of the decision matrix in order to determine the information contained by the criteria. There are many successful applications of CRITIC method for a wider range of applications such as pharmaceutical industries (Diakoulaki et al., 1995), water resource management model (Yılmaz & Harmancıoglu, 2010), index system of city's soft power (Guo et al., 2013), financial statement of stock exchange (Kazan & Ozdemir, 2014) and non-traditional machining process (Madic & Radovanovic, 2015). CRITIC method has the following simple steps, as detailed below:

Step-1. Formation of the decision matrix:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; i = 1,2,\ldots,m; \ j = 1,2,\ldots,n. \tag{1}$$

Step-2. Normalization of the decision matrix using the following equations:

$$r_{ij} = \frac{x_{ij} - \max x_{ij}}{\max x_{ij} - \min x_{ij}}; \quad \text{for benefit criteria} \tag{2}$$

$$r_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}; \quad \text{for cost criteria} \tag{3}$$

Step- 3: Calculation of symmetric linear correlation matrix (m_{ij}):

A linear correlation coefficient between the each pair of criteria is estimated using the following equation to quantify the conflict resulted among different criteria. It can be seen that the more discordant the scores of the alternatives in two criteria *i* and *j*, the lower the value m_{ij}.

$$m_{ij} = \frac{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)(r_{ik} - \bar{r}_{k})}{\sqrt{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2 \sum_{i=1}^{m}(r_{ik} - \bar{r}_k)^2}} \tag{4}$$

Step- 4: Determination of the objective weight of a criterion also requires the estimation of both standard deviation of the criterion and its correlation with other criteria. In this regard, the weight of the j^{th} criterion (w_j) is obtained using the following expression.

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \qquad 5)$$

where, C_j is the amount of information contained in the criterion *j* and is determined as follows:

$$C_j = \sigma \sum_{j'=1}^{n} 1 - m_{ij} \tag{6}$$

where σ is the standard deviation of j^{th} criterion and is the correlation coefficient between the two criteria. A higher value of C_j signifies greater amount of information contained in a particular criterion, hence it is provided with higher weight value.

2.2. Combined Compromise Solution (CoCoSo) Method

Yazdani, Zarate, Zavadskas, & Turskis, (2018) established the CoCoSo method. It is based on the integration of two most popular MCDM methods namely Simple

Additive Weighting (SAW) and Exponentially Weighted Product (MEP). Previous researchers applied CoCoSo methods in different area such as evaluation of electric vehicles under sustainable automotive environment (Biswas et al. 2019), manufacturing process (Acharya & Murmu, 2019), sustainable supplier selection (Zolfani et al. 2019). CoCoSo method consists of the following easy steps:

Step1. Formation of the original decision matrix $X=[x_{ij}]_{mxn}$..

Step2. Then normalize the decision matrix as $N=[n_{ij}]_{mxn}$ using Eqs (2) and (3).

Step3. Estimation of sum of weighted comparability (*Si*) sequence and power weighted comparability sequences (*Pi*) for each alternative respectively.

$$Si = \sum_{j=1}^{n} (w_j r_{ij}) \tag{7}$$

$$Pi = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{8}$$

Step 4. Computation of relative weights of the alternatives:

In this step, three aggregated appraisal scores are used to generate relative performance scores of the alternatives, using the following equations:

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=n}^{m} (P_i + S_i)} \tag{9}$$

$$k_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \tag{10}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda \max S_i + (1-\lambda) \max P_i)} \tag{11}$$

Step 5: The final ranking of the alternatives is determined based on *ki*, values: Higher *ki* values indicate better position of the alternatives in the ranking pre-order.

$$k_i=(k_{ia}\, k_{ib}\, k_{ic})^{1/3}+1/3(k_{ia}+k_{ib}+k_{ic}) \tag{12}$$

3. Case study

Now to explore the application potentiality of the integrated CRITIC-COCoSo model, a case study comprising five alternative vehicles is now considered under passenger car category with six criteria. The details are given in Table 1. The data set is retrieved from different manufacturers' websites and catalogue. Description of the considered evaluation criteria is provided in Table 2. Out of the six criteria, fuel economy (C1) and range (C2) are considered as beneficiary criterion or higher the better and rest four criteria are considered as non-beneficiary criterion or lower the better. Fuel cell EVs (FCEVs) are fueled with pure hydrogen gas and this is converted to electricity by the fuel cell. It is produce no harmful tailpipe emissions. FCEVs are attached with other advanced technologies like regenerative braking systems, which capture the energy lost during braking and store it in a battery. Driving range of this vehicle is very high. FCEVs are beginning to enter the consumer market in around the world. Toyota Mirai is the popular car under category of FCEV.

All BEVs get electricity from rechargeable battery packs. Benefits of the s as compare to conventional fuel are energy efficiency (EV convert above 60% of the electrical energy to power at the wheels), environmental friendliness, reduced energy dependency, smooth operation, less noise and less maintenance. Only the drawbacks are shorter driving range and high recharging time. An example of BEV is Tesla Model 3.

HEVs run by an ICE in combination with electric motors. In case of full hybrid vehicles, battery charging is done through a regenerative braking mechanism and ICE. This type of vehicle does not require plug in to charge. The benefits of HEVs are high fuel economy and low tailpipe emissions over ICE-based vehicles. Example of HEV is Toyota Prius eco.

PHEVs have an ICE and an electric motor where batteries provide the power to the motor and liquid fuel (mainly petrol or diesel) is used for the ICE. This type of vehicle has lower operating costs and low amount of fuel consumption in comparison to the conventional vehicles. PHEVs produce lower levels of GHGs, depending on the electricity source. The example of PHEV is Honda clarity.

In ICE vehicles, CNG is stored in a tank as compressed gaseous state. This fuel is used in light, medium, and heavy duty applications. Driving range is generally less in these vehicles than that of a diesel or petrol powered vehicle due to the the lower energy density. The advantages of CNG are high mileage and reduced GHG emissions over conventional petrol and diesel fuels. Light commercial vehicles are typically equipped with dedicated or bi-fuel systems. Chevrolet Impala bi-fuel car is a popular example of CNG vehicle.

Table 1. Decision matrix for selection of alternate car

Alternate fuel car	Fuel economy (Mi/ galon) (C1)	Range (miles) (C2)	Annual fuel cost($) (C3)	Acceleration (0-60mph) (C4)	Cost ($) (C5)	Tail pipe emission (gms/mile) (C6)
Toyota Mirai (A1)	67	312	1250	9.4	58365	0
Tesla model 3 (A2)	133	240	500	3.7	39500	0
Toyota Prius eco (A3)	56	633	700	10.2	28000	158
Honda-clarity plug in (A4)	110	340	700	9.5	34320	57
Chevrolet Impala Bi-Fuel (CNG) (A5)	20	360	1850	7.9	37,570	405

Sources: Manufacturing website and www.fueleconomy.gov

Table 2. Descriptions of different criteria for selecting best alternate car

Criteria	Description
C1	It indicates that how much mile the vehicle can go by using a quantity of fuel. It is expressed in mile per gallon. Improve fuel economy saves money, reduces climate change, and reduces oil dependence cost.
C2	Range means that the maximum distance the car can travel between two subsequent charging for electric vehicle but in case of petroleum fuel it indicates that how much distance covered a car by from full tank to empty tank. Its unit is mile. Range on a tank assumes 100% of fuel in tank will be used before refueling.
C3	Its calculates, based on 45% highway, 55% city driving, 15,000 annual miles and current fuel prices. (Diesel per gallon price $2.97, petrol regular fuel price $2.55 and electricity $0.13/kWh)
C4	It signifies that how much time is required to accelerate the car from 0 to 60 Mile per hour. It is identifies by time(in seconds)
C5	It is the selling price of vehicle in dollar.
C6	Tail pipe emission is the exhaust gas of the vehicle which produced after the combustion of fossil fuels. It is expressed as gram per mile. These are the responsible for greenhouse effect, causing climate change, photochemical smog, acid rain, reducing visibility, aggravating heart and lung diseases.

At first, the criteria weights for the alternate fuel car selection case study are computed using CRITIC method. As the initial step, the decision matrix of Table 1 is first normalized using Eqs. (2) and (3) respectively for beneficial and cost criteria, as shown in Table 3. This table also presents the σ values. Subsequently, inter criteria correlation values are presented in Table 4. Finally, the criteria weights are estimated using Eqn. (5), as shown in Table 5. According to the weight values of Table 5, C2 is the most important criterion, whereas C3 is the least important criterion.

Table 3. Normalized decision matrix

Alternate fuel car	C1	C2	C3	C4	C5	C6
A1	0.42	0.18	0.44	0.12	0.00	1.00
A2	1.00	0.00	1.00	1.00	0.62	1.00
A3	0.32	1.00	0.85	0.00	1.00	0.61
A4	0.80	0.25	0.85	0.11	0.79	0.86
A5	0.00	0.31	0.00	0.35	0.68	0.00
Standard deviation (σ)	0.396	0.382	0.408	0.403	0.375	0.419

Table 4. Correlation coefficient values of paired criteria

Criteria	C1	C2	C3	C4	C5	C6
C1	1	-0.4753	0.8368	0.5254	0.0038	0.8128
C2	-0.4753	1	0.0784	-0.636	0.5809	-0.3156
C3	0.8368	0.0784	1	0.2341	0.3286	0.7452
C4	0.5254	-0.636	0.2341	1	-0.0522	0.1747
C5	0.0038	0.5809	0.3286	-0.0522	1	-0.3741
C6	0.8128	-0.3156	0.7452	0.1747	-0.3741	1

Table 5. Weights of the BEV selection criteria

Criteria	C1	C2	C3	C4	C5	C6
Cj	1.306	2.204	1.134	1.916	1.692	1.659
Wj	0.132	0.222	0.114	0.193	0.171	0.167

After finding out of criteria weights using the CRITIC method, the considered alternate fuel car selection problem is now solved by CoCoSo method. After the formation of the decision matrix of Table 1, normalized decision matrix, sum of weighted comparability sequence, power weight of comparability sequences and the overall score of the alternatives are determined using the respective equations provided in Section 2. The final ranking of the considered vehicle alternatives is obtained according to the descending order of the k values (Table 6). This table indicates that Tesla model 3 (A1) is the most favorite vehicle while Chevrolet Impala Bi-Fuel (A5) emerges out as the least preferred alternative.

In Table 6, ranking of the alternative cars is also verified by comparing the performance of the integrated CRITIC-CoCoSo method with some of the well popular MADM methods like technique for order preference by similarity to an ideal solution (TOPSIS) (Chiang & Cheng , 2009) and MABAC (Pamucar & Cirovic, 2015) methods. As can be seen from Table 6 that A2 (Tesla model 3) remains the best alternative for all the considered MADM methods.

Table 6. Calculated score values in CoCoSo method and rank comparison

Alternate fuel car	Si	Pi	Kia	Kib	Kic	Ki	CoCoSo	MABAC	TOPSIS
A1	0.34	4.15	0.19	2.98	0.75	2.05	4	4	4
A2	0.71	4.92	0.23	4.77	0.94	3.00	1	1	1
A3	0.63	4.76	0.22	4.39	0.90	2.80	3	2	3
A4	0.56	5.28	0.24	4.30	0.97	2.84	2	3	2
A5	0.25	2.52	0.12	2.00	0.46	1.33	5	5	5

4. Sensitivity Analysis

The aim of the sensitivity analysis (SA) is to assess the impact of different parameters on the ranking performance of the integrated model.

4.1 Influence of criteria weights

Results of any MADM method depend on criteria weights to a great extent. Sometimes, the final selection may change when there is a change in the weight coefficients of the criteria. In this section, a sensitivity analysis is performed to assess how changes in the criteria weights affect the ranking of the alternative fuel cars by interchanging the criteria weight values in order of ${}^{6}C_{2}$ i.e. for the six considered criteria (C1–C6), the total number of possible interchanges becomes fifteen (${}^{6}C_{2}$). Here, 6 represents the number of criteria and 2 represents the number of criteria chosen at a time. Thus, in the sensitivity plot (Fig. 1), all sets of priority rankings of alternate fuel vehicle are presented. It may be observed from the sensitivity plot that the rank of the alternatives have no changes with the interchanging of criteria weights. From Fig. 1, it is clear that Tesla model 3 remains the best alternative and Chevrolet impala bi-fuel (CNG) remains the least preferred choice for the considered case study.

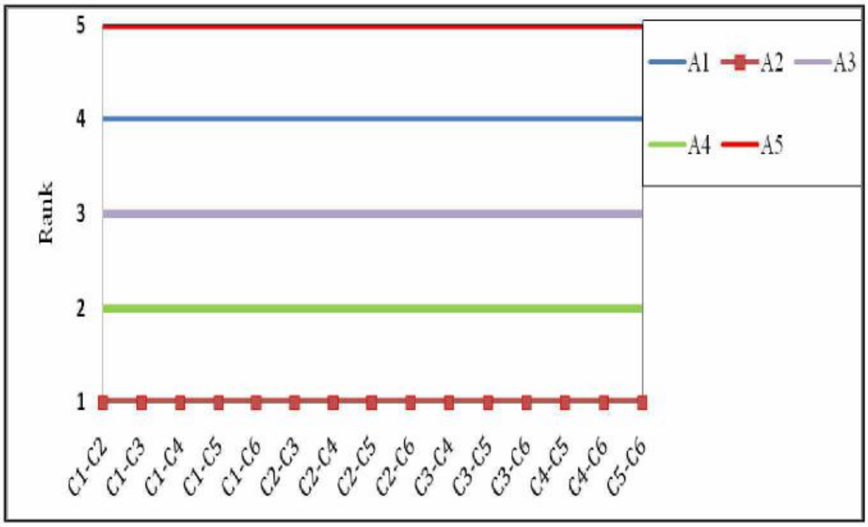

Figure 1. Sensitivity analysis by varying criteria weights

4.2 Influence of λ value in CoCoSo ranking

While applying the CoCoSo method, the associated λ value is generally assumed to be 0.5. However, in actual practice, it ranges from 0 to 1. Fig. 2 shows the effects of varying λ values in the range of 0 to 1. It is observed that there is no change in the ranking orders of the considered alternatives, thus establishing the stability of the ranking order, given by the integrated model.

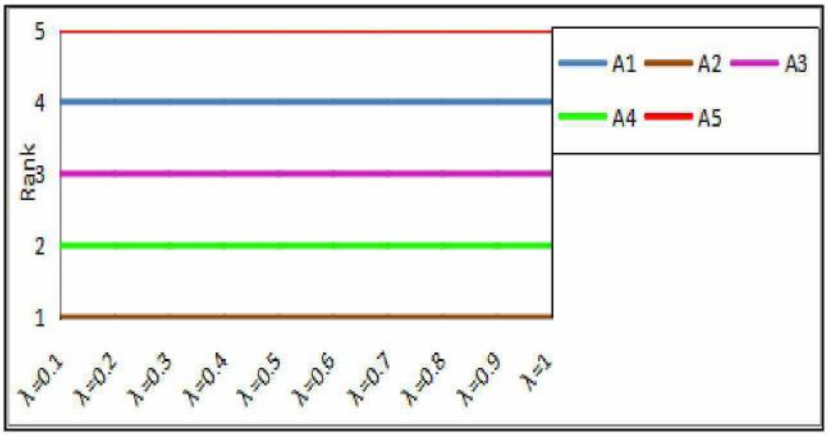

Figure 2. Sensitivity analysis for alternate fuel car by changing the λ value

5. Results and Discussion

In the context of global sustainability scenario, alternate fuel cars with higher mileage, longer range, lower annual fuel cost, quick acceleration, low price possible vehicle and reduced tail pipe emission can further reduced the tendency of global warming. In this paper, six important vehicle selection criteria has been considered and explained. The first two criteria (C1 and C2) are considered as beneficiary criterion (higher the better) and rest four criteria are considered as non-beneficiary criterion (lower the better). In order to avoid subjective judgments, CRITIC method is used for computing the criteria weights. Finally, a sensitivity analysis is shown to confirm the robustness of the ranking and further support the decision when selecting the final result. Tesla model 3 emerges out as the best alternative, which has been supported by other MADM methods like MABAC and MOORA that has been shown in Fig. 1. It is well understood from Fig. 2 that there are no changes of ranking of the alternative even their change in criteria weights. Fig. 3 establishes the robustness of the method as altering the values of λ in the range of 0.1 to 1, could not affect the ranking order at all. It is also observed that in comparison to other MADM methods in the literature, the adopted integrated model is very simple to understand and easy to execute and involves very less amount of mathematical calculations.

6. Conclusions

The proposed CRITIC-CoCoSo model is proven to be an effective decision-making tool to evaluate alternate fuel cars under requirement perspective of societal demand. It is also evident from the SA that the ranking of the alternate fuel cars does not change while interchanging the criteria weights. This indicates the strength of the integrated CRITIC-CoCoSo model. BEVs have no tail pipe emission and present EVs have longest range as similar to the conventional fuel cars along with lower operating costs. It is expected that the future BEVs will be backed with faster acceleration technology and high range capabilities. CNG cars have high amount of tail pipe emission, high annual fuel cost and very low fuel economy. The suggested methodology can be used for any type of vehicle selection problems having any number of criteria and alternatives.

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OCCUPATIONAL SAFETY AND HEALTH RISK IN BUILDING CONSTRUCTION PROJECTS: A LITERATURE REVIEW

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Review paper

Abstract. *Construction building projects have the highest accident rates compared to other industrial projects. For this reason, special attention needs to be paid to all stakeholders, starting from management, contractors and the government to reduce the number of work accidents, occupational diseases, especially in the field of construction. Based on the background of the problem and the results of the literature review sourced from journals collected and reviewed discussing occupational safety and health in construction projects in this paper concludes that there are two sources of risk that are very influential namely risks originating from internal and external, both viewed technically and non-technically. Technical results can be seen from the use of 4D-BIM technology, the use of personal protective equipment, the use of construction tools according to their permits and the non-technical results, namely awareness to work safely, knowledge and culture about occupational safety and health, construction building projects have the highest accident rates compared to other industrial projects. For this reason, special attention needs to be paid to all stakeholders, starting from management, contractors and the government to reduce the number of work accidents, occupational diseases, especially in the field of construction. Based on the background of the problem and the results of the literature review sourced from journals collected and reviewed discussing occupational safety and health in construction projects in this paper concludes that there are two sources of risk that are very influential namely risks originating from internal and external, both viewed technically and non-technically. technical results can be seen from the use of 4d-BIM technology, the use of personal protective equipment, the use of construction tools according to their permits and the non-technical results of awareness to work safely, knowledge and culture about occupational safety and health, incentives or gifts given by management and support from the government regarding commitments and supervision for occupational safety and health in construction building projects.*

Key words: *occupational safety and health, construction management, risk management, building construction.*

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1. Introduction

With the rapidly increasing construction projects in the last few decades, the challenges of occupational safety and health in the construction industry have become even greater. The safety record of the construction industry is always bad, it remains one of the most dangerous industries to work. the magnitude of the risk of accidents that occur depends also on the number of risks or hazards identified. Factors that influence include task complexity, organizational factors such as giving incentives or bonuses, personal factors such as fatigue, work environment such as work pressure, and external factors such as weather (Hallowell and Gambatese, 2009). However, the most recognised occupation safety and health hazards on construction sites have been working at height, working underground, working in confined spaces and proximity to falling materials, handling load manually, handling hazardous substances, noises, dusts, using plant and equipment, fire, exposure to live cables, poor housekeeping and ergonomics (Okoye, 2018). Occupational safety and health not only target construction workers from the local area but also need to provide protection to migrant workers (Bust et al. 2008). The reasons construction is risky and prone to occupational safety and health risks are because of the physical environment of the work, nature of the construction work operations, construction methods, construction materials, heavy equipment used, and physical properties of the construction project itself (Laryea and Mensah 2010). To overcome work accidents, efforts are also being made using technology, namely the ongoing BIM Safety research project, which aims to develop and test solutions for planning and safety management of construction sites using a more dynamic 4D site model where the aim of the BIM Safety research project is to develop procedures and use of BIM technology for safety planning, management and communication part of 4D construction planning (Sulankivi et al. 2010). Hazards in the workplace also when combined with task requests, organizational factors, work environment, personal factors, and external factors can produce unacceptable safety risks in the field of personnel and can cause severe injuries at work for that is an important form of approach this behavior is the application of an incentive safety program. Safety incentive programs, if carefully chosen and implemented correctly, can create high safety awareness that leads to reduced risk taking and enhanced behavior safety culture. Safety incentive programs are usually associated with rewards, either extrinsic or intrinsic, given to workers to encourage safe actions and behavior (Karakhan and Gambatese, 2018).

2. Methodology

Writing this article is ba sed on a literature review obtained online from a trusted source that discusses risk identification (Figure 1)and management of occupational safety and health risks which is then reviewed and synthesized to provide the latest information.

