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RARE EVENTS QUEUEING SYSTEM – REQS

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Abstract: *The paper deals with the queueing system for customers with Poisson's arrival process with the intensity λ and two service modes: in the regular service regime of the intensity control μ, customers are served with a probability of $p\approx1$, and in the special service regime provided to special customers, they are served with the intensity ξ. Special customers access REQS with a complementary probability of $(1-p)\approx0$. A special customer service is analogous to a rare event. The standard methodology has developed analytical patterns for stationary REQS with one service channel and an infinite number of positions in the queue. The analysis of the work of REQS indicates that, when favorable metering parameters $\rho=\lambda/\mu>2$ are concerned, the queueing system is resistant to collapse when an occurrence comes up. However, the regular time losses of regular customers in REQS are extremely high. For this reason, this is the first time that the system stabilization period is being promoted, representing the time interval for the completion of a special customer service before REQS. The analytical apparatus of the queueing system has shown an excellent adaptability to the heterogeneous demands for services μ and special customers, with a low service intensity ξ where $\mu>\xi$. The system can be applied to checkpoint calculations, traffic cuts due to accidents, incidents in industrial systems, i.e. in the case of the occurrence of rare events happening due to anthropogenic and technical factors in the intervals ranging from 10^{-4} to 10^{-6}. The model is not intended for natural hazards.*

Key words: *collapse, special service, critical probability, stabilization time*

1. Introduction

The development of rare events theory began in the 1970s and was above all aimed at predicting natural hazards (earthquakes) (Cornell, 1968). After the quickly

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obtained results, the importance of the new theory and the application possibilities for the calculation of the hazards induced by anthropogenic factors (e.g. by terrorism) and industrial hazards increased. Since then, rare events theory has become a research field intended to improve the reliability and security of the system (Der Kiureghian, & Liu, 1986; Yang et al., 2015).

From the point of view of systems theory, rare events are characterized by a low frequency of the implementation of the usually uncovered range. The unpredictable and undesirable jargon recognizes rare events caused by the system's current operating regimes as a "black Swan" or a "gray Swan".

The low frequency of rare events makes it impossible to form the necessary statistical set (large datasets) for the significant verification of the distribution of their occurrences. Therefore, it is common to assign an exponential distribution to the distribution of rare events (Zweimuller, 2018; Garnier and Moral, 2006; Jacquemart & Morio, 2016; Ruijters et al., 2019). Such an approach is theoretically justified because of the memoryless properties of the exponential distribution, which completely eliminates the functional relationships between consecutive rare events. Due to the unpredictability and the low probability of their occurrence, the simulation of rare events is a specific analytical task (Morio et al., 2014; Au & Patelli, 2016; Agarwal & De Marco, 2018).

In order to investigate the extreme working conditions caused by the realization of rare events, there are standards in technical systems that, under a rare event, adopt a frequency within the interval ranging from 10^{-4} to 10^{-6} during the lifetime of the system, or as low as 10^{-8}, during the one hour of the operation of the system (Paté-Cornell, 1994).

In this paper, the single-channel REQS model analyzed is the Markovian, which implies the exponential structure of each parameter. Rare events are substituted with a customer with a specific request, who accesses REQS and who is likely to be a rare event $(1-p)$. A special customer requires to be described by the crucial parameter – the time of the special customer service incomparably greater than the time of the regular customer service. Basically, REQS is a heterogeneous system. The analytical apparatus of the queueing system in the stationary mode of operation shows an exceptional adaptability to the introduction of a special customer. Thanks to analytical elasticity, the REQS limitation modes are easily calculated, and the regular capacity of the system and the special customer service regions prevent the system from collapsing.

2. The Birth-Death Process in REQS. Single-Channel REQS

Allow us now to consider the birth-death process in a system with the homogeneous birth process of the intensity λ. Let the dying process be heterogeneous, with the standard mortality intensity μ of the probability of $p \approx 1$. The mandatory working condition is $\lambda<\mu$, with the complementary probability of $(1-p) \approx 0$, which represents the special dying process occurring after the regular dying process. The intensity of the special dying process has the intensity of $\xi \neq \mu$, where $\mu > \xi$. Keeping this in mind, the mean death time represents a special case of the complementary probability of $(1-p) \approx 0$, which is incomparably longer than the regular one. The graph of the elementary states of this process is presented in Figure 1.