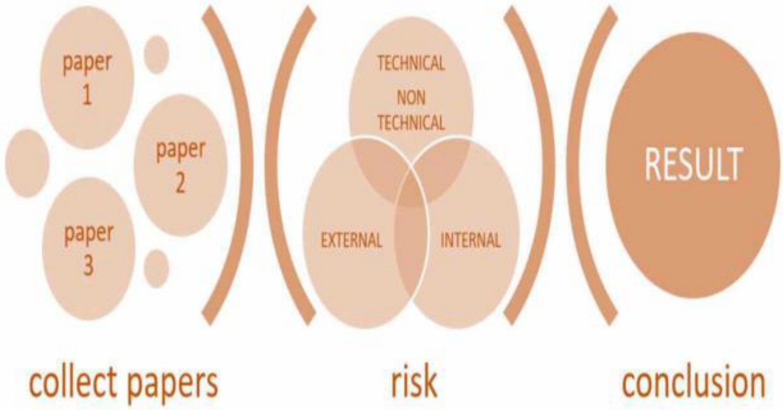

Figure 1. The method to identify risk

3. Result and Discussion

The review of the publication of scientific articles was carried out from several sources, namely: Google Scholar, ASCE, Science Direct, Researchgate, Springer, Proquest, etc. The list of selected articles is analyzed from aspects of identifying occupational safety and health risks in building construction projects as shown in Table 1.

Table 1: Review of identifying occupational safety and health risks in building construction projects

No	Paper Identity	Risk Identification				Results
		Internal		External		
		T	NT	T	NT	
1	Hallowell and Gambatese, (2009)	✓	x	x	x	Results indicate that there are 13 major activities required to construct concrete formwork and the highest risk activities are applying form oil, lifting and lowering form components, and accepting materials from a crane.
2	Okoye, (2018)	✓	x	x	x	The study found that masonry, carpentry (including formwork and roofing), and iron bending and steel fixing are common building trades associated with high risks; whereas electrical fitting and installation, painting, tiling, and plumbing are medium risk building trades.
3	Bust et al. (2008)	x	✓	x	x	The challenge of converting the health and safety systems to accommodate a multi national/ cultural workforce is being addressed using initiatives such as, translation of health and safety materials, use of interpreters and an increased use of visual methods for communicating health and safety messages.
4	Laryea and Mensah (2010)	x	✓	x	x	The primary reasons are a lack of strong institutional framework for governing construction activities and poor enforcement of health and safety policies and procedures.
5	Kahkonen et al. (2014)	✓	x	x	x	providing more illustrative site layout and safety plans, providing methods for managing and visualizing up-to date plans and site status information, as well as by supporting safety communication in various situations, such as informing site staff about coming safety arrangements or warning about risks
6	Karakhan and Gambatese, (2018)	x	✓	x	x	Incentives are motivations associated with future rewards, either extrinsic or intrinsic, that are contingent upon the fulfillment of future conditions determined ahead of time before the start of work operations.
7	Lin Mills, (2000)	x	✓	x	x	Existing government safety regulations place considerable pressure on all firms, to protect the construction workforce.
8	Cooke et al. (2008)	✓	x	x	x	The ToolSHeD™ DS tool addresses an issue of emerging importance, i.e. the need to address OHS in construction design. The potential to reduce OHS risks during the design stage of buildings and other structures has gained considerable recognition among industry policy-makers and legislators.
9	Pinto et al. (2011)	✓	x	x	x	This knowledge should be further extended to support a more in-depth risk analysis and modeling in the construction industry
10	Johnstone et al. (2014)	x	✓	x	x	Situations where the legal responsibilities of employers are more ambiguous and attenuated.While subcontracting and the leasing of workers had been a long-term feature of the some industries (like construction), the expansion of these practices to other industries creates additional logistical demands on often already stretched inspectorates.
11	Baxendale and Jones (2000)	x	✓	x	x	The CDM Regulations are aimed at improving the overall management and coordination of health and safety throughout all stages of a CP with the aim of reducing the number of serious and fatal accidents and causes of ill health that occur in the industry.
12	Manu, et al. (2017)	x	✓	x	x	While the study has shown that in each country there are practices that are not commonly implemented by contractors (and hence need attention from contractors and relevant bodies/ institutions in the countries).
13	Holmes et al. (1999)	✓	x	x	x	The risk of occupational skin disease is perceived to be unknown and associated with delayed effects. The risk of falling from height is perceived to be highly relevant to the work of small business construction firms.
14	Fortunato III et al. (2012)	✓	x	x	x	The results indicate that (1) workers on LEED construction projects are exposed to work at height, with electrical current, near unstable soils, and near heavy equipment for a greater period of time than workers on traditional projects; (2) workers are exposed to new high-risk tasks such as constructing atria, installing green roofs, and installing photovoltaic (PV) panels; and (3) some credits result in a positive impact on construction worker safety and health when low volatile organic compound (VOC) adhesives and sealants are specified.
15	Windapo, (2013)	x	✓	x	x	Regulatory requirements by contractors because of cost implications will lead to unsafe work condition, injuries and fatalities on construction sites
16	Yuan, et al. (2018)	✓	x	x	x	The results of performing SEM indicated that the direct impacts of construction workers' P&M health on work efficiency and productivity were identified to be much more important than that of the SNC. In addition, construction workers' social capital can indirectly influence the work efficiency and productivity by affecting the construction workers' P&M health.
17	Wu et al. (2018)	x	✓	x	x	This study contributes to the current stress-management research by developing a reliable factor structure of construction workers' job stress, including the job itself, family-work conflict, career development, organizational style, interpersonal relationship, and role management.
18	Wachter and Yorio, (2014)	x	✓	x	x	Results indicate the following: there is a significant negative relationship between the presenceof ten individual safety management practices, as well as the composite of these practices, with accidentrates; there is a significant negative relationship between the level of safety-focused worker emotionaland cognitive engagement with accident rates; safety management systems and worker engagementlevels can be used individually to predict accident rates; safety management systems can be used topredict worker engagement levels; and worker engagement levels act as mediators between the safetymanagement system and safety performance outcomes (such as accident rates).

19	Cheung, et al. (2004)	x	✓	x	x	The combined effect of these components results in a system that enables speedy performance assessment of safety and health activities on construction sites. With the CSHM's built-in functions, important management decisions can theoretically be made and corrective actions can be taken before potential hazards turn into fatal or injurious occupational accidents.
20	Zhou et al. (2012)	x	✓	x	x	Bringing these strands of literature together suggests new kinds of interventions, such as the development of tools and processes for using digital models to promote mindfulness through multi-party collaboration on safety.
21	Howard et al. (2017)	✓	x	✓	x	This paper describes the four major uses of UAVs, including their use in construction, the potential risks of their use to workers, approaches for risk mitigation, and the important role that safety and health professionals can play in ensuring safe approaches to the their use in the workplace.
22	Badri, et al. (2012)	x	✓	x	x	A new concept called risk factor concentration along with weighting of risk factor categories as contributors to undesirable events are used in the analytical hierarchy process multi-criteria comparison model with Expert Choice software.
23	Ringen et al. (1995)	x	✓	x	x	Potential solutions are in labor-management site safety and health planning and management. education and training of workers and supervisors, new technologies, federal regulation, workers' compensation law, medical monitoring, and occupational health delivery.
24	Idoro, (2011)	x	✓	x	x	Thus, the results reveal the challenges facing Nigerian contractors and other stakeholders working to improve the OHS performance of the industry. The findings indicate the need for effective risk management and regulation and control of OHS in the Nigerian construction industry.
25	Martinez-Aires, et al. (2018)	✓	x	✓	x	The main result shows that the growing implementation of BIM in the Architecture, Engineering and Construction (AEC) industry is changing the way safety can be approached. Potential safety hazards can be automatically identified and corresponding prevention methods can be applied using an automated approach.
26	Badri, et al. (2018)	x	✓	x	✓	As major changes are implemented, previous gains in preventive management of workplace health and safety will be at risk. If we are to avoid putting technological progress and OHS on a collision course, researchers, field experts and industrialists will have to collaborate on a smooth transition towards Industry 4.0.
27	Carter and Smith, (2006)	x	✓	x	✓	A max. of only 6.7% of the method statements analyzed on these projects managed to identify all of the hazards that should have been identified, based upon current knowledge. Maximum hazard identification levels were found to be 0.899 _89.9%_ for a CP.
28	Rahmawati et al. (2019)	✓	✓	x	x	Project Safety Review, Safety Inspection, Installation project signs, Safety morning, Personal Protective Equipment, Safety Net Installation, Installation of Safety Line, Installation of lighting to clean up the Project area is the application of the K3 program that is carried out.
29	Astiningsih et al. (2018)	x	✓	x	x	There was an association between safety inspection and the use of PPEs ($p = 0{,}024$; $\alpha=0{,}05$); safety supervision and the use of PPEs ($p = 0{,}024$; $\alpha=0{,}05$); safety morning and the use of PPEs ($p = 0{,}043$; $\alpha=0{,}05$).
30	Hidayat, (2018)	x	✓	x	x	K3 risk is known to be levelneach risk is 1 risk classified as high risk, 41 risk classified as medium, and 9 risks classified as Low Risk.
31	Bria and Loden, (2017)	x	✓	x	x	Alternative risk controls that can carried out at the risk of workers falling, controlling the risk is a daily K3 inspection for the use of PPE (Personal Protective Equipment) complete, tightening management supervision of workers who do not wear personal protective equipment, provide and complete the signs safety in construction projects if none o incomplete.
32	Atmaja et al. (2018)	✓	✓	✓	x	Construction site of cronbach's values alpha count obtained by 0.908 means that it can it is said that for characteristic variables Reliable site construction because of the alpha value between 0.61 - 0.80. Could concluded the consistency of the questions for the sub-variables is necessary training on the importance of OSH in a the project is very consistent and very appropriate.
33	Suparman and Fitriani, (2016)	✓	✓	x	x	There are 64 occupational injury risks, i.e., 13 low risk, 47 medium risk, and 4 high risk. It can be concluded that the highest risk factor for the workers is inhaled the welding smoke with the risk index of 16.
34	Endroyo, (2010)	x	x	x	✓	Educational factors correlated 0.30 (significance: 0.048) contribute to attitude of K3, and was another factor correlations were not significant. All these factors have only to give efectif contribution about to 0.213 (21.3%) of the attitude factor K3. It means that about of 78.7% which can not be explained and is a problem to be studied again.
35	Wijaya and Paing, (2018)	x	✓	x	✓	Dominant factor affecting k3 there are 5 namely change workers must be responsible for K3, K3 regulations and procedures are very in need, K3 regulations are easily applied consistently, the results of the work are fulfilling standard quality and the absence of work accidents in the work environment for certain reasons.
36	Sutrisno, et al. (2000)	x	✓	x	✓	Measurement of the influence of the safety climate on the most influential safety behavior on variable X (climate safety) of the Y variable (safety behavior), namely Communication, Perception of someone's involvement in K3 and Accidents / incidents/ nearmiss.
37	Pradipta, et al. (2015)	✓	✓	x	x	The most determining factor for the lack of completeness of K3-L is the Factor Handling of Work Accidents where workers do not apply implementation of Standard Operating Procedure (SOP) at work and less implementation of health insurance implementation.
38	Milen, et al. (2012)	x	✓	x	x	All the three project cases has a medium risk due to accident caused by ignoring the safety standards and procedure are obvious.

39	Novianto and Sri, (2016)	x	✓	x	x	Free variables occupational safety (X1) and health (X2) against K3 problem simultaneously and partial positive and significant influential variable against the performance of construction workers on the project construction of the Fly Over Palur, where the influence of variable X1 amounted to 1,903 (54,38%) and X2 of 1,098 (45,62%)
40	Hakim, (2017)	x	✓	x	x	In the risk matrix analysis there are 3 jobs that are categorized as high risk include worker falls from height at reinforcement, formwork and parapet, full electric shock on electrical installation work, and materials falls from a height and hit the worker in erection work.
41	Sanjaya et al. (2012)	x	✓	x	x	That the connection of factors that influence K3 to implementation of K3 in building construction was high (0.614), determination coefficient about 0.377 that showed the mean of K3 in building construction about 37.7 % which were determined by three factors that influenced K3, while 62.3 % were determined by the other factors. The result of relative distribution counting showed that supervising factor gave biggest influence to K3 in building construction.
42	Hartanto and Siahaan, (2018)	x	✓	x	x	The five independent variables of this order of magnitude of influence are caused by OSH Management System (X2) 73,4%, Self Protective Equipment Mechanism (X3) 60,9%, Definition and Initiation OSH (X1) 42,6%, OSH Risk (X5) 7,9% and OSH Facility and Infrastructure (X4) 3,5% so that which needs to be handled by the project leader is based on the order of the percentage.
43	Kani, et al. (2013)	x	✓	x	x	That there are still many workers who do not know about K3. What is meant by K3, how to apply K3, and so forth. This shows that there is still a lack of attention or commitment from the contracting company to implement the K3 program well.
44	Munang, et al. (2018)	x	x	x	✓	Assessing railway double rail project has identified 19 unexpected risks as a high risk and 12 unacceptable risks that are required risk mitigation to reduce the impact.
45	Triaswati et al. (2014)	x	✓	x	✓	From the K3 management system It is planned that a risk control fee of Rp 310,266,500.00 is obtained be a reference in suppressing the accident rate.
46	Soputan, et al. (2014)	x	✓	x	x	A high risk value is obtained, i.e. the material is dropped from height and override workers with a risk index of 20 and risk classification to Very High risk. For risk classification at the High Risk level as many as 21 variables can be endangering workers and jobs, while for classification at the Medium Risk level obtained as many as 18 variables.
47	Indah, (2017)	✓	✓	x	x	The level of K3 implementation on aspects of the personal protective equipment (60%), the role of emergency condition (75%), Structural work, Scaffolding and Ladder (66.7%), Use of Toxic and Dangeorus Materials (62.9%), Health and Hygiene of Work Environmental (89.2%).
48	Handayani and Prihatiningsih, (2018)	x	✓	x	x	It is found that the cause of risk in OHS for construction sector is dominated by structure criterion (44%), followed by preparation criterion (17%), sub-structure criterion (21%) and finishing criterion (19%). The biggest cause of occupational accidents is human factor by 77%,
49	Tannya et al. (2017)	x	✓	x	x	the most influential inhibiting factor is the lack of knowledge about SMK3 from the company and its employees. Of the inhibiting factors that have been obtained, it is suggested several alternative solutions

Note: √ (discussed), X (not discussed), T – technical, NT - nontechnical

3.1. Internal Technical Risk

Results indicate that there are 13 major activities required toconstruct concrete formwork and the highest risk activities are applying form oil, lifting and lowering form components, and accepting materials from a crane (Hallowell and Gambatese, 2009). The study found that masonry, carpentry (including formwork and roofing), and iron bending and steel fixing are common building trades associated with high risks; whereas electrical fitting and installation, painting, tiling, and plumbing are medium risk building trades. It also found that the rate of occurrence and magnitude of impact of different safety risk factors differ across the building trades, which could be attributed to the differences in activities and modes of operation in different building trades (Okoye, 2018). The main objective of the BIM Safety research project is to develop procedures and use of BIM technology for safety planning, management, and communications, as part of the 4D-construction planning (Sulankivi et al. 2010). Developed to help construction designers to integrate the management of OHS risk into the design process (Cooke et al. 2008). For the construction industry, discussing their limitations and pointing advantages of using fuzzy sets approaches to deal with ill-defined situations (Pinto et al. 2011). The results indicate that (1) workers on LEED construction projects are exposed to work at height, with electrical current, near unstable soils, and near heavy equipment for a greater period of time than workers on traditional projects; (2) workers are exposed to new high-risk tasks such as constructing atria, installing green roofs, and installing photovoltaic (PV) panels; and (3) some credits result in a positive impact on construction worker safety and health when low volatile organic compound (VOC) adhesives and sealants are specified. It is expected that these results can be used by practitioners to focus attention and resources on new highrisk work environments (Fortunato III et al. 2013). This review explores relationships between construction safety and digital design practices with the aim of fostering and directing further research. It surveys state-of-the-art research on databases, virtual reality, geographic information systems, 4D CAD, building information modeling and sensing technologies, finding various digital tools for addressing safety issues in the construction phase, but few tools to support design for construction safety (Yhou et al. 2012). Using UAVs in carrying out planned or reactive maintenance inspections of tall structures, such as skyscrapers, bridges, and towers where access can be costly and pose a risk to workers of falling from a great height, appears to be a clear benefit for construction managers and workers (Howard et al. 2012). The main result shows that the growing implementation of BIM in the Architecture, Engineering and Construction (AEC) industry is changing the way safety can be approached. Potential safety hazards can be automatically identified and corresponding prevention methods can be applied using an automated approach (Martinez-Aires et al. 2018). The use of appropriate methods of implementation, weak supervision of construction implementation in the field, not yet fully implementing the regulations regarding existing K3, weak supervision of the implementation of K3, inadequate both in the quality and quantity of the availability of Personal Protective Equipment (PPE) availability (Rahmawati et al. 2019). Technical equipment factors, factory ugliness problems, equipment used, machines that are no longer suitable for use (Atmaja et al. 2018). The factors assessed by respondents are still not fulfilling K3L completeness, namely lack of fire fighting equipment, no medical equipment / first aid kit at the project location, signs not properly installed, and lack of data collection for workers who experience illness or work accidents (Milen, 2012). The constraints to applying OHS in general are budget constraints, the culture of workers who are not familiar with the application of OHS and the impact of the application on the cost and selling price of property construction (Handayani and Prihatiningsih, 2018).

3.2. Internal Non Technical Risk

This context we argue that it is crucial to identify the sorts of (audio)visual narratives and forms that can effectively communicate about Health and Safety in ways that are meaningful and relevant to construction workers employed in multicultural contexts (Bust et al. 2008). The primary reasons are a lack of strong institutional framework for governing construction activities and poor enforcement of health and safety policies and procedures (Laryea and Mensah, 2010). The results show that the major factors influencing safety performance were; company size, and management and employee commitment to OHS (Lin andMills, 2001). The efforts by OSHA to make prime contractors take responsibility for their subcontractors would place pressure on them to take control of subcontractors in a way that threatens this distancing and the manipulation of legal forms it entails (Johnstone et al. 2000). The CDM Regulations are aimed at improving the overall management and coordination of health and safety throughout all stages of a construction project with the aim of reducing the number of serious and fatal accidents and causes of ill health that occur in the industry (Baxendale and Jones, 2000). Overall, the findings offer an opportunity for contractors and key industry stakeholders (e.g. state authorities) to reflect on their approach/initiatives to improving H&S management in construction (Manu et al. 2018). Social, economic and cultural factors of workers and lack of discipline among workers in complying with K3 provisions, including the use of PPE for work accidents (Rahmawati et al. 2019). The workforce still lacks understanding of PPE knowledge (Astiningsih et al. 2018; Munang et al. 2018). 1 variable with a high level of risk (High Risk) in casting jobs, namely workers falling from a height, fall of equipment / material, injured workers will be in direct contact with tools, workers exposed to dust, workers slip, until workers are exposed to electrical contact (Hidaya, 2018; Soputan et al. 2014; Indah, 2017). From the multiplication of risk frequency and risk impact, it is also obtained the criteria for the highest causes of work accidents are human beings with Risk Level L (Low) by 56% and subc criteria for the highest causes of accidents is not using PPE with Risk Level L (Low) by 56% (Bria and Loden, 2017; Handayani and Prihatiningsih, 2018). Human Factor It means that workers do not know safe procedures or dangerous actions: unable to meet work requirements so that actions occur below standard, knowing all the rules and work requirements but not complying with them (Altmaja et al. 2018). The highest risk obtained in the Palembang Musi VI Bridge construction project is risk factor 17.E is absorbed by welding fumes with a risk index of 16 (Suparman and Fitriani, 2016). Factors that influence occupational safety and health on the performance of construction work construction projects in Surabaya are communication between the contractor and the owner (Wijaya and Paing, 2018). Based on the partial regression test (backward method - Enter method), the X variable which influences Y variable is communication, perception of someone's involvement in K3, accident/incident/nearmiss (Sutrisno et al. 2000). The most decisive factor for the lack of completeness of K3-L on the Hotmix road project of the Sumbawa Regency Public Works Office is the Factor in Handling of Work Accidents where workers do not implement the Standard Operating Procedure (SOP) at work and lack the implementation of health insurance (Milen, 2012). The highest and most frequent risk is the X.15 variable, where workers do not use PPE in the field as an accident factor that occurs in construction projects (Novianto et al. 2016). The independent variable

Occupational Health Safety (X1) and Occupational Health (X2) on K3 problems simultaneously and partially have a significant and positive effect on the performance variable of construction workers on the Fly Over Palur development project, where the influence of variable X1 is 1,309 (54.38%) and X2 of 1,098 (45.62%) (Hakim, 2017). The highest risk index is known, that is, the variable of Workers falls from height in construction, formwork and parapet work with a total risk index of 13.8. The lowest risk index is found in the variable Workers exposed to respiratory disorders due to compressors on road markings with a total risk index of 5.5 (Sanjaya et al. 2014). The factor which gives the biggest influence/contribution to K3 on building construction projects is the supervision factor (Hartanto and Siahaan, 2018). The results of these five independent variables in order of magnitude of influence are caused by the K3 Management System (X2) 73.4%, the Mechanism of Personal Protective Equipment (X3) 60.9%, the Definition and Initiation of the K3 (X1) 42.6%, the K3 Risk (X5) 7.9% and K3 Facilities and Infrastructure (X4) 3.5% (Kani et al. 2013). Work accidents on construction projects are caused by human factors that neglect work safety by behaving unsafe at work (Soputan et al. 2014). K3 management plays a very important role in accident prevention in construction projects. The role starts from planning, organizing, implementing, monitoring. Furthermore, it can also be viewed from human components, materials, money, machines / tools, work methods, information. The final results of this study are: the order of the top 3 (three) of the factors that influence the implementation of the K3 work system namely (costs for PPE providers, joking while doing work, lack of knowledge of workers on the dangers and risks of the work done) (Sihombing et al. 2014).

3.3. External Technical Risk

Using UAVs in carrying out planned or reactive maintenance inspections of tall structures, such as skyscrapers, bridges, and towers where access can be costly and pose a risk to workers of falling from a great height, appears to be a clear benefit for construction managers and workers (Howard et al. 2018). The main result shows that the growing implementation of BIM in the Architecture, Engineering and Construction (AEC) industry is changing the way safety can be approached. Potential safety hazards can be automatically identified and corresponding prevention methods can be applied using an automated approach (Martinez-Aires et al. 2018). Work environment factors, the physical environment of the workplace and the wider psychological social environment (Atmaja et al. 2018).

3.4. External Non Technical Risk

Researchers, field experts and industrialists will have to collaborate on the implementation of measures based on a comprehensive vision of managing change in order to ensure a smooth and safe transition to the new paradigm. Acknowledgments The authors thank the Natural Sciences and Engineering Research (Badri et al. 2018). This is achieved using a central safety database that contains knowledge relating to safety that exists within the organization as a whole, that is construction tasks, hazards, and the relationships between them (Carter and Smith, 2006).There is no significant relationship between internal factors (level of education, experience, certification) and external (level of commitment of the company) with the attitude of K3 (Keselamatan et al. 2010). While from the education factor also said there were differences between employees with the level of junior high, high school and bachelor education (Sutrisno et al. 2000). The results showed that the construction of a double track railway project had a high risk because it directly intersected with an active train line so that there were identified 19 unexpected risks (Triaswati et al. 2014).

4. Conclusion and Recommendation

This paper concludes that there are two sources of risk that are very influential namely risks originating from internal and external, both viewed technically and non-technically. technical results can be seen from the use of 4d-BIM technology, the use of personal protective equipment, the use of construction tools according to their permits and the non-technical results of awareness to work safely, knowledge and culture about occupational safety and health, incentives or gifts given by management and support from the government regarding commitments and supervision for occupational safety and health in construction building projects. The use of appropriate methods of implementation, weak supervision of construction implementation in the field, not yet approved the implementation of existing K3 laws and regulations, weak oversight of OHS operations, inadequate both in quality and relevance supported by Personal Protective Equipment (PPE), Social environmental factors workers' economy and culture and lack of worker discipline in regulations on K3, including the use of PPE due to work (Construction and Human Resources Development Agency, 2007)(Rahmawati et al. 2019).

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THE SELECTION OF A LOCATION FOR POTENTIAL ROUNDABOUT CONSTRUCTION – A CASE STUDY OF DOBOJ

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Abstract: *The increase in the number of traffic accidents, as well as the development of modern traffic signaling, have influenced realistic traffic solutions at intersections to be aimed at constructing roundabouts, which has increased the capacity and safety of traffic participants. This paper has several goals that refer to the development of methodology for evaluating potential locations for roundabout construction. The subject of this research is based on the development of a model for the construction of a roundabout in Doboj using the integrated BWM (Best Worst Method) and MABAC (Multi-Attributive Border Approximation area Comparison) approach. Taking into account the fact that Doboj is a transport hub where many roads intersect and that it is a very important transit point, the necessity of constructing roundabouts is justified. Therefore, as part of the paper, an adequate methodology has been developed for an optimal selection of a potential location for the construction of a roundabout.*

Key words: *roundabout, location, sustainable traffic, BWM, MABAC,*

1. Introduction

In European countries, experts believe that roundabouts reduce the number of accidents and cause capacity increase, making their usage attractive since the 1980s. In the Netherlands, France, Norway, Denmark and other European countries, the number of roundabouts has been increasing progressively. In the Netherlands (Vasilyeva and Sazonova, 2017), turbo-roundabouts are being introduced with 20 to 30% higher speeds of movement in them and with greater safety. At intersections regulated by light signals, the problem occurs since pedestrian and vehicle flows intersect, which adversely affects pedestrians as a "vulnerable" category. This case is especially dominant at Russian signalized intersections, where drivers often drive under the influence of alcohol or pass the crossroad on red light. (Vasilyeva and

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Sazonova, 2017) According to the research (Møller and Hels, 2007), the performance of roundabouts was considered by the criteria of road properties, capacity and location. Their research consists of observing two types of roundabouts, with and without pedestrian crossings and cycle paths.

The trend of constructing roundabouts has also shifted to smaller urban areas, so when looking at the territory of the Republic of Srpska it is possible to see a constant increase of roundabouts in urban areas. Urban areas Bijeljina, Derventa, Trebinje, Prnjavor and others are an example of that. To solve traffic congestion and increase safety on main roads, roundabouts are being constructed extensively. When it comes to the territory of the city of Doboj and the main roads passing through the city, the number of roundabouts is zero. Taking into account the fact that Doboj is a transport hub where many roads intersect and that it is a very important transit point, the necessity of constructing roundabouts is justified.

The subject of this paper is to define potential locations for the construction of roundabouts in the area of the City of Doboj. The main objective of the paper is to identify priority intersections on the entire street network of the City of Doboj. A roundabout falls into the category of at-grade intersections, where all entering streams flow in and exiting streams flow out of usually one-way traffic flow around the central island of the intersection. Based on this, it has been formed a hypothetical assumption which implies that the introduction of a roundabout on the current street network is functionally dependent on traffic conditions and their effects on the current traffic infrastructure in the urban area of the City of Doboj. In addition, the location of a roundabout in Doboj depends on the potential urban-planning and technical conditions for the implementation of the intersection, and any potential solution can influence the change in modernity of the traffic infrastructure.

After the introduction, the second section presents an overview of the situation in the field of interest with a brief review of multi-criteria decision-making methods. The third section provides the algorithms of the methods used in this paper: MABAC, BEST WORST. The fourth section is a case study of selecting a location for the construction of a roundabout in the City of Doboj using the BWM-MABAC model. The paper ends with conclusions presenting contributions of the paper and directions for future research.

2. Brief literature review

Increasing capacity in road engineering according to (Li et al., 2014) has become an important way of solving traffic problems, and roundabouts, in addition to a large number of benefits, also cause the increase in traffic capacity (Prateli, 2006), and higher traffic flow rate (Retting et al. 2006). A properly constructed roundabout, according to (Prateli et al., 2018), can have a significant impact on increasing traffic safety, which is also confirmed by (Antov et al., 2009), who find that the construction of roundabouts is an efficient measure to increase safety.

Depending on the type of location problem, different methods are used as shown above. In the last decade, multi-criteria decision-making (MCDM) methods have been applied widely in addressing location problems (Chauhan and Singh, 2016; Nie et al., 2017; Samanlioglu and Ayag, 2017; Zhao et al., 2018; Nazari et al., 2018). Zhao et al. (2018) use a combination of AHP and TOPSIS methods to develop a metro-integrated logistics system. Using the TOPSIS method, they performed a significance evaluation for each metro station. Nazari et al. (2018) conducted a study to select a suitable site for photovoltaic installation in Iran.

3. Methods

Psychology provides an explanation why individuals frequently make irrational decisions, while economics proposes normative theories (Morselli, 2015). According to (Triantaphyllou and Mann, 1995), multi-criteria decision-making plays an important role in real-life problems since there are many everyday decisions to be made that involve a large number of criteria, whereas, according to (Chen et al., 2015), multi-criteria decision-making is an efficient, systematic and quantitative method of solving vital real-life problems in the presence of a large number of alternatives and several (opposing) criteria.

The BEST WORST (Rezai, 2015) method was used to determine the weight values of criteria, while the MABAC method was used to evaluate the intersection locations for the construction of a roundabout.

In addition, to determine model validity through a sensitivity analysis, four other multi-criteria decision-making methods were used: ARAS (Zavadskas and Turksis, 2010) WASPAS (Zavadskas and Turksis, 2012), SAW (Macrimon, 1968), and EDAS (Ghoarabaee et al., 2016).

3.1. Best – Worst Method

The following section presents the algorithm of the BW method based on interval rough numbers. Determining the weight coefficients of evaluation criteria using the IRN-BW method includes the following steps:

Step 1. Determining a set of evaluation criteria. In this step, we consider a set of evaluation criteria C = {C_1, C_2, ... C_n}, where *n* represents the total number of criteria.

Step 2. Determining the most significant (most influential) and worst (least influential) criterion. If there are two or more criteria that are best, i.e. worst, it is arbitrary to choose the best, i.e. the worst criterion.

Step 3. Determining the preferences of the most significant (most influential) criterion in a set C over all other criteria in a defined set. The scale of numbers in the interval of 1-9 is used to determine the preferences. As a result, the best-to-others (BO) vector is obtained:

$$A_B = (a_{B1}, a_{B2,\ldots\ldots,} a_{Bn}) \tag{1}$$

where a_{Bj} represents the influence (preference) of the best criterion B over the criterion *j*, while $a_{BB} = 1$.

Step 4. Determining the preferences of all criteria in a set C over the worst (least influential) criterion in a defined set. To determine the preferences, as in *Step 3*, a scale of numbers in the interval of 1-9 is used. The result is obtaining the others-to-worst (OW) vector:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW}) \tag{2}$$

where a_{Bj} represents the influence (preference) of the criterion *j* over the worst criterion W, while $a_{BB} = 1$.

Step 5. Calculation of optimal values of the weight coefficients of the criteria in a set C, $(w_1^*, w_2^*, \ldots, w_n^*)$. The aim is to determine the optimal values of the evaluation criteria, which should satisfy the condition that the maximum absolute gaps (3)

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \quad \text{and} \quad \left|\frac{w_j}{w_W} - a_{jW}\right| \tag{3}$$

for all values of *j* be minimized. In order to satisfy these conditions, a solution that satisfies the maximum gaps by absolute value $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jW}\right|$ should be minimized for all values of *j*. This condition can be shown through the following min-max model:

$$\begin{aligned} &\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\} \\ &s.t. \\ &\sum_{j=1}^{n} w_j = 1 \\ &w_j \geq 0 \quad \forall j \end{aligned} \tag{4}$$

The presented model (4) is equivalent to the following model:

$$\begin{aligned} &\min \xi \\ &s.t. \\ &\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \forall j \\ &\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \forall j \\ &\sum_{j=1}^{n} w_j = 1 \\ &w_j \geq 0 \quad \forall j \end{aligned} \tag{5}$$

By solving the system of equations and inequations of model (5), we obtain the optimal values of the weight coefficients of the evaluation criteria $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^*.

Definition 1. The criterion comparison is consistent when the condition that $a_{Bj} \times a_{jW} = a_{BW}$ is fulfilled for all criteria *j*, where a_{Bj} , a_{jW} and a_{BW} respectively represent the influence (preference) of the best criterion over the criterion *j*, the influence (preference) of the criterion *j* over the worst criterion, and preference of the best criterion over the worst criterion.

However, when comparing criteria, it may be that for some pairs of criteria *j*, the comparisons are not fully consistent. Therefore, the following section defines a consistency ratio (CR) that provides information on the consistency of the BO and OW comparisons. To show the determination of CR, we start from the calculation of the minimum consistency in the comparison of criteria, which is explained in the following section.

As noted above, pair-wise comparisons of criteria are made on the basis of the scale $a_{ij} \in \{1,2,...,a_{BW}\}$, where the highest value from scale a_{BW} is a value of 9 or any other maximum value of a scale defined by the decision-maker. The consistency of the comparison decreases when $a_{Bj} \times a_{jW}$ is lower or higher than a_{BW}, i.e. when $a_{Bj} \times a_{jW} \neq a_{BW}$.

It is clear that the greatest inequality occurs when a_{Bj} and a_{jW} have maximum values that are equal to a_{BW}, which further affects the values of ξ. Based on the relations defined above, we can conclude that there is a relation as follows:

$$(w_B/w_j) \times (w_j/w_W) = w_B/w_W \quad (6)$$

Since the greatest inequality occurs when a_{Bj} and a_{jW} have maximum values (a_{BW}), then the value of ξ needs to be subtracted from a_{Bj} and a_{jW} and added to a_{BW}.

Thus, we obtain Expression *(7):*

$$(a_{Bj} - \xi) \times (a_{jW} - \xi) = (a_{BW} + \xi) \quad (7)$$

Since the minimum consistency implies the equality that $a_{Bj} = a_{jW} = a_{BW,}$ Expression (7) is presented as follows:

$$(a_{BW} - \xi) \times (a_{BW} - \xi) = (a_{BW} + \xi) \;\Rightarrow\; \xi^2 - (1 - 2a_{BW})\xi + (a_{BW}{}^2 - a_{BW}) = 0 \quad (8)$$

For different values of $a_{BW} \in \{1,2,...,9\}$ based on Expression (8), we obtain maximum values of ξ (max ξ). Table 1 presents the maximum values of ξ (consistency index) for different values of $a_{BW} \in \{1,2,...,9\}$.

Table 1. Consistency Index (CI) values

a_{BW}	1	2	3	4	5	6	7	8	9
CI (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Based on CI (Table 2), we obtain a consistency ratio (CR)

$$CR = \frac{\xi^*}{CI} \quad (9)$$

CR takes values from the interval $[0,1]$, where values closer to zero show high consistency, while *CR* values closer to one show low consistency.

The solution space of model (5) includes all positive values of w_j ($j = 1,2,\ldots n$) that satisfy two conditions: (1) the sum of all weight coefficients should be equal to one and (2) the ratio of the weighted coefficients of the criteria which are compared should be at most equal to ξ.

3.2. MABAC method

The MABAC (Multi-Attributive Border Approximation area Comparison) method is a recent method. The MABAC method was developed by Dragan Pamučar at the Center for Defense Logistics Research at the University of Defense in Belgrade and was first introduced to the scientific community in 2015 (Pamučar and Ćirović, 2015). So far, it has found wide application and modification in solving various problems in the field of multi-criteria decision-making.

The basis of the MABAC method is seen in the definition of the distance of the criterion function of each alternative from the border approximation area. The following section shows the process of implementing the MABAC method, consisting of six steps:

Step 1. Formation of the initial decision matrix (X).

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \ldots & C_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \end{array} \tag{10}$$

Step 2. Normalization of the elements from the initial matrix (X).

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

The elements of the normalized matrix (N) are determined by applying the following expressions:

For benefit-type criteria (higher criterion value is preferable)

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{12}$$

For cost-type criteria (lower criterion value is preferable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{13}$$

where

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

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

Step 3. Calculation of the elements from the weighted matrix (V).

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{14}$$

where t_{ij} represents the elements of the normalized matrix (N), w_i represents the weight coefficients of criteria. By applying Expression (14), we obtain the 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 4. Determining the border approximation area matrix (G).

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{15}$$

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

After calculating the values of g_i by criteria, a border approximation area matrix G (16) of the form $n\,x\,1$ is created (n represents the total number of criteria by which the offered alternatives are selected).

$$\begin{matrix} & C_1 & C_2 & \cdots & C_n \\ G = & [g_1 & g_2 & \cdots & g_n] \end{matrix} \tag{16}$$

Step 5. Calculation of matrix elements of alternative distance from the border approximation area (Q).

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{17}$$

The distance of alternatives from the border approximation area (q_{ij}) is determined as the difference of the weighted matrix elements (V) and the values of the border approximation areas (G)

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \tag{18}$$

$$Q = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{19}$$

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

The alternative A_i can belong to the border approximation area (G), the upper approximation area (G^+) or the lower approximation area (G^-), i.e. $A_i \in \{G \vee G^+ \vee G^-\}$

The upper approximation area (G^+) represents the area where the ideal alternative (A^+) is located, while the lower approximation area (G^-) represents the area where the anti-ideal alternative (A^-) is located. The affiliation of the alternative A_i to the approximation area (G, G^+ or G^-) is determined on the basis of Expression (20)

$$A_i \in \begin{cases} G^+ \ \ if \ q_{ij} > g_i \\ G \ \ if \ q_{ij} = g_i \\ G^- \ \ if \ q_{ij} < g_i \end{cases} \tag{20}$$

In order for the alternative A_i to be selected as the best alternative of the set, it should belong to the upper approximation area (G+) by as many criteria as possible. For instance, if the alternative belongs to the upper approximation area by five criteria (out of a total of six criteria), and to the lower approximation area (G^-) by one criterion, it means that the alternative is close or equal to the ideal alternative by five criteria, while it is close or equal to the anti-ideal alternative by one criterion. If the value of $q_{ij} > 0$, i.e. $q_{ij} \in G^+$, then the alternative A_i is close or equal to the ideal alternative. The value of $q_{ij} < 0$, i.e. $q_{ij} \in G^-$, indicates that the alternative A_i is close or equal to the anti-ideal alternative.

Step 6. Ranking alternatives. The calculation of the values of criterion functions by alternatives (21) is obtained as the sum of the distances of alternatives from the border approximation area (q_i). By summing the elements of the matrix Q by rows, we obtain the final values of the criterion functions of alternatives

$$S_i = \sum_{j=1}^{n} q_{ij}, \ j = 1,2,...,n, \ i = 1,2,...,m \tag{21}$$

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

4. A case study in the city of Doboj – Description of the situation in the City of Doboj

The selection of the location for the construction of a roundabout consists of several stages that are described in detail below. The first stage implies the formation of a multi-criteria model based on the realistic needs for traffic infrastructure in the city of Doboj. The second stage implies the collection of data on the basis of measurements of traffic indicators and other sources, such as the Ministry of Interior, where data on the number of traffic accidents at the locations for roundabout construction were obtained. The third stage refers to the expert evaluation of the significance of criteria as the first step and the determination of the weights of the criteria using the BWM method as the second step. The fourth stage is the evaluation of the locations based on the MABAC method. This paper will analyze six potential locations for the introduction of a roundabout intersection in the city of Doboj, where no roundabout has been constructed so far. As already mentioned, the city of Doboj, by its geographical position, is located at the crossroads of the most important main and regional roads in the Republic of Srpska and Bosnia and Herzegovina.

This research involved traffic experts. They are on average 50 years old and there were 62 respondents.

The 105 main road (M1) passes in the north-south direction and, in the east, it is connected to the 110 main road from (M1) the direction of Tuzla (Federation of BiH). The most frequent part of the 105 main road (M1) is on the Šešlije - Doboj - Karuše - Federation of BiH route.

The intersections of city streets with access to the main roads are not well resolved in the city, which significantly hinders a normal flow of traffic, especially at peak hours. Taking into account the transport significance of the city of Doboj, as well as the fact that nearby towns, such as Modriča, Derventa, Teslić and many other smaller towns and municipalities already have roundabouts, six potential intersections have been selected for the construction of a roundabout in the city, as well as on the 105 main road (M1). The following table gives an overview of the potential coordinates for the roundabout.

Table 2. Coordinates for the roundabout

Location	A1	A2	A3	A4	A5	A6
Coordinates	44.743443 18.095140	44.735776 18.096611	44.733405 18.096111	44.726579 18.091869	44.713155 18.080535	44.730244 18.081451

4.1. Forming a multi-criteria model

Six locations, out of which one is located in the very center of the city, four locations representing the connection between the streets for the entrance into/exit from the city and the first-order main road, and one location where the first-order main roads intersect, are evaluated on the basis of a total of eight criteria presented in Table 3.

Table 3. Criteria in a multi-criteria model and their description

No.	Criterion	Criterion description
1	Flow of vehicles	The number of vehicles passing through the observed road intersection in a unit of time in both directions
2	Flow of pedestrians	The number of pedestrians crossing the observed intersection at the point for pedestrian movement (pedestrian crossing, zebra, etc.) at a given time interval
3	Traffic Safety Indicator	The number of traffic accidents on the observed section of road
4	Cost of construction and exploitation	Cost estimation (construction, exploitation and maintenance)
5	Type of intersection	Three-way or four-way intersections
6	Average vehicle intensity per access arm	The limit intensity is the intensity at the entry arm into the intersection of 360 PA/h
7	Functional criterion of spatial fitting	What is the primary role of the intersection observed? This section analyzes what type of intersection is the most acceptable due to its role in traffic
8	Public opinion	It implies a survey of local people who have chosen one of the offered locations as a priority for the construction of a roundabout.

The criteria were selected according to the current needs of the City of Doboj and relevant literature that considered similar studies (Day et al., 2013; Benekohal and Atluri, 2009; Deluka-Tibljaš et al., 2010; Steiner et al., 2014). In all the aforementioned studies, the criteria are organized into several categories: traffic criteria, safety criteria, functional criteria, performance, cost, etc. The criteria used in this study are the most commonly used criteria in Croatia: functional criterion, spatially-urbanistic criterion, traffic flow criterion, design and technical criterion, traffic safety criterion, capacity criterion, environmental criterion, economic criterion; in Serbia and Slovenia: functional criterion, capacity criterion, spatial criterion, design and technical criterion, traffic safety criterion and economic criterion (Kozić et al., 2016). The results provided by the study (Retting et al., 2007) indicate that public support increases with time since traffic participants become more familiar and comfortable with this form of traffic control. Considering this, the use of the last criterion in this research has its justification.