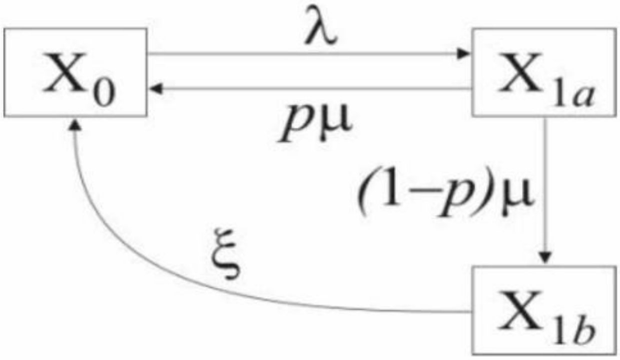

Figure 1. The elementary states of the single-channel REQS

The average dying time is equal to, as in Equation (1):

$$p\int_0^{\infty} te^{-\mu t}dt+(1-p)\int_0^{\infty} te^{-\mu t-\xi t}dt=\frac{p}{\mu}+\frac{(1-p)}{\mu}+\frac{(1-p)}{\xi}=\frac{1}{\mu}+\frac{(1-p)}{\xi} \quad (1)$$

The implications of this process for queueing systems are considered under the conditions of the limited value of the probability of the distribution of customers p in the case when the $p\to 1$ system is reduced to the standards of the Markovian system with one channel of services(i.e. in a system without customers with special requests), which is expressed by Kendall's notation M(λ)/M(μ)/1/0, Equation (2):

$$\lim_{p\to 1}\left(\frac{1}{\mu}+\frac{(1-p)}{\xi}\right)=\frac{1}{\mu} \quad (2)$$

In the case where $p\to 0$ (all customers are special customers), the average time of the service described in Raikov's theorems is obtained. The stability of the Poisson stream creates the second boundary result, as in Equation (3). In the boundary conditions of Equation (3), the queueing system is again the standard Markovian queueing system, which is expressed by Kendall's notation M(λ)/M($\mu^{-1}+\xi^{-1}$)/1/0, Equation (3):

$$\lim_{p\to 0}\left(\frac{1}{\mu}+\frac{(1-p)}{\xi}\right)=\frac{1}{\mu}+\frac{1}{\xi} \quad (3)$$

The boundary conditions determine the mean time of the services of the single-channel queueing system in the regular operation mode $0<p<1$, Equation (4):

$$\frac{1}{\mu}\leq\frac{1}{\mu}+\frac{(1-p)}{\xi}\leq\frac{1}{\mu}+\frac{1}{\xi} \quad (4)$$

3. Single-Channel REQS with an Infinite Queue

If the system of the homogeneous birth and heterogeneous dying processes is projected with an infinite number of points in the queue, the reciprocal value obtained from Equation (4) or Equation (5) is the intensity of the customer services in the queue (Figure 2):

$$\mu_q = \frac{\mu\xi}{\xi + \mu(1-p)} \tag{5}$$

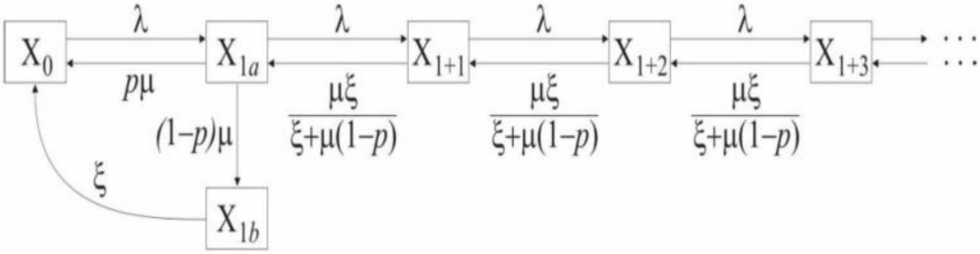

Figure 2. The single-channel REQS with an infinite number in the queue

This system's solution starts from setting balanced equations in the stationary operation mode. The probability of the states X_0, X_{1a}, X_{1b}, X_{1+i} is indicated by the protocol: $P(X_0)=x_0$, $P(X_{1a})=x_{1a}$, $P(X_{1b})=x_{1b}$, and the probability of the state of the queue system for $i\in(1,\infty)$ with $P(X_{1+i})=x_{1+i}$, Equation (6), reads as follows:

$$\begin{aligned}
&X_0 : 0 = -\lambda x_0 + p\mu x_{1a} + \xi x_{1b} \Leftrightarrow x_0 = \frac{p\mu x_{1a} + \xi x_{1b}}{\lambda} \\
&X_{1a} : 0 = +\lambda x_0 - (p\mu + (1-p)\mu + \lambda)x_{1a} + \frac{\mu\xi}{\xi + \mu(1-p)} x_{1+1} \\
&X_{1b} : 0 = +(1-p)\mu x_{1a} - \xi x_{1b} \Leftrightarrow x_{1b} = \frac{(1-p)\mu}{\xi} x_{1a}
\end{aligned} \tag{6}$$