4.2. Evaluating and ranking the locations for roundabout construction using the MABAC method

Flow measurement was performed at the sampling level in the period September-November 2017. The data collected for each location based on established criteria are presented in Table 4.

Table 4. Values of alternatives according to criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	1256	8	2	3	3	419	7	85
A_2	2194	4	2	9	3	731	5	89
A_3	1037	5	4	7	3	346	3	45
A_4	2878	32	3	7	4	720	5	8
A_5	1052	2	4	5	4	263	5	27
A_6	4197	124	1	3	4	1050	7	74

Table 4 shows the values for all the locations by established criteria. It can be noticed that the highest intensity of traffic flows of vehicles and pedestrians belongs to the sixth location with 4197 vehicles and 124 pedestrians in one hour. Locations 4 and 2 have slightly less intensity regarding vehicle flows, while the intensity of pedestrians is 32 for the fourth, and only four for the second location. The remaining locations have double less intensity than the two previously mentioned locations, and almost four times less than the sixth location. If the sixth and fourth locations are excluded, the flows of pedestrians are very low. The reason is that the sixth location is in the city center, and the fourth location represents the connection between entering the city and the railway station. Regarding the number of traffic accidents, the largest number of accidents occurred at locations 3 and 5, four accidents per each, while the lowest number of accidents occurred at the sixth location. The average vehicle intensity per an arm (Table 4) is the largest at the sixth location, 1050, while for the second and fourth location it is almost identical, 731 and 720, respectively. The minimum intensity per an arm is at the fifth location since this location has four arms and an additional arm that is not presented in the paper as an arm, as it is a side road with no frequent traffic. Based on the public opinion survey for potential locations, the largest number of citizens have characterized the first two locations as a priority for the construction of a roundabout, and as the third one, they designated the sixth location.

After obtaining the matrix Q, it is necessary to sum the elements by rows and rank them. Table 5 shows the final values of roundabout locations using the MABAC method.

Table 5. Final values and ranking the alternatives

	Values	**Rank**
A_1	-0.042	**5**
A_2	0.010	**4**
A_3	-0.043	**6**
A_4	0.074	**3**
A_5	0.132	**2**
A_6	0.167	**1**

5. Sensitivity analysis

In order to validate the model and test the results obtained by applying the MABAC method, a sensitivity analysis consisting of the application of the ARAS (Table 6), EDAS (Table 7), SAW (Table 8), and WASPAS (Table 9) methods is performed in the paper.

5.1. Ranking the locations using the ARAS method

Compared to MABAC and other methods used in this paper, the initial matrix for the ARAS method is slightly different. It is reflected through the formation of an additional row that represents the optimal alternative. This alternative consists of the best values depending on the type of criteria. If it is a criterion belonging to the benefit group, the maximum value is taken, while for the criteria belonging to the cost group, the minimum value is taken. After forming the optimal alternative, the initial matrix is as shown in Table 6.

Table 6. Ranking the locations using the ARAS method

	Si	Ki	Rank
A1	0.111	0.519	6
A2	0.134	0.626	3
A3	0.122	0.573	5
A4	0.131	0.614	4
A5	0.144	0.673	2
A6	0.144	0.675	1
Ao	0.214	1.000	

5.2. Ranking the locations using the EDAS method

Table 7. Results obtained using the EDAS method

	SPI	NSI	NSPI	NSNI	ASI	Rank
A_1	0.080	0.177	0.233	0.462	0.348	6
A_2	0.167	0.118	0.488	0,.642	0.565	1
A_3	0.189	0.210	0.554	0.363	0.459	5
A_4	0.149	0.144	0.435	0.563	0.499	4
A_5	0.253	0.201	0.740	0.390	0.565	2
A_6	0.342	0.329	1.000	0.000	0.500	3

5.3. Ranking the locations using the SAW method

Table 8. Ranking the locations using the SAW method

	Values	Rank
A_1	0.547	6
A_2	0.634	3
A_3	0.595	5
A_4	0.633	4
A_5	0.694	2
A_6	0.694	1

5.4. Ranking the locations using the WASPAS method

This method, as already mentioned in the paper, contains the previously applied SAW method in its steps, so that the normalization, weighting of the normalized matrix, and summarizing the values by alternatives are identical as by the SAW method, thus there is no need to display those matrices.

Table 9. Ranking the locations using the WASPAS method

	WPM	Qi	Rank
A_1	0.508	0.528	6
A_2	0.615	0.624	2
A_3	0.522	0.558	5
A_4	0.564	0.599	4
A_5	0.576	0.635	1
A_6	0.514	0.604	3

Based on the presented calculation, it can be noticed that the location under the number 6 is best and a priority for the construction of a roundabout. Since it is the location that has the largest traffic flow of pedestrians, an alternative solution for this location is the installation of traffic lights at this intersection, which has been done in the meantime, as it is well-known that if there is a high rate of pedestrians at a roundabout, alternative solutions are used. The intensity of pedestrians at this location for the period of one hour is 124 and, according to the authors' opinion, it is not a limitation for the roundabout construction. Location 6 represents the location in the city center. The second priority location for the construction of a roundabout is location 5 representing the last exit from the city towards Sarajevo and which is a four-way intersection with an additional side road. There is often traffic congestion at this intersection where city streets are its arms, so there is often a situation where drivers carelessly merge onto the main road, as evidenced by a number of accidents. Considering the above, the priority for the construction of a roundabout at this location is justified.

Since there is a change in the ranks of the alternatives, it is necessary to make a statistical comparison of the ranks, i.e. to determine their correlation. Table 10 shows Spearman's correlation coefficient of the ranks of the alternatives for all the methods used.

Table 10. Spearman's correlation coefficient of the ranks of the alternatives for all the methods used

Methods	MABAC	ARAS	WASPAS	SAW	EDAS	Average
MABAC	1.000	0.886	0.657	0886	0.543	0.794
ARAS	-	1.000	0.829	1.000	0.771	0.900
WASPAS	-	-	1.000	0.829	0.943	0.924
SAW	-	-	-	1.000	0.771	0.886
EDAS	-	-	-	-	1.000	1.000
Overall average						0.901

Based on the total calculated statistical correlation coefficient (0.910), it can be concluded that the ranks are in a high correlation in all the created scenarios. Regarding the rank correlation of MABAC with other methods, there is a high correlation with ARAS and SAW methods, while there is a lower correlation with the other two methods, with WASPAS 0.657 and with EDAS 0.543. ARAS has the total correlation with the SAW method (1.000), with WASPAS (0.829), while it has the lowest correlation of 0.771 with EDAS. WASPAS and EDAS have the highest correlation between each other, when considering these two methods, and it is 0.943. By observing the overall ranks and correlation coefficients, it can be concluded that the model obtained is very stable and the ranks are in a high correlation since all values higher than 0.80 according to (Keshavarz Ghorabaee et al., 2016) represent a very high correlation of ranks.

6. Conclusion

The developed model that includes the integration of BWM and MABAC methods has been applied in a case study of selecting the location for the construction of a roundabout in the City of Doboj, which is one of the important factors for increasing the mobility and functional sustainability of the city. Taking into account the geographical position of Doboj, it is imperative to construct roundabouts on the territory covered by this urban area. Its location affects a significant share of transit flows, increasing negative externalities to traffic sustainability. The solution is certainly the construction of roundabouts that significantly eliminate or reduce current negative effects. The hypotheses set out in the paper have been proven through the development of the integrated model and analysis of all necessary parameters, which can be seen from the results obtained. The paper considers six potential locations, which have been evaluated using the integrated multi-criteria model.

Based on the obtained results, it can be concluded that the sixth location is best in terms of the defined optimization criterion and represents a priority location for the construction of a roundabout. Location 6 represents the location that is in the city center. The second priority location for the construction of a roundabout is location 5 representing the last exit from the city towards Sarajevo and a four-way intersection with an additional side road. There is frequently traffic congestion at this intersection where city streets are its arms. Taking into account the above, the priority for the construction of a roundabout at the mentioned locations has been evaluated as justified. The model stability was verified throughout a sensitivity analysis in which the scenarios were created by applying different approaches.

When observing the current state in the field of interest and infrastructure construction that involves smaller local projects, it is often one or two criteria considered when building infrastructure. The development of such a model as in this research creates the possibility of comprehensive consideration of all the important factors for infrastructure construction, which is one of the contributions of this research. In addition to the traffic flows of vehicles that are the main criterion, it is necessary to take into account the number of traffic accidents that occurred at the considered locations, pedestrian traffic flows, the economic aspect of construction and other factors covered in detail throughout the paper.

Future research with respect to this paper refers to the development of a model that will enable the measurement of parameters that enhance traffic sustainability and the possibility of developing new approaches in the area of multi-criteria decision-making.

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RANKING BANKS BY APPLYING THE MULTILEVEL I–DISTANCE METHODOLOGY

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Abstract: *Banks in the Republic of Srpska are one of the most important drivers of the economy and household savings. The activity of the financial market of the Republic of Srpska is low and banks are still the main source of funding. The question of the objective ranking of banks based on business results is an important element in the business decisions made by companies and the population. A bank's position and quality would depend on the criteria to be included in the analysis. The professional literature recommends that banks' liquidity, profitability, efficiency and solvency should be monitored. In most cases, whether to rank banks based on liquidity or adequacy or on another indicator is doubtful. The best picture of the state of the banks is obtained when all indicators are involved in such ranking. The aim of this study is to define and rank the banks headquartered in the Republic of Srpska by following a total of four indicators. In this paper, the calculation of banks' liquidity, efficiency, profitability and solvency based upon the publicly presented audit reports for the years 2013 and 2014 is given. Then, the statistical model that absorbs information and generates the final ranking of banks in the RS is defined. The subject of the study is the banks that operate and are headquartered in the RS. The hypothesis is to determine their rankings based on their business performance.*

Keywords: *bank, ranking list, I-distance, criteria.*

1. Introduction

The quality evaluation of banks' success includes monitoring a bank from different perspectives and measuring its quality from different aspects. Successful

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banks are those banks that do not have a problem with liquidity and solvency, thereby achieving the optimal amount of the profit. These aspects are the main principles of banking operations, well-known as the “golden rules” of banking. Performance analysis is closely related to liquidity, efficiency, profitability, and solvency (capital adequacy).

1.1. Liquidity

The ***liquidity*** of a bank is a complex concept, usually interpreted as a bank's ability to meet its obligations upon maturity. A bank's management are required to continuously monitor its liquidity from the static and dynamic aspects. By disrupting the liquidity of only one bank, the survival of the entire financial system may be brought into question. If a bank is unable to service its obligations, general confidence in the financial system is lost, which leads to the erosion of the monetary assets of all banks. The following indicators are used both in theory and in practice to assess liquidity:

- L1 = Cash and pledged marketable securities / Business assets,
- L2 = Total deposits / Borrowings,
- L3 = Variable funds / Liquid assets,
- L4 = Total loans / Total deposits,
- L5 = Liquid assets / Operating assets (Ćurčić, 1995).

During the management of a bank's liquidity, the indicators L1, L2 and L5 need to be maximized, i.e. a higher value of these ratios shows the presence of better liquidity. The indicators L3 and L4 have a completely opposite meaning, i.e. a low value of these indicators implicates high liquidity, and *vice versa*. When analyzing a bank, it should not be forgotten that too high liquidity causes low profitability.

1.2. Efficiency

Efficiency is defined by the phrase “do things right” and, in a specific case, it is indicative of the fact that banks must manage their assets by implementing the best possible strategy. A bank’s efficiency is achieved when the bank produces bigger effects with as-low-as-possible costs, increasing its productive assets by placing liabilities in the best way under current circumstances (Ćurčić, 1995). Productive assets bring interest income, after which banks increase capital, provided that they have achieved a positive financial result. The indicators providing information about effectiveness are as follows:

- E1 = Interest expense / Interest income
- E2 = Provisions / Net interest income,
- E3 = Interest income / Total number of employees (Sinkey, 1989).

The data for this calculation are taken from the income statement, and banks tend to minimize the indicators E1 and E2 – a lower value rejects greater efficiency, and *vice versa*. The indicator E3 has an alternative explanation, i.e. the maximum value increases efficiency.

1.3. Profitability

Profitability indicators are crucial for business analysis and are defined as a bank's earning ability, i.e. its ability to receive income from invested assets and increase them during business cycles. They are used to evaluate a bank's profitability in a given time, usually at the end of the accounting period (Roman et al., 2015):

- P1 = Profit before tax / Equity,
- P2 = Profit before tax / Business assets
- P3 = Profit before tax / Interest income.

Higher values of the profitability indicators signal a greater earning power, and thus there is a possibility of increasing share capital. Caution should be exercised when interpreting the profitability indicators, because numbers may distort the true picture. The profitability indicators are maximized as a result of an increase in a net profit before tax, not under the influence of a reduction in capital, assets or income from interest and the like.

1.4. Solvency

The ***solvency***, or ***capital adequacy***, of a bank is an indicator which should be paid more attention to in the banking practice. To support this indicator, there is the statutory rate of the minimum capital adequacy ratio of 12%, which represents a bank's ability to eventually fulfill all of its obligations, even from its bankruptcy estate. "A bank is considered insolvent when its liabilities exceed the value of its assets, or when realized losses exceed its equity capital." In that case, the bank does not have enough capital to cover the incurred losses, and a part of the assets are non-performing loans, receivables and loans, and there is no possibility for the bank to fulfill all of its obligations (Ćurčić, 1995; Garcia et al., 2010). The criteria used to test the solvency (capital adequacy) of the bank are:

- S1 = Total Liabilities / Equity;
- S2 = Total deposits / Equity;
- S3 = Venture capital / Total risk-weighted assets;
- S4 = Shareholders' equity / Business assets;
- S5 = Shareholders' equity / Risk-weighted assets;
- S6 = Shareholders' equity / Total deposits;
- S7 = Shareholders' equity / Loans (Dragašević, 2010).

When managing solvency, a bank should tend to minimize the indicators S1 and S2 and have the values of the other indicators as high as possible. Instead of total assets and total resources, operating assets and business assets are included in the calculation of these indicators. Banks are for-profit organizations and business assets, which represent the funds arising from operations, participate directly in making a profit and are fully justifiably included in the calculation. The confirmation for this is the fact that total assets represent a sum of operating assets and off-balance assets, where the off-balance sheet positions are sureties, guarantees, acceptances, bills of exchange and other forms of guarantees, uncovered letters of credit, irrevocable, approved but undrawn loans and so forth. It is characteristic of the off-balance sheet positions that they are potential liabilities or claims, and that there is an amount of uncertainty regarding whether and when those contingent liabilities and receivables would be implemented. Banks often use off-balance sheet transactions in order to earn additional income, accomplished through commission fees. To conclude, off-balance sheet (assets) are excluded from the calculation, because the research is aimed at showing the real rank and position of the banks operating in the Republic of Srpska's banking sector based on their core business.

2. Methods

There are numerous methods and ways for ranking certain units within a set or a sample. In particular, it is possible to use various multicriteria ranking methods for banks, such as ELECTRE, PROMETHEE, CAMELS, and so on. In this paper, however, we decided to apply the I-distance method. The I-distance method was originally introduced and defined in professor Branislav Ivanović's publications in the 1960s and the 1970s. Professor Ivanović designed this method so as to rank countries by the development level, which he described by means of various socio-economic indicators (Jeremić et al., 2013). The relative position of a unit in relation to another within the units of a dataset can be determined by using this method. The linear (clustered and non-clustered) and quadratic distances were worked out in the method, and further research in this field has led to the development of a multistage I-distance, which will be used in this paper (Ivanović, 1977; Jeremić et al., 2013; Jovanović–Milenković et al., 2015).

The process of the construction of the I-distance is iterative (Jeremić et al., 2013), the number of iterations depending on the number of the indicators to be included in the analysis. If observing a set of indicators $C^T = (C_1, C_2, \dots C_k)$, which in this case describe the quality of a certain field of operations, the I-distance between the two observed units (i.e. banks in this case) $e_{r=(c_1, c_2, \dots c_{k,r})}$ and $e_{s=(c_1, c_2, \dots c_{k,s})}$ is calculated by applying the following equation:

$$D(r,s) = \sum_{i=1}^{k} \frac{|d_i(r,s)|}{\sigma_i} \prod_{j=1}^{i-1} (1 - r_{ji.12\dots j-1}) \tag{1}$$

where:

$d_i(r,s)$ is the distance between the units e_r and e_s for the indicator C_i;

σ_i is the standard deviation for the value of all the units as per indicator C_i;

$r_{ji.12\dots j-1}$ represents a partial correlation coefficient between the indicators C_i and C_j (Marković et al., 2020; Radojičić et al., 2012).

It was pointed out that the calculation of the I-distance is a procedure consisting of several iterations. The process, first, involves the entire discriminatory effect of the indicator X1, i.e. the indicator with the most information about the level of the "quality" of the unit. After that, the part of the discriminatory effect of the second indicator not involved in the discriminatory effect of the first indicator is added. In a fashion similar to the previous one, the part of the information provided by the third indicator not involved in the discriminatory effect of the first two is added. The whole process continues, so that the level of the "quality" of the unit ej, defined by a set of the indicator X, might finally be as follows:

$$D_j = \sum_{i=1}^{n} D_{ji} \tag{2}$$

If the variables have a different (either positive or negative) sign resulting in the occurrence of a negative correlation coefficient between the variables, it is necessary to use the square I-distance (Jeremić et al., 2013) in the analysis. The inclusion of the indicators with less information is greater in the square distance than in the plain distance, which is another reason why the square I-distance should be used when there is a large number of indicators. The square I-distance is calculated as follows:

$$D^2(r,s) = \sum_{i=1}^{k} \frac{|d_i^2(r,s)|}{\sigma_i^2} \prod_{j=1}^{i-1} (1 - r^2{}_{ji.12\ldots j-1}) \tag{3}$$

In this paper, the ranking of the banks will be performed by means of the square I-distance, because of the occurrence of the negative partial correlation coefficients between the observed indicators for the ranking. It is, however, necessary to say that, due to the specific problem being solved, the two-stage method of the I-distance will be applied. This method involves the calculation of the I-distance for units in the set in several stages, i.e. in two stages in this particular case. The results of the I–distance will be obtained within each segment and the measurement of the banks' performances (liquidity, profitability, efficiency, solvency), after which the same method will be applied again to the obtained results in order to obtain the final ranking of the banks in the RS. This method will allow us to determine the best-performing banks for each of these segments, and the most successful one among them (Marković et al., 2020; Jovanović – Milenković et al., 2015).

Apart from the final ranking, this method also allows the determination of weight coefficients for each indicator individually, also establishing the relative importance of bank performance indicators (liquidity, profitability, efficiency, solvency) and giving a picture of the quality assessment of each bank individually (Dobrota et al., 2015).

3. Research Results

The research study includes all the banks headquartered in the RS. It is aimed at forming the final ranking, which realistically reflects the quality of the operations of the banks by the observed indicators. The years the survey was conducted for are 2013 and 2014, the data having been taken from the official financial and audit reports of the included banks. Table 1 shows the quantitative indicator values expressed for the observed banks in 2013.

Table 1. The indicators of the banks' performance in 2013

Ind.	*Nova bank*	*NLB*	*Uni-credit*	*Hypo*	*Sberbank*	*Komercijalna*	*Banka Srpske*	*Pavlov. banka*	*MF*	*Bobar*
I Liq.										
L1	*0.059*	*0.103*	*0.030*	*0.052*	*0.062*	*0.046*	*0.082*	*0.104*	*0.052*	*0.066*
L2	*0.834*	*0.863*	*0.844*	*0.902*	*0.881*	*0.878*	*0.712*	*0.948*	*0.657*	*1.001*
L3	*5.695*	*2.451*	*6.534*	*4.242*	*4.287*	*6.236*	*4.339*	*3.594*	*12.64*	*4.634*
L4	*0.950*	*0.861*	*1.161*	*1.055*	*1.158*	*1.096*	*1.108*	*0.822*	*1.330*	*0.901*
L5	*0.170*	*0.396*	*0.150*	*0.225*	*0.229*	*0.158*	*0.208*	*0.261*	*0.078*	*0.209*
II Effic.										
E1	*0.492*	*0.385*	*0.203*	*0.445*	*0.348*	*0.307*	*0.487*	*0.353*	*0.398*	*0.456*
E2	*0.031*	*0.038*	*0.013*	*2.241*	*0.020*	*0.118*	*1.564*	*0.177*	*0.055*	*0.751*
E3	*124714*	*102893*	*128527*	*104789*	*116425*	*100021*	*58208*	*55980*	*77257*	*97697*
III Prof.										
P1	*0.103*	*0.113*	*0.128*	*0.000*	*0.039*	*0.006*	*0.000*	*0.024*	*0.016*	*0.043*
P2	*0.008*	*0.011*	*0.020*	*0.000*	*0.006*	*0.001*	*0.000*	*0.003*	*0.002*	*0.006*
P3	*0.009*	*0.013*	*0.023*	*0.000*	*0.007*	*0.002*	*0.000*	*0.004*	*0.002*	*0.007*
IV Sol.										
S1	*11.80*	*8.89*	*5.54*	*4.82*	*5.76*	*3.07*	*7.80*	*6.17*	*6.36*	*6.18*
S2	*9.42*	*7.32*	*4.60*	*3.71*	*4.95*	*2.64*	*5.19*	*5.79*	*3.97*	*5.26*
S3	*0.130*	*0.186*	*0.226*	*0.202*	*0.128*	*0.255*	*0.142*	*0.133*	*0.186*	*0.143*
S4	*0.064*	*0.052*	*0.103*	*0.134*	*0.093*	*0.228*	*0.156*	*0.092*	*0.171*	*0.124*
S5	*0.082*	*0.039*	*0.171*	*0.190*	*0.099*	*0.317*	*0.202*	*0.117*	*0.225*	*0.151*
S6	*0.087*	*0.071*	*0.147*	*0.210*	*0.128*	*0.351*	*0.265*	*0.114*	*0.316*	*0.169*
S7	*0.092*	*0.054*	*0.126*	*0.199*	*0.110*	*0.320*	*0.239*	*0.159*	*0.238*	*0.187*

All indicators were calculated as stated in the introductory part, the example of the calculation being the method for the calculation of the criteria L1 and L2 for *Nova banka*.