In the sequel, all the three probabilities from Equation (6) are shown through the probability of the state x_0, Equation (7):

$$\begin{aligned}
&x_0 = \frac{p\mu x_{1a} + \xi x_{1b}}{\lambda} = \frac{p\mu x_{1a} + \xi \frac{(1-p)\mu}{\xi} x_{1a}}{\lambda} \Leftrightarrow x_{1a} = \frac{\lambda}{\mu} x_0 \\
&x_{1b} = \frac{(1-p)\xi}{\mu} x_{1a} = \frac{(1-p)\xi}{\mu} \cdot \frac{\lambda}{\mu} x_0 \Leftrightarrow x_{1b} = \frac{(1-p)\lambda\xi}{\mu^2} x_0 \\
&0 = +\lambda x_0 - (p\mu + (1-p)\mu + \lambda)x_{1a} + \frac{\mu\xi}{\xi + \mu(1-p)} x_{1+1} \Leftrightarrow \\
&\frac{\lambda^2}{\mu} x_0 = \frac{\mu\xi}{\xi + \mu(1-p)} x_{1+1} \Leftrightarrow x_{1+1} = \frac{\lambda(\xi + \mu(1-p))}{\mu\xi} \cdot \frac{\lambda}{\mu} x_0
\end{aligned} \tag{7}$$

Allow us now to proceed with solving the probability in the order of X_{1+i}, Equation (8):

$$
\begin{aligned}
&X_{1+1}: 0=+\lambda x_{1a}-\frac{\mu\xi}{\xi+\mu(1-p)}x_{1+1}-\lambda x_{1+1}+\frac{\mu\xi}{\xi+\mu(1-p)}x_{1+2}\Leftrightarrow\\
&\lambda\frac{\xi+\mu(1-p)}{\mu\xi}\frac{\lambda^2}{\mu}x_0=\frac{\mu\xi}{\xi+\mu(1-p)}x_{1+2}\Leftrightarrow x_{1+2}=\left(\frac{\lambda(\xi+\mu(1-p))}{\mu\xi}\right)^2\frac{\lambda}{\mu}x_0\\
&X_{1+2}: 0=+\lambda x_{1+1}-\frac{\mu\xi}{\xi+\mu(1-p)}x_{1+2}-\lambda x_{1+2}+\frac{\mu\xi}{\xi+\mu(1-p)}x_{1+3}\Leftrightarrow\\
&x_{1+3}=\left(\frac{\lambda(\xi+\mu(1-p))}{\mu\xi}\right)^3\frac{\lambda}{\mu}x_0;\quad x_{1+4}=\left(\frac{\lambda(\xi+\mu(1-p))}{\mu\xi}\right)^4\frac{\lambda}{\mu}x_0;\ldots
\end{aligned}
\tag{8}
$$

Furthermore, for the probability of all the states in the induction queue, a recurrent form is obtained for the purpose of conducting the probability analysis of the state in the queue of x_{1+i}, Equation (9):

$$
x_{1+i}=\left(\frac{\lambda(\xi+\mu(1-p))}{\mu\xi}\right)^i\frac{\lambda}{\mu}x_0 \tag{9}
$$

The normative condition is as follows, Equation (10):

$$
\begin{aligned}
x_0+x_{1a}+x_{1b}+\sum_{i=1}^{\infty}x_{1+i}&=x_0+x_0\frac{\lambda x_0}{p\mu+(1-p)\xi}+x_0\frac{(1-p)\lambda\xi}{p\mu^2+(1-p)\mu\xi}\\
&+x_0\frac{\lambda}{(p\mu+(1-p)\xi)}\sum_{i=1}^{\infty}\left(\frac{\lambda(\xi+\mu(1-p))}{\mu\xi}\right)^i=1
\end{aligned}
\tag{10}
$$

Since $\mu>>\xi\wedge 0\leq p\leq 1$, it follows that the input condition is required of the input intensity λ and the basic intensity of the service $\mu>\lambda$, the sum of Equation (10) being the required geometric order only under the conditions of Equation (11).

$$
\frac{\lambda\xi+\lambda\mu(1-p)}{\mu\xi}<1\Leftrightarrow\lambda\xi+\lambda\mu(1-p)<\mu\xi\Leftrightarrow\xi_{min}>\frac{\lambda\mu(1-p)}{\mu-\lambda} \tag{11}
$$

Otherwise, if the condition of Equation (11) is not met, the average time of the ξ^{-1} special customer service is extremely long, and the number of the customers in the queue diverges, i.e. REQS enters into collapse.