L1 = Cash and pledged marketable securities / Business assets

L1 = 103,560,819/ 1,737,567,592 = 0.059

L2 = Total deposits / Borrowings

L2 = 1,074,122,000/1,288,604,269=0.834

The results show the performance of the ten banks, only one of which (Banka Srpske) is a bank in the majority ownership of the state. The following is the final ranking combining all the aspects of the banking operations of the analyzed banks in 2013.

Table 2. The ranking of the banks according to performance indicators in the RS in 2013

Number	Bank	I-distance (TOTAL)
1	UniCredit	14.2327838
2	Komercijalna Bank	11.610584
3	NLB	3.56011666
4	Sberbanka	2.13446858
5	Pavlović	1.78470972
6	MF	1.70531188
7	Hypo	1.3461246
8	Nova banka	1.30309752
9	Banka Srpske	0.96692585
10	Bobar	0.83768652

According to the performance results in 2013, the most successful bank was *UniCredit Bank Inc. Banja Luka*, only to be followed by *Komercijalna Bank*, while *Bobar Bank Inc. Bijeljina* ranked the last. The market verification and justification of the use of the method was confirmed by the data analysis. In 2014, *Bobar Bank* lost its banking license, which confirmed the results obtained by the ranking method, because it is exactly that bank that was identified as the worst.

Also, an additional analysis was performed, which included the ranking of the banks by each individual criterion, and the results are presented below. The first to have been analyzed is the liquidity criterion, the ranking results being presented in Table 3. The above-described indicators (L1 to L5) were used for the ranking.

Table 3. The ranking of the banks by the liquidity criterion (2013)

Number	Bank	I-distance (TOTAL)
1	NLB	16.8738237
2	Pavlović	15.0160139
3	Bobar	8.5174958
4	Nova Banka	5.6421245
5	Hypo	4.05662494
6	Banka Srpske	3.75091339
7	Sberbank	3.054496
8	Komercijalna	1.86807697
9	UniCredit	1.33231758
10	MF banka	0

The results indicate that *NLB Bank* had the best liquidity in 2013, only to be followed by *Pavlović Bank* and *Bobar Bank*. On the other hand, *MF Bank* and *UniCredit Bank* had the lowest liquidity. Given the fact that UniCredit Bank was previously seen to be the best-ranked in general, this indicates that they had no problem with the placement of their funds, and the following criteria will show that they are doing it the right way.

After liquidity, the banks were also analyzed according to the profitability criterion, which included the three aforementioned and explained indicators. The ranking results for this criterion are given in the following table.

Table 4. The ranking of the banks by the profitability criterion (2013)

Number	Bank	I-distance (TOTAL)
1	UniCredit	17.23932
2	NLB	6.275044
3	Nova Banka	4.048731
4	Bobar	1.651467
5	Sberbank	1.455483
6	Pavlović	0.523299
7	MF banka	0.188562
8	Komercijalna	0.089404
9	Hypo	0
10	Banka Srpske	0

By far, the most profitable bank is UniCredit, only to be followed by *NLB Bank*, and *Nova banka* being in the 3rd place. *Hypo* and *Banka Srpske* are the banks ranked the worst, with the lowest values in all the observed indicators.

The next ranking criterion was efficiency, which included a total of three indicators. The results are given in the following table.

Table 5. The ranking of the banks by the efficiency criterion (2013)

Number	Bank	I-distance (TOTAL)
1	UniCredit	25.381683
2	Sberbank	6.9713765
3	Nova Banka	6.6322243
4	Komercijalna	4.4184533
5	NLB	3.2628914
6	Hypo	3.2233851
7	Bobar	2.8586987
8	MF banka	1.2178958
9	Pavlović	0.6498732
10	Banka Srpske	0.0025168

UniCredit Bank, which has shown a dramatically better score than the second-ranked *Sberbank*, ranked the highest. The three worst banks were *Bobar*, *MF Bank* and *Pavlović Bank*.

The last criterion observed was solvency, including a total of seven individual indicators.

Table 6. The ranking of the banks by the solvency criterion (2013)

Number	Bank	I-distance (TOTAL)
1	Komercijalna	32.93711
2	Banka Srpske	15.234933
3	MF banka	14.380753
4	Hypo	12.070788
5	Bobar	8.7877177
6	UniCredit	6.5899765
7	Pavlović	4.1813884
8	Sberbank	2.4290309
9	Nova Banka	0.8491772
10	NLB	0.2067228

It can be noticed here that the most solvent were *Komercijalna* and *Banka Srpske*, whereas the lowest solvency was that of *Nova* and *NLB* banks.

The same complete analysis for the year 2014 was also performed. In addition to the final rankings, the individual rankings of the banks in all the selected performance criteria were also given. The quantitative indicators of the banks' business success for the year 2014 are given in the following table.

Table 7. The banks' performance indicators in 2014

Ind.	*Nova banka*	*NLB*	*UniCredit*	*Hypo*	*Sberbank*	*Komercijalna*	*Banka Srpske*	*Pavlović*	*MF*
I Liq.									
L1	*0.053*	*0.176*	*0.087*	*0.078*	*0.108*	*0.039*	*0.083*	*0.102*	*0.032*
L2	*0.861*	*0.884*	*0.872*	*0.916*	*0.907*	*0.857*	*0.743*	*0.929*	*0.754*
L3	*6.201*	*2.077*	*4.307*	*4.149*	*3.859*	*6.332*	*2.889*	*3.230*	*15.383*
L4	*0.935*	*0.932*	*1.032*	*0.964*	*0.930*	*1.141*	*1.054*	*0.886*	*1.167*
L5	*0.155*	*0.468*	*0.228*	*0.228*	*0.256*	*0.156*	*0.326*	*0.287*	*0.064*
II Effic.									
E1	*0.465*	*0.369*	*0.240*	*0.455*	*0.352*	*0.282*	*0.577*	*0.359*	*0.435*
E2	*0.060*	*0.043*	*0.014*	*0.948*	*0.015*	*0.246*	*0.141*	*0.155*	*0.165*
E3	*139110*	*103618*	*131912*	*79899*	*122774*	*96497*	*44440*	*65204*	*88029*
III Prof.									
P1	*0.107*	*0.133*	*0.121*	*0.000*	*0.038*	*0.002*	*0.012*	*0.027*	*0.032*
P2	*0.008*	*0.014*	*0.018*	*0.000*	*0.005*	*0.001*	*0.001*	*0.004*	*0.004*
P3	*0.009*	*0.016*	*0.021*	*0.000*	*0.006*	*0.001*	*0.001*	*0.005*	*0.004*
IV Sol.									
S1	*11.823*	*8.338*	*5.761*	*4.256*	*6.585*	*3.142*	*8.614*	*5.121*	*7.609*
S2	*9.703*	*7.034*	*4.928*	*3.262*	*5.834*	*2.644*	*6.138*	*4.707*	*5.461*
S3	*0.1250*	*0.1710*	*0.1990*	*0.255*	*0.1421*	*0.2590*	*0.1220*	*0.13*	*0.1388*
S4	*0.064*	*0.052*	*0.089*	*0.131*	*0.091*	*0.224*	*0.142*	*0.108*	*0.139*
S5	*0.084*	*0.036*	*0.152*	*0.252*	*0.118*	*0.320*	*0.149*	*0.130*	*0.178*
S6	*0.085*	*0.070*	*0.122*	*0.210*	*0.118*	*0.351*	*0.222*	*0.140*	*0.219*
S7	*0.091*	*0.075*	*0.118*	*0.218*	*0.127*	*0.308*	*0.210*	*0.158*	*0.188*

In 2014, there were nine banks headquartered in the RS, of which only *Banka Srpske* was in the majority ownership of the state. When speaking about the banks' liquidity, the following table provides an overview of the performance of the banks' liquidity criterion.

Table 8. The ranking of the banks by the liquidity criterion (2014)

Number	Bank	I-distance (liquidity)
1	NLB	23.0679518
2	Pavlović	12.2169568
3	Sberbank	10.1900486
4	Hypo	7.50696812
5	UniCredit	5.50971948
6	Banka Srpske	4.53137136
7	Nova banka	4.09852271
8	Komercijalna	2.11820058
9	MF Bank	0.01845142

The bank with the best liquidity was *NLB Bank*, only to be followed by *Pavlović* Bank and *Sberbank*, while the last place was occupied by *MF Bank*, which had significantly poorer liquidity than the other banks included in the survey.

The next criterion according to which the banks were ranked was profitability, which included three individual indicators. According to this criterion, the success achieved by the banks is given in the following table.

Table 9. The ranking of the banks by the profitability criterion (2014)

Number	Bank	I-distance (profitability)
1	UniCredit	9.646974
2	NLB	5.556958
3	Nova banka	1.802034
4	Sberbank	0.742712
5	Pavlović	0.598086
6	MF Bank	0.384051
7	Banka Srpske	0.039267
8	Komercijalna Bank	0.013401
9	Hypo	0

Based on the data, the best-ranked is UniCredit Bank, only to be followed by *NLB Bank* and *Nova Bank*. The three banks with very poor profitability are *Banka Srpske*, *Komercijalna Bank* and *Hypo Bank*.

The third criterion is efficiency, which includes three individual indicators.

Table 10. The ranking of the banks by the efficiency criterion (2014)

Number	Bank	I-distance (efficiency)
1	UniCredit	23.528331
2	Sberbank	13.591869
3	Nova Bank	7.9688431
4	Komercijalna Bank	7.6410548
5	NLB	5.1772631
6	Pavlović Bank	2.242352
7	MF Bank	2.1212785
8	Hypo	1.3832248
9	Banka Srpske	0.0561461

According to the previous criterion, the best-ranked bank is *UniCredit Bank*, only to be followed by *Sberbank* and *Nova Bank*, whereas *Banka Srpske* is ranked the last again, being far behind the other banks in terms of efficiency.

The final performance criterion to be analyzed was capital adequacy (solvency), which included a total of seven single indicators, and the classification of the banks according to this criterion is as follows:

Table 11. The ranking of the banks by solvency criterion (2014)

Number	Bank	I-distance (solvency)
1	Komercijalna Bank	27.191051
2	Hypo	13.274755
3	MF Bank	6.067496
4	Banka Srpske	5.90802
5	Pavlović Bank	3.3239149
6	UniCredit	2.9352242
7	Sberbank	1.8211099
8	Nova Bank	0.4040932
9	NLB	0.0739856

The best bank is *Komercijalna Bank*, only to be followed by *Hypo Bank* and *MF Bank*. The worst banks in terms of solvency are *Nova Bank* and *NLB Bank*.

Finally, the survey included all the criteria in the joint ranking list and all the aspects of the business performance of the banks in the final ranking of the banks headquartered in the RS for the year 2014.

Table 12. The ranking of the banks by the performance indicators in the RS in 2014

Number	Bank	I-distance (TOTAL)
1	UniCredit	13.82901
2	NLB	11.99673
3	Komercijalna Bank	10.09697
4	Hypo	3.149554
5	Sberbank	3.100193
6	Pavlović Bank	2.499681
7	Nova Bank	1.170214
8	Banka Srpske	0.757758
9	MF Bank	0.517659

According to the results given in the tables (above), it can be concluded that *UniCredit Bank* was the best-ranked, only to be followed by *NLB Bank*, whereas *Komercijalna Bank* was the third. *Banka Srpske* and *MF Bank* ranked the last, significantly lagging behind the leading banks. Before the discussion of the obtained results, it is important to note that the application of this method allows for the calculation of the importance of individual criteria and indicators. Based on the correlation coefficients, the weight coefficients were determined not only for each individual indicator, but also for the criteria, and these data are clearly specified in the figure below (Maričić et al., 2014). The calculation was performed in such a manner that the correlation coefficients between each of the indicators and the values of the I-distance for the corresponding criterion were first determined. Subsequently, the correlation coefficients of the individual indicators were put into relation to the total sum of the correlation coefficients, thus the relative importance of each indicator being obtained individually. The identical calculation method was applied to all the main criteria, as well as the corresponding sub-criteria. The following is an example of the calculation of the weighting coefficients for the individual indicators within the profitability criteria (2014):

$r_{31}=0.977$; $r_{32}=0.953$; $r_{33}=0.869$; sum $(r)=2.797$

$w_{31^*}=0{,}977/2{,}797=0.348$; $w_{32^*}=0.953/2{,}797=0.341$; $w_{33^*}=0{,}869/2{,}797=0.311$

After this round of the calculation, the values obtained were multiplied by the weighting factor of the profitability criterion, which was calculated in the identical manner, but with the correlation coefficients obtained from the values of all the main criteria and the final value of the I-distance. In this case, the value of the weight coefficient w_3 was 0.4; therefore, w_{31} = 0.14; w_{32} = 0.14; w_{33} = 0.12 (rounded to two decimal places), exactly as is shown in Figure 1.

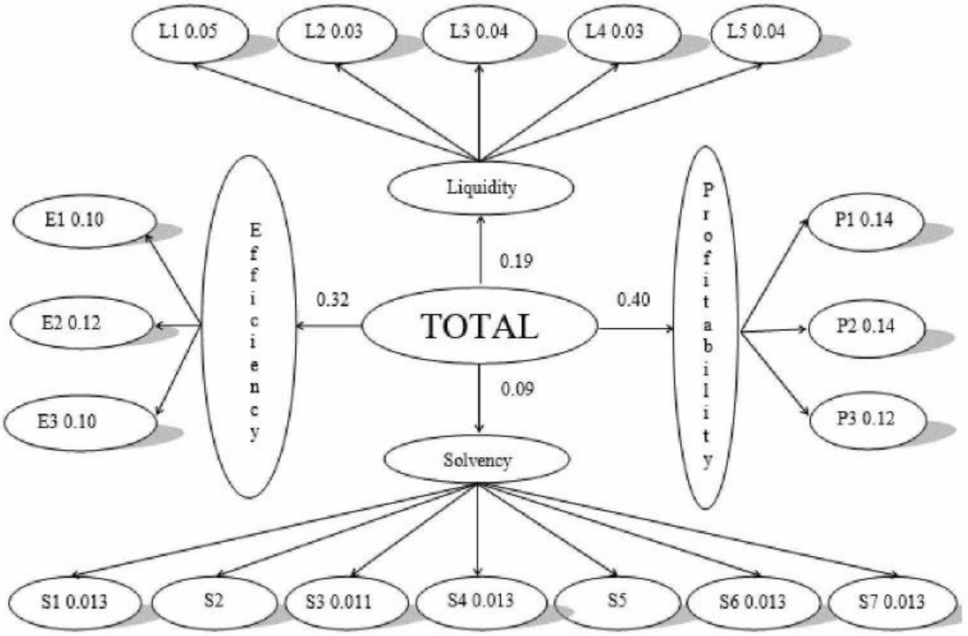

Figure 1. *The relative importance of the criteria and the individual indicators*

In the literature and in practice, throughout the territory of the Republic of Srpska and a wider environment, capital adequacy (solvency) was taken as the primary indicator of the ranking of the banks. Applying the described model, completely different data were obtained. As can be seen in Figure 1, the most important criterion in the analysis was profitability, whose significance is 0.40, which is only followed by efficiency, with the importance of 0.32, then liquidity, with 0.19, and ultimately solvency (capital adequacy), with 0.09. Such an order is justified in terms of successful business, so that the banks may increase assets effectively and also service their obligations on a regular basis. The main goal for the banks is to be solvent and fulfill their obligations, even from their bankruptcy estate.

4. Discussion

It should be taken into consideration that banks are supposed to operate indefinitely, for which reason a conclusion can be drawn that the importance of individual the indicators was fairly evenly distributed within the criteria and the distances of the individual indicators had a very short range, namely: liquidity (0.03:0.05), profitability (0.12:0.14), efficiency (0.10:0.12) and solvency (0.011:0.014). The model also included the arithmetic mean of all the parameters individually. The arithmetic mean presents the average, the minimum value of the banking sector in the RS. All the banks headquartered in the RS that had not reached the minimum value were classified into the group of the banks with risky business.

The ranking of the banks according to the liquidity criterion in 2014 is shown in Table 4 of the previous section, according to which the most liquid was *NLB*

Development Bank, whereas the worst-ranked was *MF Bank*. It is important to note that the average value of the liquidity criterion in the banking sector in the RS was 5.403 for the year 2014. *Banka Srpske*, *Nova Bank*, *Komercijalna Bank* and *MF Bank* were in the so-called gray, alarming business zone.

The average value of profitability was 1.084, and only three banks achieved profitability above the minimum required value, the first being *UniCredit Bank*, only to be followed by *NLB Development Bank* and *Nova Bank*, whereas the other four banks (*Pavlović Bank*, *MF Bank*, *Banka Srpske*, *Komercijalna Bank* and *Hypo Bank*) had the profitability value below the average. The final ranking list of the banks' profitability indicator is shown in Table 5.

Table 6 accounts for the order of the banks starting from the most efficient to the least efficient bank in the RS. The average value for the efficiency indicator of the banks in the RS was 4.533. In 2014, *Pavlović Bank*, *MF Bank*, *Hypo Bank* and *Banka Srpske* failed to reach the minimum threshold of the average value. The ranking of the banks according to the last indicator, i.e. solvency, with the least significance for the ranking of the banks is presented in Table 7. The average value of the solvency for the banks in the RS was 4.49. *Pavlović International Bank*, *UniCredit Bank*, *Sberbank*, *Nova Bank* and *NLB Development Bank* were in the gray business zone when solvency is concerned.

The list of the final ranking of the banks in the RS according to all the tested indicators is given in Table 8 of the previous section. The average value of all the indicators, here used as the landmark when companies enter into the gray business area, was 2.34. According to that criterion, *Nova Bank*, *Banka Srpske* and *MF Bank* were the banks with "problematic" business in 2014. According to the criterion with the greatest significance for the ranking, i.e. the profitability criterion, and also based on the efficiency and solvency criteria, *Banka Srpske* ranked the worst. If the fact that these three indicators account for 79% of the overall significance of the model is taken into account, then it is can be concluded that *Banka Srpske* had a worse ranking than *MF Bank*, regardless of the final ranking. *Banka Srpske* was better-ranked than *MF Bank* only according to the liquidity criterion, which means that it had not used resources at its disposal as it should have.

Attention should be paid to the worst-ranked banks in 2013. *Banka Srpske* was slightly better than *Bobar Bank* in 2014. *Banka Srpske* still holds the same position (the penultimate place). If *MF Bank*, which is quite a young and small bank in relation to the other banks, were omitted, then *Banka Srpske* could be said to have ranked the worst in 2014. This is supported by the abstained audit opinions for *Banka Srpske* in the year 2013, and a negative audit opinion for the year 2014. *MF Bank* received an unqualified audit opinion for both periods.

5. Conclusion

The model for ranking the banks is based on the official data obtained from the financial statements and the annually valorized indicators. The results show that *Bobar Bank* was the worst and had the lowest business indicators of all the banks in the overall ranking in the RS in 2013. The audit report in which the auditors refrained from expressing an opinion was a confirmation of this. In the model for ranking the banks in 2013, the worst-ranked bank confirmed its low indicators and risky business by the loss of the banking license in 2014. The indicators in the statistical model pointed out the weakening market position and were a signal for change in the bank's business policy. According to the criteria of the established model, *MF Bank* was the worst-ranked in 2014, although it must be noted that *MF Bank* has been operating for eight years now, that it is a small bank, and that it has not been firmly established on the financial market. Also, the results obtained by using the I-distance method in relation to the data obtained by analyzing the financial and audit reports indicate that *MF Bank* was the worst-ranked, but there was a high business risk for *Banka Srpske*. It can be expected that *MF Bank* and *Banka Srpske* will change positions in the forthcoming period and that the indicators of the I-distance will point to the fact that *Banka Srpske* is the least reliable.