With the above-mentioned condition, the value of the geometric order of Equation (10) is equal to that of Equation (12), namely as follows:

$$
\sum_{i=1}^{\infty}\left(\lambda\left(\frac{\xi+\mu(1-p)}{\mu\xi}\right)\right)^i=\frac{1}{1-\lambda\left(\frac{\xi+\mu(1-p)}{\mu\xi}\right)}-1=\frac{\lambda\xi+\lambda\mu(1-p)}{\mu\xi-\lambda\xi-\lambda\mu(1-p)} \tag{12}
$$

From the normative condition expressed in Equation (9), the geometric order of Equation (12) gives the probability from x_0, Equation (13):

$$x_0 = \frac{1}{1+\frac{\lambda}{\mu}+\frac{\lambda}{\mu}\cdot\frac{(1-p)\xi}{\mu}+\frac{\lambda}{\mu}\cdot\frac{\lambda\xi+\lambda\mu(1-p)}{\mu\xi-\lambda\xi-\lambda\mu(1-p)}} \tag{13}$$

and all the probabilities of the system from Equations (7) and (9). The average number of the customers in the queue for the fulfilled condition of Equation (11) in the system is equal to that of Equation (14):

$$k_q = \sum_{i=1}^{\infty} i\cdot\left(\lambda\left(\frac{\xi+\mu(1-p)}{\mu\xi}\right)\right)^i = \frac{\left(\frac{\lambda\xi+\lambda\mu(1-p)}{\mu\xi}\right)^2}{1-\frac{\lambda\xi+\lambda\mu(1-p)}{\mu\xi}} = \frac{(\lambda\xi+\lambda\mu(1-p))^2}{\mu\xi(\mu\xi-\lambda\xi-\lambda\mu(1-p))} \tag{14}$$

The average time that the customers spend in the queue is as expressed in Equation (15):

$$t_q = \frac{\bar{k}_q}{\lambda} = \frac{\lambda(\xi+\mu(1-p))^2}{\mu\xi(\mu\xi-\lambda\xi-\lambda\mu(1-p))} \tag{15}$$

4. The Limits of Collapse and Stabilization Time T_{st} in REQS

As in most queueing systems, the basic relationship in Equation (15) determines the operation of the system:

$$\rho = \frac{\lambda}{\mu} \tag{16}$$

For the values of the probability of the findings of special customers "$(1-p)$" and the anticipated average time of special customers ξ^{-1}, the minimum intensity of the regular customer μ_{min} in Equation (17) can be calculated, which guarantees the sustainability of the system:

$$\xi_{min} > \frac{\lambda\mu(1-p)}{\mu-\lambda} \Leftrightarrow \mu_{min} > \frac{\xi_{min}\lambda}{\xi_{min}-\lambda(1-p)} \tag{17}$$

On the contrary, if the conditions from Equation (17) are not satisfied, REQS goes into collapse by diverging the number of the customers in the queue. If the condition for the operation of a single-channel system in Equation (17) is not satisfied, the service intensity may increase (if there is a variable capacity or capacity reserves) or the service additional channels may be introduced into the system.

For the maximum industrial probability of the occurrence of rare events of 10^{-4}, i.e. p=0.9999, the boundary conditions of REQS are presented in Figure 3. The collapse limits are as follows for the different values of ρ:

- $\mu=1.5\lambda \Leftrightarrow \rho=0.75$, $\xi_{min}>0.00030$, or for the relative relation of the intensity of the ordinary and special customer services$\mu/\xi_{min}=5000$, REQS very quickly enters into collapse, and the number of the customers in the queue rapidly diverges. The occurrence of a rare event, i.e. a rare customer with special requests, quickly destabilizes REQS.

- μ=2.0$\lambda \Leftrightarrow \rho$=0.50, ξ_{min}>0.00020, or for the relative relation of the intensity of the ordinary and special customer servicesμ/ξ_{min}=10000, REQS relates well to the appearance of a rare customer. The system is hardly introduced into collapse, but such collapse is a consequence of a high burden placed on the regular customers forming a queue, its slow customer service in the queue, and the big losses of time on the part of the customers in the queue.
- μ=3.0$\lambda \Leftrightarrow \rho$=0.33, ξ_{min}>0.000150, or for the relative relation of the intensity of ordinary and special customer services μ/ξ_{min}=20000, REQS is hardly introduced into collapse, remains stable for a long time with the low accumulation of the customers in the queue.
- μ=4.0$\lambda \Leftrightarrow \rho$=0.25, ξ_{min}>0.000133, or for the relative relation of the intensity of ordinary and special customer services μ/ξ_{min}=30000, REQS behaves similarly to the previous case.