In a time period shorter than a fiscal year, high-risk businesses change indicators much faster. For that reason, it is recommended that they should be observed in shorter intervals, for example on a monthly basis. Calculations in shorter intervals provide more objective indicator values than average values do annually. Monthly performance results indicate reliable positioning through the ranking indicator of business performance, thereby enabling high-quality information for the immediate effect on business indicators, both internally and externally.

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DETERMINING CRITERIA SIGNIFICANCE IN SELECTING REACH STACKERS BY APPLYING THE FUZZY PIPRECIA METHOD

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Abstract: *Handling facilities play the essential role in the work of the complete transport chain, especially when performing operations at ports or container terminals. In this paper, a list of 15 criteria for the evaluation and selection of a reach stacker for the container terminal in Belgrade were formed in a double hierarchical structure, with an equal number of the elements. There are three main groups of the criteria: economic, technological and technical, each containing a total of the five sub-criteria. The survey involved 15 decision-makers, who evaluated all the criteria. To determine the individual significance of each criterion, the Fuzzy PIvot Pairwise RElative Criteria Importance Assessment (i.e. fuzzy PIPRECIA) method was applied. The results showed that the most essential criteria belong to the technology group.*

Key words: *reach stacker, container terminal, Fuzzy PIPRECIA*

1. Introduction

"Railway Integral Transport" (RIT) Limited Liability Company (*ŽIT d.o.o.*) Belgrade was founded in 1983 as a subsidiary of ŽELEZNICE SRBIJE (JSC Serbian Railways), when a container terminal was built in the area of the former Belgrade Central Railway Station. During 2016, the RIT terminal has been relocated to the new location at the Belgrade Marshalling Yard. One of the Company's primary activities is the provision of terminal services in the international container transportation of cargo, such as the handling, loading and containerization of goods, and the transportation of loaded and empty containers. Due to limited space, the maximum dispatch and distribution capacity of the terminal is about 15,000 intermodal units (containers) annually

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The main technological process of the transhipment of containers from the rail mode to the road transportation mode and *vice versa*, as well as the storage of loaded and empty containers in the area of the terminal itself, is carried out by the reach-stacker-type container handlers Belloti (the load capacity being 45 t) and Kalmar (the load capacity being 42 t). It should be noted that both reach stackers are over 20 years old.

In order to perform the primary operations at the terminal, two tracks of a length of 250 m and a shunting track for shunting units of 250 m in length are available. At the terminal, there are also three tracks in the shunting and dispatching groups of the Belgrade Marshalling Yard used by cranes and for the movements of trains from the terminal, as well as the storage of spare wagons.

The construction of the Phase 2 of the container terminal, i.e. the expansion to the fifth marshalling group of the Belgrade Marshalling Yard, would enable the conditions for the RIT Terminal to process over 80,000 containers per year, or about 120,000 TEU units. According to the analysis conducted in the period from 2016 to 2019, the RIT terminal processes about 40% of all the containers arriving by rail, which is about 15% of all the containers arriving in Serbia. Of this, about 90% of the containers processed by the RIT Terminal come from the Rijeka – Belgrade–Rijeka line (three trains running on that route weekly). The completion of the Phase 1 of the new terminal is expected to introduce the fourth pair of trains, and the fifth pair of trains in the year 2021.

This paper aims to evaluate and determine the significance of the criteria by which the reach stacker selection will be made. All of the above data indicate the need to expand the range of the handling equipment, for which reason buying at least one reach stacker is a necessity.

The rest of the paper is structured into several chapters. In Chapter Two, a brief description of the volume of business at the container terminal and some forecasts for this year and for next year are given. In Chapter Three, the Fuzzy PIPRECIA method applied in the paper in order to determine the significance of the criteria is presented in detail. Chapter Fur of the paper deals with a case study, detailing the input parameters and the calculation procedure. In Chapter Five, the conclusion concerning the continuation of this research is presented.

2. A Short Description of the Extent of Work for the Terminal

Taking into account the expected increase in the scope of work (Figure 1), it is necessary that new reach stackers should be purchased, since the installation of a bridge crane for the transhipment of intermodal units is not foreseen in the first phase of the construction and operation of the terminal. Given the state of the existing two reach stackers, it is necessary to procure two new ones so as to ensure the reliability and continuity of the performance of the basic technological operations at the terminal.

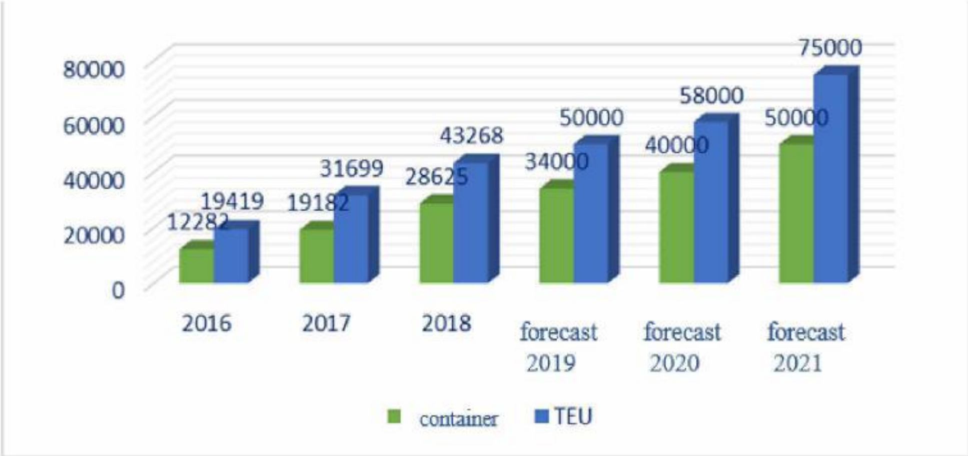

Figure 1. The achieved and the planned scopes of work at the RIT Terminal

By constructing a large logistics centre (Figure 2), which is planned to be operated in the Makiš Field, the workload might also double.

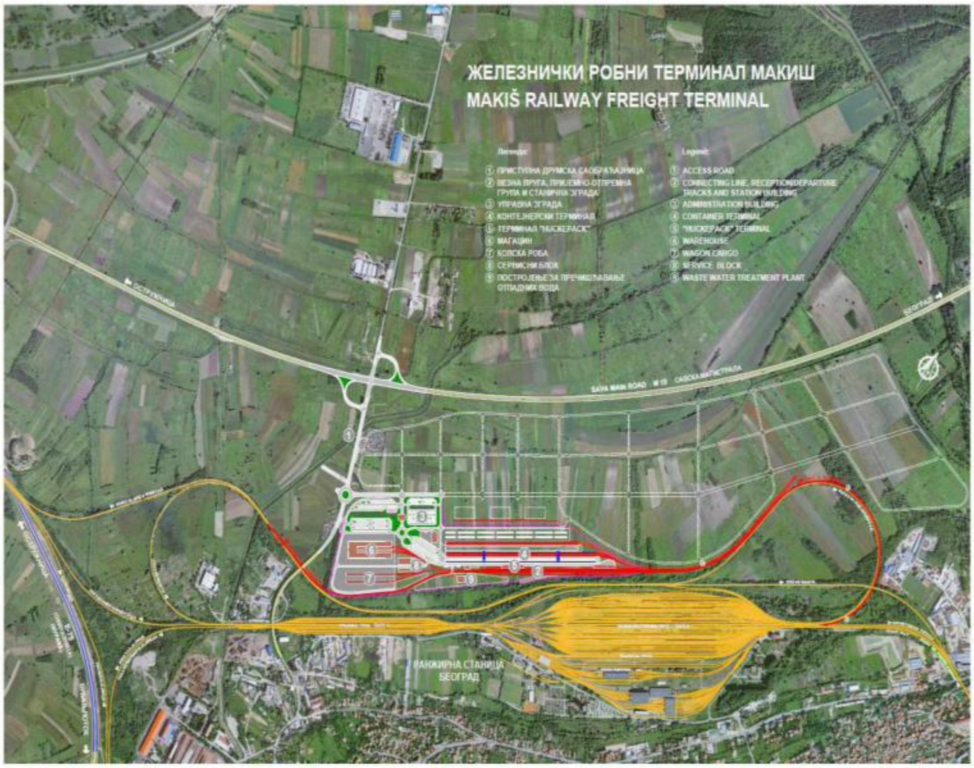

Figure 2. The plan for the construction of the new RIT Terminal

3. Methods

3.1. Operations on fuzzy numbers

A fuzzy number $\overline{A}$ on R to be a TFN if its membership function $\mu_{\overline{A}}(x)$: R→[0,1] is equal to the following Equation (1):

$$\mu_{\overline{A}}(x)=\begin{cases}\dfrac{x-l}{m-l} & l\leq x\leq m\\ \dfrac{u-x}{u-m} & m\leq x\leq u\\ 0 & otherwise\end{cases} \tag{1}$$

From equation (1), l and u denote the lower and the upper bounds of the fuzzy number $\overline{A}$, and m is the modal value for $\overline{A}$. The TFN can be denoted by $\overline{A}=(l,m,u)$.

The operational laws of TFN $\overline{A}=(l_1,m_1,u_1)$ and $\overline{A}=(l_2,m_2,u_2)$ are displayed as the following equations.

Addition: $\overline{A}=(l_1,m_1,u_1)$

$$\overline{A_1}+\overline{A_2}=(l_1,m_1,u_1)+(l_2,m_2,u_2)=(l_1+l_2,m_1+m_2,u_1+u_2) \tag{2}$$

Multiplication:

$$\overline{A_1}\times\overline{A_2}=(l_1,m_1,u_1)\times(l_2,m_2,u_2)=(l_1\times l_2,m_1\times m_2,u_1\times u_2) \tag{3}$$

Subtraction:

$$\overline{A_1}-\overline{A_2}=(l_1,m_1,u_1)-(l_2,m_2,u_2)=(l_1-u_2,m_1-m_2,u_1-l_2) \tag{4}$$

Division:

$$\frac{\overline{A_1}}{\overline{A_2}}=\frac{(l_1,m_1,u_1)}{(l_2,m_2,u_2)}=\left(\frac{l_1}{u_2},\frac{m_1}{m_2},\frac{u_1}{l_2}\right) \tag{5}$$

Reciprocal:

$$\overline{A_1}^{-1}=(l_1,m_1,u_1)^{-1}=\left(\frac{1}{u_1},\frac{1}{m_1},\frac{1}{l_1}\right) \tag{6}$$

3.2. The Fuzzy PIvot Pairwise RElative Criteria Importance Assessment (i.e. fuzzy PIPRECIA) method

The PIPRECIA method in a crisp form has been developed in (Stanujkić et al., 2017). The fundamental advantage of the PIPRECIA method lies in the fact that it allows criteria to be evaluated without their prior sorting by importance, which is not the case with the fuzzy SWARA method. Today, the largest number of the problems of multicriteria decision-making are solved by applying group decision-making. In such cases, especially with an increase in the number of the decision-makers involved in the fuzzy model, PIPRECIA achieves its advantages. The fuzzy PIPRECIA method consists of the 11 steps that are shown below (Stević et al., 2018; Đalić et al. 2020).

Step 1. Forming the required benchmarking set of criteria and forming a decision-making team. Sorting the criteria according to the marks from the first to the last, which means that they need to be sorted unclassified. Therefore, their significance does not play any role at all in this step.

Step 2. In order to determine the relative importance of the criteria, each decision-maker individually evaluates the pre-sorted criteria by starting from the second criterion, as in Equation (7).

$$\overline{s_j^r} = \begin{cases} > \bar{1} & if \quad C_j > C_{j-1} \\ = \bar{1} & if \quad C_j = C_{j-1} \\ < \bar{1} & if \quad C_j < C_{j-1} \end{cases} \tag{7}$$

where $\overline{s_j^r}$ denotes the criteria assessment made by the decision-maker *r.*

In order to obtain a matrix $\overline{s_j}$, it is necessary to perform the averaging of the matrix $\overline{s_j^r}$ by using the geometric mean. The decision-makers evaluate the criteria by applying the scales defined in Tables 1 and 2.

The second and third steps of the developed method are closely dependent on one another, and new fuzzy scales are defined in order to meet the second and third steps of the fuzzy PIPRECIA method. If the facts that the nature of fuzzy number operations and that, in the third step, the values $\overline{s_j}$ are subtracted from number two are taken into consideration, then it is required that these scales be defined. It is important to note that, by defining these scales, the appearance of number two is avoided, which might cause difficulties and lead to wrong results in the case of calculation. Therefore, no other previously developed fuzzy scales, but only the scales defined in this paper, may be used.

Table 1. The Criteria Assessment Scale 1-2

			l	m	u	DFV
An almost equal value	**Scale 1-2**	1	1.000	1.000	1.050	1.008
Slightly more significant		2	1.100	1.150	1.200	1.150
Moderately more significant		3	1.200	1.300	1.350	1.292
More significant		4	1.300	1.450	1.500	1.433
Much more significant		5	1.400	1.600	1.650	1.575
Dominantly more significant		6	1.500	1.750	1.800	1.717
Absolutely more significant		7	1.600	1.900	1.950	1.858

When a criterion has greater importance concerning the previous one, an assessment is made by using the above scale (Table 1). In order to make it easier for the decision-makers to evaluate the criteria, the table shows the defuzzified value (DFV) for each comparison.

Table 2. The Criteria Assessment Scale 0-1

	l	m	u	DFV	
Scale 0-1	0.667	1.000	1.000	0.944	Slightly less significant
	0.500	0.667	1.000	0.694	Moderately less significant
	0.400	0.500	0.667	0.511	Less significant
	0.333	0.400	0.500	0.406	Really less significant
	0.286	0.333	0.400	0.337	Much less significant
	0.250	0.286	0.333	0.288	Dominantly less significant
	0.222	0.250	0.286	0.251	Absolutely less significant

When a criterion is of less importance compared to the previous one, an assessment is made by using the above scale (Table 2).

Step 3. Determining the coefficient $\overline{k_j}$:

$$\overline{k_j} = \begin{cases} =\bar{1} & if \quad j=1 \\ 2-\overline{s_j} & if \quad j>1 \end{cases} \tag{8}$$

Step 4. Determining the fuzzy weight $\overline{q_j}$:

$$\overline{q_j} = \begin{cases} \underline{=\bar{1}} & if \quad j=1 \\ \dfrac{q_{j-1}}{\overline{k_j}} & if \quad j>1 \end{cases} \tag{9}$$

Step 5. Determining the relative weight of the criterion $\overline{w_j}$:

$$\overline{w_j} = \frac{\overline{q_j}}{\sum_{j=1}^{n} \overline{q_j}} \tag{10}$$

In the following steps, the inverse methodology of the fuzzy PIPRECIA method needs to be applied.

Step 6. Performing the assessment of the above-defined applied scale, this time starting from the penultimate criterion.

$$\overline{s_j^r}' = \begin{cases} > \bar{1} & if \quad C_j > C_{j+1} \\ = \bar{1} & if \quad C_j = C_{j+1} \\ < \bar{1} & if \quad C_j < C_{j+1} \end{cases} \tag{11}$$

where $\overline{s_j^r}'$ denotes the criteria assessment made by the decision-maker *r.*

It is, again, necessary to perform the averaging of the matrix $\overline{s_j^r}$ by applying a geometric mean.

Step 7. Determining the coefficient $\overline{k_j}'$:

$$\overline{k_j}' = \begin{cases} = \bar{1} & if \quad j = n \\ 2 - \overline{s_j}' & if \quad j > n \end{cases} \tag{12}$$

where *n* denotes the total number of the criteria. Specifically, in this case, it means that the value of the last criterion is equal to the fuzzy number one.

Step 8. Determining the fuzzy weight $\overline{q_j}'$:

$$\overline{q_j}' = \begin{cases} = \bar{1} & if \quad j = n \\ \dfrac{\overline{q_{j+1}}'}{\overline{k_j}'} & if \quad j > n \end{cases} \tag{13}$$

Step 9. Determining the relative weight of the criterion $\overline{w_j}'$:

$$\overline{w_j}' = \frac{\overline{q_j}'}{\sum_{j=1}^{n} \overline{q_j}'} \tag{14}$$

Step 10. In order to determine the final weights of the criteria, it is first necessary to perform the defuzzification of the fuzzy values $\overline{w_j}$ and $\overline{w_j}'$ as follows:

$$\overline{w_j}'' = \frac{1}{2}(w_j + w_j') \tag{15}$$

Step 11. Checking the results obtained by applying the Spearman and Pearson correlation coefficients.

4. Determining Criteria Significance When Selecting a Reach Stacker by Applying the Fuzzy PIPRECIA Method

For the evaluation and selection of a reach stacker, a total of the 15 criteria formed into the two levels of the hierarchical structure were applied. As it is essential to obtain objective results, the hierarchical structure should be balanced. This means that each major criterion has an equal number of criteria. This problem was to some extent addressed in (Markovic et al., 2020), where it was found that it was necessary to form a hierarchical structure with an equal number of the elements at the lower levels of the hierarchy. Therefore, this paper approached the formation of a group of criteria in this manner, with the three main criteria inclusive of the five sub-criteria in each group.

CE - Economic:

CE1 – The cost

CE2 – The supply of spare parts

CE3 – Fuel consumption when manipulating one hour of operation

CE4 – The tire type and price

CE5 – Maintenance costs

CTH - Technological:

CTH1 – Life expectancy

CTH2 – The capacity

CTH3 – The number of the TEUs processed as per unit of time,

CTH4 – Manipulative abilities,

CTH5 – The lift height

CTR - Technical Solutions:

CTR1 – The engine type

CTR2 – The gross mass (the net mass)

CTR3 – The engine power

CTR4 – The lift speed

CTR5 – The driving speed

As already pointed out, the three main criteria are economic (CE), technological (CTH) and applied technical solutions (CTR). These three criteria cover the whole aspect of the operation of a reach stacker, i.e. the performance of the necessary technological activities at the terminal.

The first set of the economic criteria, which describe the financial and economic aspects of the acquisition and exploitation of a reach stacker, include the following sub-criteria:

- The purchase price on the market (CE1) is expressed as a numerical value. The goal of every terminal operator is to achieve the top-notch performance of a reach stacker for minimum investment. CE1 → min.
- The supply of spare parts (CE2) is essential for the reliable operation of a reach stacker and the quality maintenance system. This parameter is represented as a linguistic variable, and the same can be wrong, good, very good or excellent. CE2 → max.
- Manipulation fuel consumption (CE3) is expressed as per hour of operation. This parameter directly affects the exploitation cost. CE3 → min.
- The tire type (CE4) directly influences its price, and as such is classified into this parameter group. The purchase and replacement of tires are a significant source of the operation cost. CE4 → min.
- Maintenance costs, if the result of the technological process of the maintenance process can significantly affect the choice of a type of a reach stacker. They cover all the aspects of the maintenance process (both current and investment) and are expressed every year. CE5 → min

The second group consists of the technological criteria, which describe the technological parameters and characteristics of a reach stacker, the sub-criteria being as follows:

- The expected service life (CTH1) is expressed as a numerical value. The manufacturer proposes the expected service life in quality maintenance conditions, but the value of this parameter is also determined by customers' experience at the terminals. CTH1 → max.
- The reach stacker capacity (CTH2), i.e. the maximum payload declared by the manufacturer, is essential for operators, as it may be a limiting factor in processing certain types and intermodal units and their loads. CTH2 → max.
- The number of the TEUs processed as per unit of time (CTH3) represents the output, i.e. the processing power of a reach stacker, thus determining the processing power and capacity of the terminal. CTH3 → max.
- Manipulative abilities (CTH4) are an essential parameter for the operation of a reach stacker, especially so in confined spaces. This parameter is presented as a linguistic variable, and the same can be weak, satisfactory, good and excellent. CTH4 → max.
- The lift height (CTH5) is a parameter declared by the manufacturer and expressed in meters or in the number of the containers that can stack the height for the first and second stack orders. CTH45 → max.

The third group is represented by the applied technical solutions in a reach stacker, namely including the following sub-criteria:

- The motor type (CTR1) is expressed as a linguistic value. Usually, diesel engines are the EURO3, EURO4 or EURO5 type. The engine type affects fuel consumption, thus also making an influence on the environment. The negative impact of this parameter by engine type is high, medium and low, while the lowest negative environmental impact is desirable. CTR1 → min.
- The reach stacker gross mass (CTR2) is a parameter declared by the manufacturer. It is desirable that this parameter should be as high as possible for the purpose of the stability of operation, i.e. for the purpose of lifting heavy intermodal units. CTR2 → max.
- The engine power (CTR3) is a parameter declared by the manufacturer. It is desirable for this parameter to be as high as possible, because of the reliability of the work, i.e. the low load of a reach stacker. CTR3 → max.
- The lifting speed (CTR4) is a parameter declared by the manufacturer. This parameter is expressed in m/s and is given for the following lifting conditions: empty/full. In the model, the value of lifting a full container is considered. CTR4 → max.
- The driving speed (CTR5) is a parameter declared by the manufacturer. This parameter is expressed in km/h and is given for the conditions of the movement of a reach stacker with empty/full intermodal units. In the model, the value of the maximum driving speed with full intermodal units is considered. CTR5 → max. CTR5 – The travel speed (km/h) empty/full

The evaluation of the criteria was performed by using a linguistic scale involving quantification into fuzzy triangle numbers. Table 3 shows the evaluation of the criteria for fuzzy PIPRECIA and inverse fuzzy PIPRECIA carried out by the decision-maker.