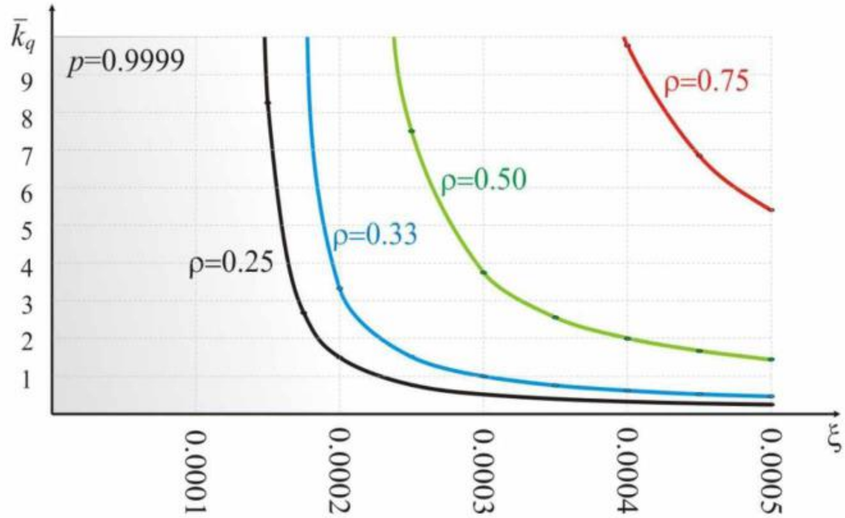

Figure 3. The average number of the customers in the queue for p=0.9999 and the different parameter values of ρ and ξ

If REQS provides special customer service protocols, it does not have to be specifically tailored to rare events. REQS points out the optimization issue regarding the relationship boundary, namely as follows in Equation (18):

$$\frac{\mu}{\xi_{min}} \geq \frac{1}{1-p} \tag{18}$$

which theoretically results in a relative relation μ=2.0λ, i.e. ρ=0.50. One-channel REQS can be optimized. If the inverse value of the parameter of the service ρ^{-1} is accepted for the independent variable (i.e. how many times the intensity of the regular customer service μ is greater than the intensity of incoming customers λ), and if the product $\rho(\xi_{min})^{-1}$ (i.e. the relative parameter of the engagement of the regular and special customer service) is accepted for the dependent variable, then the function shown in Figure 4 is obtained.

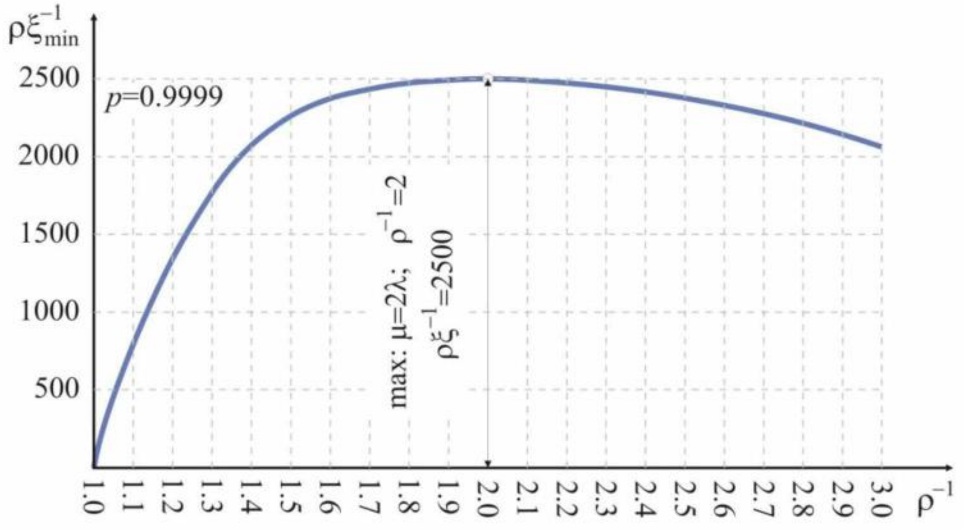

Figure 4. The boundary of the collapse of REQS for the maximum engagement of the service channel

For p=0.9999, the maximum ratio $\rho\xi^{-1}=f(\rho^{-1})$ is obtained for $\mu=2\lambda$. In these circumstances, the maximum time of the special customer service $(\xi_{min})^{-1}$ is equivalent to the time required for the arrival of 5000 regular customers, i.e. the services of 2500 regular customers. For ξ_{min}=0.00020 as per Equation (17), the system is on the edge of collapse.

If the customer service time is reduced by 25%, i.e. if the intensity of special customer services increases to ξ=0.00025 (which is an equivalent to the arrival time of 4000 regular customers, or the service of 2000 customers), the average number of the customers in the queue during the lifecycle of the system without special customers is k_q=7.50. Comparatively, for the queueing system without special customers $M(\lambda)/M(\mu)/1/\infty$, at a ratio $\mu=2\lambda$, the average number of the customers in the system is k_q=0.5, i.e. 15 times smaller than in REQS. It is possible to conclude that the relations $\mu=2.0\lambda$ the REQS are resistant to collapse, but the average number of the customers in the queue during the lifecycle of the system, i.e. the resulting time losses due to the appearance of special customers with the probability of p=0.9999, is/are extremely high.

If the intensity of the services increases to $\mu=3\lambda$, with the same intensity of special customer services ξ=0.00025, the average number of the customers in the queue is 1.527, and for $\mu=4\lambda$ at ξ=0.00025, the average number of the customers in the queue is 0.773.

A standard example of the application of REQS is a survey of traffic accidents. The basis of the numerical example lies in the calculation of the road capacity (Bogdanović et al., 2013) and the application of the queueing system in the calculation of the road capacity (Tanackov et al., 2019). For the mean intensity of the traffic flow of the main roads in the peak period of λ=900 vehicle/h and the maximum throughput of the traffic lane of $\mu\approx$2200 vehicle/h, a special customer service is analogous to the closing of the traffic lane in order to protect the injured, perform surveys and undertake the other operations necessary for the remediation of the accident. A special customer service (i.e. the service of such a customer as a participant in a traffic accident) lasts incomparably longer than the regular customer service. For the likelihood of the occurrence of regular customers from p=0.99995, i.e. the occurrence of an accident on every 20000 vehicles, REQS collapses if the closing time of the traffic lane (the special customer service) is greater than $(\xi_{min})^{-1} \geq$ 13.13h.

However, in the conditions of urban peak periods with twice the intensity of λ=1800 vehicle/h, the collapse limit is the closing of the traffic lane of $(\xi_{min})^{-1} \geq 2.02$h, i.e. for a traffic flow twice as intense, under the same conditions of the regular customer service, the time to collapse is 6.5 times lesser.

Except for the collapse limit of REQS, another important parameter not evaluated in the literature until now is the stabilization time of REQS, which is marked with the tag T_{st}. The users of REQS subjectively and usually negatively react to a loss of the service quality over time T_{st}.

During special customer services, there is an intensive accumulation of regular customers equal to the product of the input stream and the average time of a special customer service, i.e. $\lambda\xi^{-1}$. At the end of the accumulation of regular customers, the regular operation of the system begins with the intensity μ to service to accumulated clusters $\lambda\xi^{-1}$ and new regular customers, who arrive with the intensity λ. Therefore, the difference expressed in Equation (19) must be greater than ρ, i.e. the regular regime of REQS:

$$\lambda\xi^{-1} - (\mu - \lambda)T_{st} \leq \rho \Leftrightarrow T_{st} \geq \frac{\lambda\xi^{-1} - \rho}{(\mu - \lambda)} \tag{19}$$

For the average time, the special customer services (closing the traffic lane) from ξ^{-1}=2h in the first numerical example (λ=900 vehicle/h) of the system stabilization time are equal to T'_{st}=1.285 h, whereas in the second (λ=1800 vehicle/h) T''_{st}=8.997h≈9h. The vehicle total cumulative time losses in the second numerical case (for the system stabilization period T''_{st}≈9h) are equal to 84000 vehicle·h, or 3500 vehicle·days. In the first numerical example, the time losses are about 7.5 times smaller.

For a well-designed intensity, REQS resistance to collapse is certain. However, the appearance of the first "strike" of rare events and the stabilization period T_{st} are a risky REQS time interval. If another special customer appears in the stabilization period, the risks of the collapse of REQS are incomparably larger. If t_{cr} is indicated as the critical time elapsed since the beginning of the stabilization period $t_{cr} \in (0, T_{st})$, the critical probability P_{cr} of the occurrence of special-customer rare events in the period passed since the beginning of the stabilization is equal to that of Equation (20). Although this probability is lesser than the probability of the appearance of the first special customer, it should not be neglected.

$$P_{cr} = (1-p) \int_{T_{st}-t_{cr}}^{T_{st}} \lambda e^{-\lambda t} dt \leq (1-p) \tag{20}$$

In addition to the specified case in road traffic, REQS can analogously be applied to the disruptions of the schedule of railways caused by accidents, in river traffic in the case of the malfunctioning of ship locks, in the case of the suspension of air traffic due to bad weather conditions, etc.

REQS can also be applied in indirect cases, without the arrival of special customers. For example, in all systems that serve customers through the application of information systems, a "failure" of the information system can be considered as a phenomenon of a rare event with the probability of (1−p), and the system "rebooting" time can be considered as the intensity of special customer services.

The principle to be followed refers to the classification of the system states that can be either stable (the regular mode), or metastable, or unstable. The arrival of customers with special requests always introduces the queueing system into a metastable state, and the appearance of customers with special requests at a critical time $t_{cr} \in (0, T_{st})$ introduces the system into an unstable state.