There are a total of 15 decision-makers, whose structure is viewed from the following three aspects:

- the profession, i.e. what activity (function) the expert performs,
- the expert's competence field,
- the expert's work experience.

When the expert's occupation is in question (Figure 3), three occupational groups are covered. The largest number of the experts, i.e. 47% of them in total, belong to the group of traffic and mechanical engineering university professors, only to be followed by those employed in the economic sector (practitioners), accounting for 33%, and finally, the employed in design institutions in the transportation field, accounting for 20%.

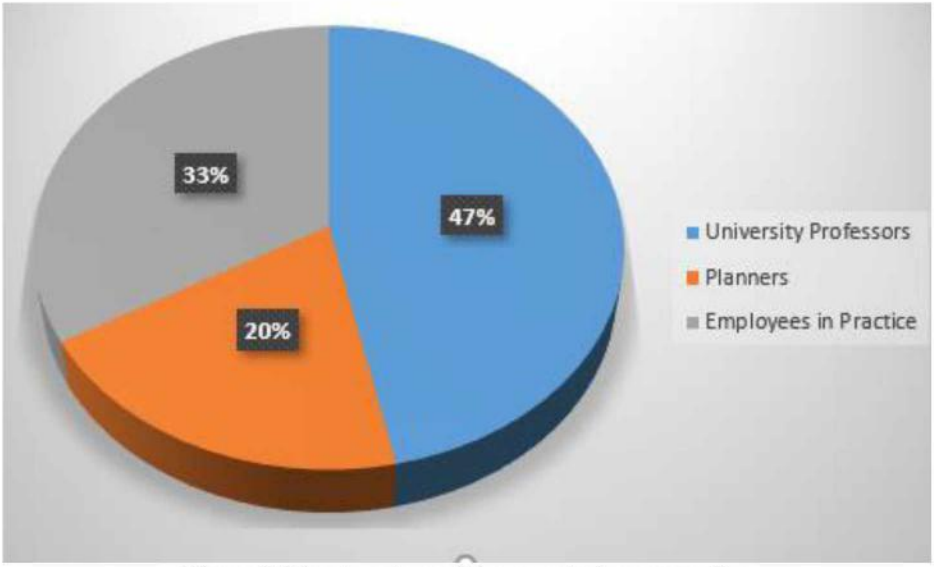

Figure 3. The structure of the experts by occupation

The structure of the experts in the competence field is shown in Figure 4. The survey included 47% of the experts in railway transport, 20% of the experts employed in logistics and mechanical engineering, and 13% of the experts working in road transportation.

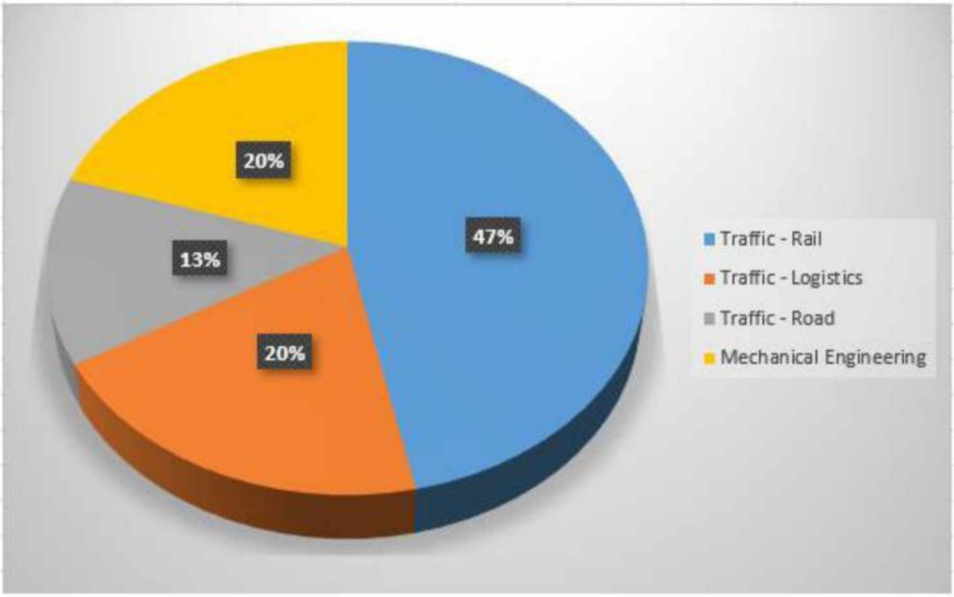

Figure 4*. The structure of the experts by the competence field*

The last analysis refers to the experience (the experts' work experience) and is shown in Figure 5. The largest number of the experts included in the survey, i.e. 40% of them, have a work experience ranging from 21 to 30 years; a total of 27% have a work experience ranging from 11 to 20 years, and 20% of the experts have a work experience exceeding 30 years. The smallest number of the experts, actually 13% of them, have a work experience of less than ten years.

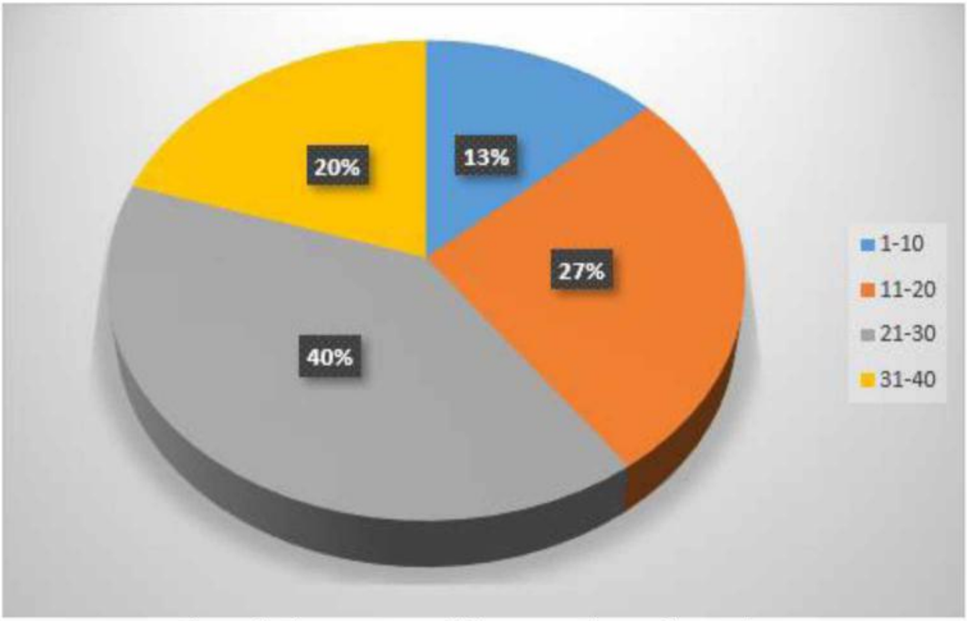

Figure 5. The structure of the experts by work experience

Table 3. The criteria ratings for fuzzy PIPRECIA and inverse fuzzy PIPRECIA for the main criteria

PIPR.		C2			C3		PIPR-I		C2			C1	
DM1	1.200	1.300	1.350	0.250	0.286	0.333	DM1	1.500	1.750	1.800	0.400	0.500	0.667
DM2	1.000	1.000	1.000	1.000	1.000	1.000	DM2	1.000	1.000	1.000	1.000	1.000	1.000
DM3	1.200	1.300	1.350	0.286	0.333	0.400	DM3	1.400	1.600	1.650	0.400	0.500	0.667
DM4	1.000	1.000	1.000	1.200	1.300	1.350	DM4	0.400	0.500	0.667	1.000	1.000	1.000
DM5	1.200	1.300	1.350	0.286	0.333	0.400	DM5	1.400	1.600	1.650	0.400	0.500	0.667
DM6	1.000	1.000	1.000	0.400	0.500	0.667	DM6	1.200	1.300	1.350	1.000	1.000	1.000
DM7	1.400	1.600	1.650	1.000	1.000	1.000	DM7	1.000	1.000	1.000	0.286	0.333	0.400
DM8	1.300	1.450	1.500	1.100	1.150	1.200	DM8	0.500	0.667	1.000	0.333	0.400	0.500
DM9	1.300	1.450	1.500	1.000	1.000	1.000	DM9	1.000	1.000	1.000	0.333	0.400	0.500
DM10	1.000	1.000	1.000	1.000	1.000	1.000	DM10	1.000	1.000	1.000	1.000	1.000	1.000
DM11	1.100	1.150	1.200	0.250	0.286	0.333	DM11	1.500	1.750	1.800	0.500	0.667	1.000
DM12	1.200	1.300	1.350	0.500	0.667	1.000	DM12	1.100	1.150	1.200	0.400	0.500	0.667
DM13	1.500	1.750	1.800	1.000	1.000	1.000	DM13	1.000	1.000	1.000	0.250	0.286	0.333
DM14	1.100	1.150	1.200	1.000	1.000	1.000	DM14	1.000	1.000	1.000	0.500	0.667	1.000
DM15	1.300	1.450	1.500	0.286	0.333	0.400	DM15	1.400	1.600	1.650	0.333	0.400	0.500
AV	1.187	1.280	1.317	0.704	0.746	0.806	AV	1.093	1.194	1.251	0.542	0.610	0.727

Note: As has been shown in the method steps, it ranges from the second criterion for the fuzzy PIPRECIA method, and the penultimate criterion for the inverse fuzzy PIPRECIA method, i.e. C2 in the first column and also C2 in the third column.

Based on the evaluation of the criteria and Equation (7), the matrix s_j is formed.

$$s_j = \begin{bmatrix} & \cdots & \\ 1.187 & 1.280 & 1.317 \\ 0.704 & 0.746 & 0.806 \end{bmatrix}$$

Applying Equation (8), these values are subtracted from number two. Following the rules of operations with the fuzzy numbers of the k_j matrices, the following is obtained:

$$k_j = \begin{bmatrix} 1.000 & 1.000 & 1.000 \\ 0.683 & 0.720 & 0.813 \\ 1.194 & 1.254 & 1.296 \end{bmatrix}$$

According to Equation (8), the value $\overline{k_1} = (1.000, 1.000, 1.000)$

$$\overline{k_2} = (2 - 1.317, 2 - 0.280, 2 - 1.187) = (0.683, 0.720, 0.813)$$

Applying Equation (9) to the value of q_j

$$q_j = \begin{bmatrix} 1.000 & 1.000 & 1.000 \\ 1.230 & 1.389 & 1.463 \\ 0.949 & 1.107 & 1.225 \end{bmatrix}$$

the following is obtained:

$$\overline{q_1} = (1.000, 1.000, 1.000)$$

$$\overline{q_2} = \left(\frac{1.000}{0.813}, \frac{1.000}{0.720}, \frac{1.000}{0.683}\right) = (1.230, 1.389, 1.463)$$

After that, the values for q_j are summed up and the following are obtained: 3.178; 3.496 and 3.689, respectively.

Applying Equation (10), the relative weights are calculated in the following manner:

$$\overline{w_1} = \left(\frac{1.000}{3.689}, \frac{1.000}{3.496}, \frac{1.000}{3.178}\right) = (0.271, 0.286, 0.315)$$

$$\overline{w_j} = \begin{bmatrix} 0.271 & 0.286 & 0.315 \\ 0.333 & 0.397 & 0.460 \\ 0.257 & 0.317 & 0.386 \end{bmatrix}$$

Then, the following equation must be applied: $df_{crisp} = \frac{l + 4m + u}{6}$ so as to get crisp value: 0.288; 0.397 and 0.318

In order to determine the final weights of the criteria, it is necessary to apply Equations (11)-(15) and the methodology of the inverse fuzzy PIPRECIA method. The matrix sj' was obtained from the decision-maker.

$$s_j' = \begin{bmatrix} 0.542 & 0.610 & 0.727 \\ 1.093 & 1.194 & 1.251 \end{bmatrix}$$

Applying Equation (12), the values of the matrix kj' are obtained as follows:

$$k_j' = \begin{bmatrix} 1.273 & 1.390 & 1.458 \\ 0.749 & 0.806 & 0.907 \\ 1.000 & 1.000 & 1.000 \end{bmatrix}$$

$$\overline{k_3}' = (1.000, 1.000, 1.000)$$

$$\overline{k_2}' = (2 - 1.251, 2 - 1.194, 2 - 1.093) = (0.749, 0.806, 0.907) \text{ itd.}$$

Applying Equation (13), the following values are obtained:

$$q_j = \begin{bmatrix} 0{,}757 & 0{,}893 & 1{,}049 \\ 1.103 & 1{,}241 & 1{,}335 \\ 1{,}000 & 1{,}000 & 1{,}000 \end{bmatrix}$$

$$\overline{q_3}' = (1.000, 1.000, 1.000)$$

$$\overline{q_2}' = \left(\frac{1.000}{0.907}, \frac{1.000}{0.806}, \frac{1.000}{0.749}\right) = (1.103, 1.241, 1.335) \text{ itd.}$$

After that, the values for q_j are summed up and the values obtained are as follows: 3.178, 3.496 and 3.689, respectively.

After that, it is necessary to apply Equation (14) so as to obtain the relative weights for the fuzzy inverse PIPRECIA method.

$$\overline{w_j}' = \begin{bmatrix} 0.224 & 0.285 & 0.367 \\ 0.326 & 0.396 & 0.467 \\ 0.296 & 0.319 & 0.350 \end{bmatrix}$$

$$\overline{w_3}' = \left(\frac{1.000}{3.689}, \frac{1.000}{3.496}, \frac{1.000}{3.178}\right) = (0.296, 0.319, 0.350)$$

Then, the equation $df_{crisp} = \frac{l + 4m + u}{6}$ must be applied in order to obtain the crisp values 0.288, 0.396 and 0.320, after which the obtained w_j values are aggregated and the final weighted values for the main criteria are obtained: 0.288, 0.397 and 0.319.

The results of the methodology applied are presented in Table 4.

Table 4 shows the complete previous calculation, and the last column shows the deficient values of the relative weights of the criteria.

Table 4. The calculation of the weights and values of the main criteria

P		sj			kj			qj			wj		DF	Rang
c1				1.000	1.000	1.000	1.000	1.000	1.000	0.271	0.286	0.315	0.288	3
c2	1.187	1.280	1.317	0.683	0.720	0.813	1.230	1.389	1.463	0.333	0.397	0.460	0.397	1
c3	0.704	0.746	0.806	1.194	1.254	1.296	0.949	1.107	1.225	0.257	0.317	0.386	0.318	2
SUM							3.178	3.496	3.689					
P – I		sj			kj			qj			wj			
c1	0.542	0.610	0.727	1.273	1.390	1.458	0.757	0.893	1.049	0.224	0.285	0.367	0.288	3
c2	1.093	1.194	1.251	0.749	0.806	0.907	1.103	1.241	1.335	0.326	0.396	0.467	0.396	1
c3				1.000	1.000	1.000	1.000	1.000	1.000	0.296	0.319	0.350	0.320	2
SUM							2.860	3.135	3.384					

The Spearman correlation coefficient (Erceg et al., 2019) for the obtained ranks is 1.00, which means that these ranks are in absolute correlation. The Pearson correlation coefficient (Stevic et al., 2018) was also calculated for the criterion weights of 0.985.

Table 5 presents the final weight results by using the fuzzy PIPRECIA method.

As can be seen from the application of the complete methodology and the results obtained in Table 5, the technological criteria group represents the most important group for the selection of a reach stacker, because the three priority criteria belong to this group: CTH4 – manipulative abilities, CTH5 – the lift height and CTH3 – the number of the processed TEU in the unit of time. Of the economic criteria group, the most important is CE4 – the tire and price types, which ranks fourth in the overall ranking.

Table 5. The criteria ranking by applying the FUZZY PIPRECIA method

ECONOMIC	Local value	Global value	Rank
CE1	0.184	0.043	19
CE2	0.187	0.049	17
CE3	0.228	0.061	13
CE4	0.152	0.073	4
CE5	0.281	0.071	7
TECHNOLOGICAL			
CTH1	0.150	0.059	15
CTH2	0.171	0.068	10
CTH3	0.211	0.084	3
CTH4	0.253	0.100	1
CTH5	0.246	0.098	2
TECHNICAL			
CTR1	0.228	0.073	6
CTR2	0.185	0.059	16
CTR3	0.214	0.068	9
CTR4	0.206	0.066	11
CTR5	0.195	0.062	12

5. Conclusion

In this paper, the fuzzy PIPRECIA method for the determination of the significance of the reach stacker selection criteria for a rail container terminal is presented. A total of 15 criteria were considered, those criteria being divided into the three groups: economic, technological and technical. The survey involved 15 decision-makers of different structures, which is presented in detail in the paper. The results show that the most essential criteria belong to the technology group. Continued research would imply drafting a list of potential reach stackers, collecting quantitative and qualitative data and evaluating those data. Some of the classical MCDM methods can be applied for evaluation and selection (Stevic et al., 2020; Zavadskas and Turskis, 2010; Pamučar and Ćirović) individually or in combination with uncertainty theories (Stojić et al., 2018; Stanujkić and Karabašević, 2018; Stevic et al., 2019; Kahraman et al., 2017).

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PROJECT MANAGEMENT SOFTWARE EVALUATION BY USING THE MEASUREMENT OF ALTERNATIVES AND RANKING ACCORDING TO COMPROMISE SOLUTION (MARCOS) METHOD

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Abstract: *Every organization needs to invest in order for it to grow, and investments are made through projects. Thus, investment management is performed by applying project management techniques. Different project management software programs are used to manage multiple projects. There is a lot of project management software on the market, and four pieces of the software were selected and analyzed. In this paper, the best management software rated by the beneficiaries of these projects in the United Arab Emirates are explored. The research required for this study was conducted in the United Arab Emirates. The MARCOS method was used to evaluate the program. The results showed that Smartsheet had been rated the best by users. This paper provides an overview of how multicriteria analysis methods can be used when ranking project management programs.*

Keywords: *project management, software, United Arab Emirates, MARCOS method*

1. Introduction

Every organization is required to invest. In order to implement their project investments, it is necessary for such organizations to apply the project management techniques that enable the smooth implementation of project investments. A project is a very complex undertaking, especially when organizational constraints and elements used, resources and costs involved, a large number of people working on it, as well as the other elements that further complicate the project, are concerned (Puška, 2013). Due to project complexity and its importance for any organization, a

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project requires special IT support for its implementation. Market demand in this field has led to the development of a broad range of IT software solutions supportive of the creation, monitoring and implementation of projects in order to meet set investment goals.

The task of project management software is to facilitate the business operations of the company pertaining to project management. These pieces of software are used to plan, monitor and control projects (Sajad et al., 2016). However, project management software often does not efficiently facilitate project work and failures in project management occur. The failure status of project management software programs has not changed much today, some projects still being delayed, overbilling or not meeting customer expectations (Hassan et al., 2018).

All these software solutions are different, so it is necessary to choose the software that best suits the appropriate project in a company. On the market, there are several tools for automated project program management, and these projects are steadily increasing in number. Given the ongoing process of change, it is not possible to provide a list of all project management programs (Kostalova and Tetrevova, 2014). Each tool specializes in the different fields of project management, so some programs are used in specific project lifecycles, whereas others are used throughout the project.

The purpose of this study is to rank different software solutions intended for the project management implementation based on the evaluations provided by project managers in the United Arab Emirates (UAE). This will provide information on which software features are best-suited for the project manager in the UAE. This allows software companies to find out the gaps within their software solutions which need to be addressed so as to make them more user-friendly. For this study, a comparison was made between the four pieces of software that are very much appreciated globally among practitioners, namely Smartsheet, Asana, Microsoft Project and Basecamp, based on a total of six criteria. Since software evaluation was based on multiple criteria, the logical choice is to use multicriteria analysis methods. The contribution of this study reflects in the application of the Measurement of Alternatives and Ranking According to Compromise Solution (MARCOS) method in project management software ranking. This multicriteria analysis method is a new method developed by Stević et al. (2020) and has only just begun to be put into practice. This method has shown excellent results in the sustainable selection of suppliers (Stević et al., 2020) and has shown a certain advantage over other multicriteria analysis methods, which is why this method was chosen.

This paper is divided into six sections, excluding the literature. The introductory section sets out the purpose and contribution of this paper. The second section is dedicated to the application of multicriteria methods in project management software ranking, and the theoretical foundations of the MARCOS method are presented. In the third section, the model is presented and the research methodology is explained. The fourth section is focused on processing the results of the survey. In the fifth section, the results of the sensitivity analysis performed are shown, and the obtained results are confirmed. In the sixth selection, the most important results, shortcomings and recommendations for future research are presented.

2. The Application of Multicriteria Analysis Methods in Project Management

Multicriteria analysis methods are concerned with decision-making taking into consideration multiple criteria. These criteria may be different. Some criteria are numerical, some are quantitative, some have units of measurement, and so on. Certain criteria can solely be obtained through a subjective attitude, whereas other criteria can be measured and determined (Erdogan et al., 2019). The basic features of the application of multicriteria analysis are: (Rifle, 2013)

- It often happens that one alternative is better than another in one criterion, while the other is better than the first in the second criterion.
- It is not always the case that one alternative is better than another in all criteria, so there is no optimal solution in a strict mathematical sense in that case.
- A solution to the problem implies finding a compromise solution.