5. Conclusion

REQS modeling and analyzing indicate that the resistance of the system to the occurrence of rare events (special customers) is based on the capacity of the regular operation mode. If the intensity of the services μ in the conditions of the usual occurrences of rare events from 10^{-4} to 10^{-6}, and when a special customer service lasts incomparably longer than a regular customer service, namely several thousand times (up to 10,000 times) as long, for the relative relationships of $\mu \geq 2\lambda$, the boundary collapse of REQS are "so far". The quantity of services can be maintained even in the conditions of disorder. This fact is encouraging for REQS managers.

However, for regular users of REQS, the collapse limit, i.e. the system's capacity, is not the primary parameter. In the implementation of rare events, REQS regularly operates in the destabilization mode. The new parameter of queueing theory, the stabilization time of the T_{st} system, is the key parameter of the quality of the service that special customers (rare events) degrade primarily through regular customers' intensive cumulative time losses. Therefore, the REQS modes can be justified in exceptional, imperative, and most often unwelcome cases.

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APPLICATION OF THE AHP-VIKOR HYBRID MODEL IN MEDIA SELECTION FOR INFORMING ABOUT THE ENDANGERED IN SITUATIONS OF EMERGENCY

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Abstract: *A distribution of information in situations of emergency represents a serious challenge for the expert services engaged in protection and rescue. The number of the people who need help in situations of emergency is rather large and the number of those who can really be helped depends on their availability to expert services. A large number of people, especially endangered groups, can be saved with the help of timely and qualitative information. In the conditions determined by a lack of time, the staff in charge of situations of emergency have to make a decision on informing the population about the incoming danger. In the paper, a hybrid model based on the analytic hierarchy process (AHP) and multi-criteria compromise ranking (VIKOR) is presented, as applied through the selection of the best medium for informing the population in situations of emergency. The AHP method is used to determine criteria weight coefficients, while the VIKOR method is applied in order to find the best media by means of making a selection amongst numerous concrete options – i.e. alternatives.*

Key words: *media, situations of emergency, AHP method, VIKOR method.*

1. Introduction

Situations of emergency represent the state of the high endangerment of a social community. The consequences of situations of emergency are manifold and have far-reaching effects. Considering the size of a danger from various natural disasters and other accidents, and different categories of the endangered population, timely warning and informing are of great significance. Preventive acting through informing and alerting the population is the basis for reducing the consequences of situations of emergency. There are various population categories that need be informed about the incoming danger. The most endangered are persons with special needs, only to be followed by women and children, and, in the end, the persons who are able to save themselves on their own.

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In a situation of emergency, the problem of the functionality of the media may occur due to their territorial prevalence and the signal reception (for the television and the radio) or equipment supply and functionality (the internet). Informing by emergency sirens could be a solution in the areas with good coverage and a high population density. Otherwise, the effect of emergency sirens can be very small. Depending on the type of the situation of emergency, electricity supply can also be problematic (Komazec et al. 2014).

The manner in which people should be informed is mostly restricted by the effects of a situation of emergency and its diffusion, and very frequently, the availability of information to certain groups of people is the only criterion (Акимов & Порфирьев, 2004). However, by carrying out a thorough analysis of the relevant factors, conclusions can be drawn which refer to the selection of the optimal medium (or media) for the purpose of informing as many people as possible in order to select those media that meet the created needs. In this paper, the Analytic Hierarchy Process (AHP) and the Multi-Criteria Compromise Ranking (VIKOR) methods are applied to problem solving. The contribution of the paper reflects in the enhancement of the evaluation and selection methodologies regarding the media for the purpose of informing the population in situations of emergency through a new approach to the treatment of imprecision due to the fact that the application of this model or similar models in situations of emergency has not been reviewed in the existing literature.

2. Problem Description

The paper is focused on finding out the hybrid model which will enable the optimal selection of the media for informing the population in situations of emergency.

The occurrence of the need for informing the population in the situations of natural disasters and technical-technological accidents depends on the level of the endangerment of the social community. The alert signal announcing a danger is activated by the authorities according to the law. The level of the danger, i.e. the endangerment, is the basis for the proclamation of a situation of emergency (Karovic & Komazec, 2009). A situation of emergency is proclaimed by the staff in charge of situations of emergency when risks and threats, or the resulting consequences are on such a scale and of such an intensity that they cannot be stopped or diminished by conducting the authorities' regular activities, for which reason it is necessary that special measures, additional strengths and the means with an enhanced operation mode should be taken for the purpose of their mitigation and removal (Zakon o smanjenju rizika od katastrofa i upravljanju vanrednim situacijama [Law on Disaster Risk Reduction and Emergency Management], 2018; Pamucar et al. 2016).