Different methods have been used in different studies on project management. Alencar and Almeida (2010) used the PROMETHEE VI method in the selection of project management members. Zavadskas et al. (2012) applied the AHP and ARAS methods in the evaluation of project managers. Chang et al. (2012) applied a fuzzy approach in order to evaluate which criterion is the most important in improving the project team performance by using the DEMATEL, ANP, and VIKOR methods. Górecka (2013) applied the ELECTRA and PROMETHEE methods when choosing the best alternative for road construction. Wang et al. (2014) applied a hybrid model by using the DEMATEL, ANP and VIKOR methods in the estimation and improvement of the Six Sigma projects so as to reduce the performance differences in each criterion. Jafarnejad Chaghooshi et al. (2016) made a choice of the project manager by using the fuzzy DEMATEL method and the Fuzzy VIKOR method. Puška et al. (2017) used the TOPSIS method to examine the impact of subjective judgments on project management decision-making. Khoshnava et al. (2018) used the DEMATEL and fuzzy ANP methods to improve green project management. Erdogan et al. (2019) used the AHP method when designing a sustainable construction in project management. Piengang et al. (2019) selected project management programs by using the AHP and VIKOR methods.

Based on this brief overview of the research studies carried out so far, it can be seen that different multicriteria analysis methods have been used for project management purposes. In the following section, the MARCOS method used in the paper in order to rank software intended for project management is explained.

2.1. The Measurement of Alternatives and Ranking According to Compromise Solution (MARCOS) method

The MARCOS method is based on defining the relationship between alternatives and reference values (ideal and anti-ideal alternatives) (Stević et al., 2020). Decision-making preferences are defined based on utility functions. A utility function is the position of an alternative in relation to the ideal and anti-ideal solutions (Stanković et al., 2020). The best alternative is that closest to the ideal point and farthest from the anti-ideal point. The MARCOS method is implemented through the following steps (Stević, et al, 2020):

Step 1. The formation of the initial decision matrix.

Step 2. The formation of an extended initial matrix. This step defines the ideal and anti-ideal solutions. The ideal solution is an alternative with the best alternative for certain criteria, whereas the anti-ideal solution is the worst alternative for certain criteria. This is based on the following equations:

$$AAI = \min_{j} x_{ij} \quad if\ j \in B \quad and \quad \max_{j} x_{ij} \quad if\ j \in C \tag{1}$$

$$AI = \max_{j} x_{ij} \quad if\ j \in B \quad and \quad \min_{j} x_{ij} \quad if\ j \in C \tag{2}$$

where B stands for the criteria to be maximized, and C stands for the criteria to be minimized.

Step 3. The normalization of the extended initial matrix. Normalization is performed by using the following equations:

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if\ j \in C \tag{3}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if\ j \in B \tag{4}$$

where the elements x_{ij} and x_{ai} represent the elements from the initial decision matrix.

Step 4. The determination of a weighted matrix. Aggravation is performed by multiplying normalized matrix values by corresponding weights.

Step 5. The calculation of the utility degree of the alternatives K_i. The utility degree is determined by applying the following equations:

$$K_i^- = \frac{S_i}{S_{aai}} \tag{5}$$

$$K_i^+ = \frac{S_i}{S_{ai}} \tag{6}$$

where S_i (*i*=1,2,..,*m*) represents the sum of the elements of a difficult matrix:

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{7}$$

Step 6. The formation of the utility function of the alternatives *f(Ki)*. The utility function is calculated by using the following equation:

$$f(K_i)=\frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^-)}+\frac{1-f(K_i^-)}{f(K_i^-)}}; \tag{8}$$

where $f(K^-_i)$ is the utility function *versus* the anti-ideal solution, while $f(K^+_i)$ is the utility function *versus* the ideal solution. The utility functions are calculated by using the following equations:

$$f(K_i^-)=\frac{K_i^+}{K_i^+ + K_i^-} \tag{9}$$

$$f(K_i^+)=\frac{K_i^-}{K_i^+ + K_i^-} \tag{10}$$

Step 7. Ranking the alternatives. A rank is formed based on the final value of the utility function. It is desirable that the alternative should have the greatest value of the utility function (Stević and Brković, 2020).

3. Model and Methodology

The methodology used in this research study consists of the following stages:

- Phase 1. Defining the research problem and goal
- Phase 2. Defining the criteria and alternatives, and the creation of the models
- Phase 3. Drafting a survey questionnaire and data collection
- Phase 4. The selection of multicriteria analysis methods
- Phase 5. Data processing and preparation for analysis
- Phase 6. The analysis of the collected data
- Phase 7. Conducting a sensitivity analysis

The initial stage in this study is focused on the definition of the research problem. The problem of this research is how to choose the software for project management needs that best meets the needs of managers in the UAE. Based on this problem, the aim of the research is presented, which is highlighted in the introductory part of the paper.

The most important project management software ranking criteria are related to human, technical and managerial factors (Chatzoglou et al., 2007). Many authors have used these software rankings. Gharaibeh (2014) used the following criteria in his ranking of project management software: Accuracy, Affordability, Ease of Use and Ability to Handle Complexity. Ahmad and Laplante (2006) used the following criteria: Task Scheduling, Resource Management, Collaboration, Time Tracking, Estimating, Risk Assessment, Change Management, Reporting/Charts, File Attachment, E-mail Notification, Process/Methodology and Portfolio Management. Rouhani and Zare Ravasan (2016) identified a total of the 48 criteria that may be used to evaluate project management software. Due to a large number of different criteria, these criteria were systematized in this paper into six criteria, each including several sub-criteria.

In order to rank project management implementation software, it is necessary to, first, define the criteria and determine the alternatives that will be ranked. In this study, those six criteria were defined as follows:

- The *Tasks* (C1) criterion evaluated how tasks can be created and assigned with software, what is done from identified activities, and how to set agreed dates in the project, how to prioritize the project, and how to determine the project to-do lists.
- The *Collaboration* (C2) criterion assessed how collaborative joint project planning is, how comments can be made, how documents can be uploaded and downloaded.
- The *Projects* criterion (C3) evaluated support for individual projects in terms of the project map design, respectively the Gantt map, what the calendar view of the planned activities is, what support for the activity display is, how the project is budgeted for individual activities and for the entire project, and how the implementation of certain activities is monitored.
- The *Portfolio Management* (C4) criterion assessed the coordination of the projects that a particular company owns, how those projects are budgeted, how the What-If Scenarios are developed, the workflow for individual activities, how project request management is monitored, how support for cost tracking and Return on Investment (ROI) calculations is implemented, various project projections, and how project risk analysis is performed through software.
- The *Resource Management* (C5) criterion evaluated the bases used to store the data, how resources could be allocated, how the workload of the project workers is monitored, and the time spent in the project execution.
- The *Platform* (C6) criterion evaluated support for the project alerts, mobile access to these programs, user management, roles and access, the integration of the Application Programming Interface, reporting on and the monitoring of these programs, how the program is adjusted to users, how reliable the software is and how fast it runs.

After the criteria for the evaluation of the project management software had been defined, the software that will be evaluated was determined. In this study, globally recognized software solutions (i.e. Smartsheet (A1), Asana (A2), Microsoft Project (A3) and Basecamp (A4)) and their applicability in the UAE were evaluated. *Smartsheet* is a cloud-based platform, which allows organizations of all sizes to plan, capture, manage, automate and report on work across the business, empowering you to move faster, drive innovation, and achieve more. *Asana* is a web and mobile application, designed to help teams organize, track and manage their work. *Asana* is the work management platform that teams use to stay focused on the goals, projects and daily tasks that grow business. *Microsoft Project* is a project management software product developed and sold by Microsoft. It is so designed to assist a project manager in developing a schedule, assigning resources to tasks, tracking progress, managing the budget and analyzing workloads. *Basecamp* is focused on the development of a simple interface, in which users can create projects, document progress and manage tasks. It is a web-based piece of software, allowing users to sign in anywhere, anytime, either through a web browser or through applications compatible with many mobile devices.

Based on the defined criteria and the alternative in the study, the research model was created, which is shown in Figure 1. In order to choose the best characteristics of project management software, it is necessary the weight of the criteria should, first, be determined, after which the value of the alternatives should be determined according to all the criteria. Based on this, two questionnaires were formed. The first survey questionnaire refers to the determination of the weight of the criteria representing a certain feature of the software indicated as important for practitioners in the UAE. In this questionnaire, the experts were asked to anonymously rate the importance of individual criteria, which ranged from 1 to 5, the questionnaire resulting in the experts' ratings (Table 1). For the second questionnaire, the secondary data drawn from the g2.com user community were used. This web portal monitors how different software solutions are accepted by users. On the platform, they ask users daily to evaluate the software they use. These data represent the evaluations of different project management software solutions from global users and practitioners. They rated the selected programs with the grades ranging from 1 to 10. Based on their grades, a mean value was formed for each criterion for the individual alternatives (Table 2). In this way, the data needed to conduct the research were collected.

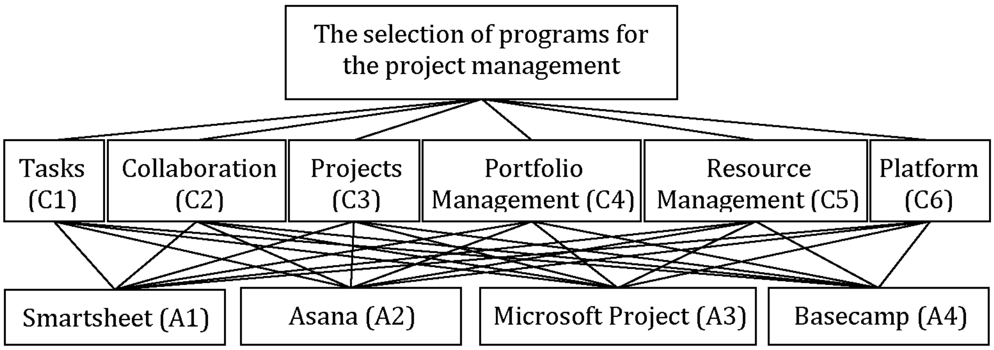

Figure 1. The project management software selection model

Once the data were collected, it was necessary to select a multicriteria analysis method. Since the focus of this research is on the MARCOS method, the weights of the criteria were calculated by applying a simple sum of ratings from the experts and converting those ratings into the percentage that, in fact, is the weight of each criterion. The MARCOS method was selected for ranking the alternatives.

After the data had been collected, they were processed and prepared for the research. Based on the data collected, the initial decision-making tables were formed; the first table was for the determination of the value of the criteria weights (Table 1), and the second was for the determination of the ranking of the alternatives (Table 2). Once the decision tables were formed, the defined analysis were carried out and the research results were obtained. In order to confirm the results obtained, a sensitivity analysis was also conducted. The sensitivity analysis was aimed at examining the dependence of the results on the change in the weights of the criteria. The details on stages 6 and 7 are given in Chapter 4.

4. Results

This chapter provides a more detailed elaboration on the manner in which the research results were generated. First, the weights of the criteria used in the decision model were calculated and presented.

The ratings given by the experts on an anonymous basis are presented in Table 1. They determined the rating based on the subjective assessment of the importance of certain criteria, where the score 1 represents a value of little or no importance, whereas the score 5 represents a value of a very important criterion. After the criteria had been collected by the experts, all the individual criteria were summed up. Based on the total value of the criteria, a percentage of the importance of the individual criteria expressed in decimals was formed. These values represent the weight of each criterion.

Table 1. The experts' evaluation of the importance of the criteria

	C1	C2	C3	C4	C5	C6
Expert 1	5	4	5	5	4	2
Expert 2	5	4	5	4	3	2
Expert 3	4	4	5	5	4	4
Expert 4	5	4	5	5	4	3
Expert 5	5	4	5	5	4	3
Sum	24	20	25	24	19	14
Weight	0.190	0.159	0.198	0.190	0.151	0.111

Based on the results obtained, it can be observed that the criterion C3 – Projects (w = 0.198) has the highest importance according to the experts, whereas the criterion C6 – Platform (w = 0.111) has the lowest importance. Based on all the other values, it can be concluded that the criteria C1 and C4 were assigned high values, whereas the criteria C2 and C5 were assigned mean values. This means that the criteria C1, C3 and C4 are the most important for the evaluation of individual software, the criteria C2 and C5 are of medium importance, while the criterion C6 is the least important.

Once the weights were established for the criteria, it was necessary to determine the rankings for the selected alternatives. Based on the data collected, an initial decision matrix for the observed alternatives was formed (Table 2). Forming an initial decision matrix is the first step in all multicriteria analysis methods. In order to determine the ranking of the alternatives, it was necessary to normalize the data so as to make them be uniform. Simple linear normalization (Equation 3) was applied to the MARCOS method. It was necessary to determine the maximum value of the criteria, since it is desirable for all criteria that the values of the alternatives should be maximized. The normalization of the initial decision matrix is Step 3 of the MARCOS method.

Table 2. The initial decision matrix

	C1	C2	C3	C4	C5	C6
Smartsheet	8.675	8.433	8.000	7.800	8.025	8.043
Asana	8.825	8.600	7.420	7.463	7.825	8.229
Microsoft Project	8.325	7.600	8.040	7.700	7.925	7.600
Basecamp	8.525	8.667	7.180	7.375	7.750	8.071
Max	8.825	8.667	8.040	7.800	8.025	8.229

The results of the normalized decision matrix (Table 3) show that the alternatives A1 and A2 have two maximum values of the criteria each, while the alternatives A3 and A4 have one maximum value of the criteria. Based on this, it was necessary that a compromise solution should be made, since there was no optimal solution, speaking in a strictly mathematical sense. In these cases, multicriteria analysis methods were applied, because one alternative had all the best indicators and there was no need to rank them, because the best alternative was known.

Table 3. The normalized decision matrix

	C1	C2	C3	C4	C5	C6
Smartsheet	0.983	0.973	0.995	1.000	1.000	0.977
Asana	1.000	0.992	0.923	0.957	0.975	1.000
Microsoft Project	0.943	0.877	1.000	0.987	0.988	0.924
Basecamp	0.966	1.000	0.893	0.946	0.966	0.981
Weight	0.190	0.159	0.198	0.190	0.151	0.111

After the normalization of the data in the decision matrix, these values needed to be aggravated by the weighting coefficients. This was the fourth step in the MARCOS method. The fifth step in the MARCOS method was to calculate the utility degree. In order to perform this step, it was first necessary to determine the ideal and anti-ideal solutions. The ideal solution represents the maximum value of a certain criterion, whereas anti-ideal values represent the minimum value of a specific criterion. Then, the values for the individual alternatives and for the ideal and anti-ideal solutions were summed up and the utility degrees were calculated (Equations 5 and 6).

Table 4. The aggravated normalized decision matrix

	C1	C2	C3	C4	C5	C6	Sum
Smartsheet	0.187	0.154	0.197	0.190	0.151	0.109	0.989
Asana	0.190	0.158	0.183	0.182	0.147	0.111	0.971
Microsoft Project	0.180	0.139	0.198	0.188	0.149	0.103	0.957
Basecamp	0.184	0.159	0.177	0.180	0.146	0.109	0.955
Ideal	0.190	0.159	0.198	0.190	0.151	0.111	1.000
Anti-ideal	0.180	0.139	0.177	0.180	0.146	0.103	0.924

The sixth step of the MARCOS method was to form the utility function of the alternatives. The utility function was calculated by using Equation 8. In order to calculate the utility function of the alternatives, it was necessary to calculate the utility function in relation to the ideal and anti-ideal solutions. These functions are the same for all the values and their values: f (Ki-) = 0.520 and f (Ki +) = 0.480. The inclusion of these values generated the final value for the alternatives (Table 5) and determined the ranking of the alternatives.

Table 5. The ranking of the alternatives.

	K_i^-	K_i^+	$f(K_i)$	Rank
Smartsheet	1.070	0.989	0.685	1
Asana	1.051	0.971	0.673	2
Microsoft Project	1.035	0.957	0.663	3
Basecamp	1.033	0.955	0.661	4

The survey results show that *Smartsheet* received the highest ratings, while the *Basecamp* ranked the worst among the selected pieces of software. According to these results, there was a very small difference between the final values for the alternatives based on the MARCOS method calculation. *Microsoft Project* received slightly over 0.002 more value than *Basecamp*, while *Asana* was better than *Microsoft Project* by 0.01, and *Smartsheet* was better than Asana by 0.012. Based on all the foregoing, the difference between the first-ranked and the last-ranked software is 0.024, which leads to the conclusion that neither software deviates from the others according to the estimates made by the experts through their anonymous responses. The original normalized decision matrix also shows that all the selected pieces of software have the best grades for certain criteria. In order to confirm these results, a sensitivity analysis was carried out.

5. Sensitivity Analysis

A sensitivity analysis was performed in such a manner that the weights of the criteria varied, and it was observed that the change made in the weights influenced the ranking of the alternatives (Puška et al., 2018). Seven scenarios were used for this purpose. In the first six scenarios, an individual criterion was assumed to be five times as significant as the other criteria, and it was assigned a weight of 0.5, while the other criteria were assigned a weight of 0.1 (Table 6). The seventh scenario assumed that the validity of all the criteria was the same, and the assigned weight was 0.167. The aim of the sensitivity analysis was to avoid the subjective evaluation of the criteria by the experts. Using these criteria, the results of the study were tested so as to understand whether they were sensitive to changing weights. This enabled us to confirm or deny the results. In addition, this analysis shows the advantages and disadvantages of different software solutions according to certain criteria.

Table 6. The scenarios for sensitivity analysis

	C1	C2	C3	C4	C5	C6
Scenario 1	0.5	0.1	0.1	0.1	0.1	0.1
Scenario 2	0.1	0.5	0.1	0.1	0.1	0.1
Scenario 3	0.1	0.1	0.5	0.1	0.1	0.1
Scenario 4	0.1	0.1	0.1	0.5	0.1	0.1
Scenario 5	0.1	0.1	0.1	0.1	0.5	0.1
Scenario 6	0.1	0.1	0.1	0.1	0.1	0.5
Scenario 7	0.167	0.167	0.167	0.167	0.167	0.167

The research study provided an opportunity to explore the opinion of the users of these programs. They provided the grades from 1 to 10, and this interval was the basis for the evaluation of these software solutions. These ratings were, then, ranked by using the defined scenarios. The results of the survey show that *Smartsheet* achieved the best results in six scenarios, whereas only in Scenario 6 it ranked the second. This shows that *Asana* has better C6 – Platform criterion than *Smartsheet*, according to the users' ratings, so it did not rank the first in this scenario. The same situation is with *Asana*, which was the third in Scenario S3, in which *Microsoft Project* achieved better results than this software solution. *Microsoft Project* achieved the worst results in four scenarios, whereas the Basecamp achieved the worst results in three scenarios. Based on the results of the sensitivity analysis, a conclusion can be drawn that *Smartsheet* achieved the best results in the user-made evaluation, whereas *Microsoft Project* and *Basecamp* showed the worst results.

Table 7. The ranking of the project management software by scenarios

	Rank (S1)	Rank (S2)	Rank (S3)	Rank (S4)	Rank (S5)	Rank (S6)	Rank (S7)
Smartsheet	1	1	1	1	1	2	1
Asana	2	2	3	2	2	1	2
Microsoft Project	4	4	2	3	3	4	4
Basecamp	3	3	4	4	4	3	3

6. Conclusion

Project management is very important for any organization. An organization may deal with multiple and very complex projects, so they need to be managed appropriately. In such cases, project management is performed with the support of IT software. There are many software solutions on the market. In this paper, four pieces of software were selected. The selection was made through the evaluation provided by the g2.com user community for different software features and whether these features were relevant in the United Arab Emirates or not was evaluated. These findings led to the results implicative of user preferences in the UAE for using a certain software solution. Only an overview of whether the software features for the selected software solutions were relevant for users in the UAE or not was presented. The weights of the criteria were determined in collaboration with the experts. Using the MARCOS method, the selected project management software was ranked. The research results show that the *Smartsheet* features are the most relevant in the experts' opinions. Still, this does not reflect the fact that this solution is the most used solution, but rather that its futures are most apricated by the experts.

The disadvantage of this research study is that only a limited number of software solutions were included in the evaluation. Another disadvantage of this research study is the use of the six criteria according to which the pieces of software were evaluated. This number of the criteria were used due to the availability of the secondary data provided by the g2.com user community about different software solutions in project management. However, the respondents were instructed to perceive the sub-criteria through the basic criteria and provide a cumulative rating for the software they are using. In this manner, more criteria were considered than the stated. Future research may be focused on presenting the ratings of the sub-criteria by going deeper into the main criteria.

It is also necessary to conduct a research study on the importance that criteria have for users in order to enable them to obtain the necessary information about the criteria which they should pay attention to when ranking different software options. The purpose of each evaluation is to see how a particular solution suits the user, so it is necessary to obtain all the necessary information from users.

This study has presented a new approach to how to evaluate project management software by using the newly-introduced MACROS method. In future research, this model and this methodology should be applied, because they are very simple and can be applied to other decision problems as well.

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