The proclamation of a situation of emergency follows immediately after becoming aware of the danger. This moment is a milestone in the protection and salvation of the endangered population, material goods and the environment. Namely, as long as the staff in charge of situations of emergency are unaware of a danger, they cannot proclaim a situation of emergency, nor can they inform the endangered population about it; competent services (Republic Hydrometeorological Service of Serbia (RHMS), Republic Geodetic Authority (RGA), etc.) are, however, responsible for informing the population. The competent services usually inform people through the media (the television and the radio) and via the internet (posting warnings on relevant websites). In that period of time, the staff in charge of situations of emergency collect pieces of information and may perform such informing through local communities and responsible individuals.

In some special situations, the electric-power industry, the water industry and the other business associations using hydro-accumulations and landfills are obliged to ensure that the population is timely informed about the incoming danger (Zakon o smanjenju rizika od katastrofa i upravljanju vanrednim situacijama [Law on Disaster Risk Reduction and Emergency Management], 2018).

The members of the staff in charge of situations of emergency may use local radio and television stations. The transmission of information to the endangered population carried out by the Republic staff in charge of situations of emergency The law also envisages the obligation of mobile companies to transfer information to endangered people. All mass-media means are applicable when informing the population is concerned, even before situations of emergency occur (Petrovic et al. 2017). A special problem is a situation of emergency when a danger to the population, material goods and the environment has arisen. The conditions of all the people inside the endangered territory are such that they all fear for themselves, for their families, and for their material possessions. There is a similar situation in business companies which, simultaneously having to protect their own assets, also need to engage the employees whose families are jeopardized at that moment as well. In the case of a concrete problem, persons with special needs, the elderly, women and children are considered as special and specific groups of people.

In the case of a particular problem, the means of mass communications are restricted to a segment of the mass media (the television, the radio and the internet – especially social networks and mobile communications)[1] (Radojkovic & Miletic, 2005). There is a possibility of using print media, but this way of communication is restricted by the type and level of the influence of the concrete danger.

2.1 Informing in Situations of Emergency

The practical usage of effective informing is the basis for effective management (Moriarty et al. 2012). Informing in situations of emergency (and alerting, too) is an activity of great significance with respect to decreasing human casualties and mitigating damage to material goods and the environment. Namely, timely information provides a quick and right reaction of the endangered population to the danger. Timelessness depends on the type of danger (Dey, 2001). Situations of emergency and other accidents which may occur suddenly and develop rapidly are more complex to announce. Practically, their announcement is conducted after the moment of their occurrence. The possibility that the majority of the population will not receive information on time is most likely (Komazec et al. 2018). The dangers that occur in a longer period of time and develop gradually are much easier to announce, along with the appearance of the first indicators.

The staff in charge of situations of emergency and the authorities' specialized institutions (RHMS, RGA, etc.) have the legal obligation to provide information in situations of emergency. This approach is essential for controlling the information flow, the types of information, and the process of receiving information to as many

[1]The presence of social media is generally implied, due to the fact that they include mobile companies and their ability to transfer information as well.

people as possible. For the purpose of informing effectively and efficiently, the staff in charge of situations of emergency have several instruments at their disposal, namely:

1. the television and the radio;
2. the Internet-social networks;
3. the early warning, informing and alerting system;
4. print media and
5. mobile telecommunications.

The television and the radio belong to a group of highly widespread and available media. It is to be assumed that every single home has the ability to access them. The main issue in the usage of such media is the ability of the municipality staff in charge of situations of emergency to send information through the national television and radio network due to the fact that the national services are watched/listened to by a large number of individuals. Also, there is a problem in local services in the territory of the municipality and their availability throughout that territory.

The Internet is also a widely applicable instrument for the transmission of information. There is a certain limitation when access to the internet is in question. It is possible to quickly transfer information to a large number of people throughout social networks, but the availability of those individuals to the staff in charge of situations of emergency may be an issue. A special problem implies those elderly ones who do not use the internet at all, or use it poorly.

The early warning, informing and alerting system is directly available to the staff in charge of situations of emergency. The limitation lies in the operational correctness of the system, the territorial coverage and the ability of all endangered groups to understand the sent signals.

Print media belong in the group of slower and mass means of information transfer. The limitation of their application lies in the fact that, in a situation of emergency, the distribution of such media may be stopped. Also, not every municipality owns its own print media, which may refer to the dependence on a publishing house, its distance and capacity.

Mobile telecommunications represent a powerful, widespread and easily accessible medium for information transfer. A large number of people in all endangered groups own a mobile telephone. The main issue is the development of a database of telephone numbers, especially of the numbers of the endangered groups of individuals responsible for them.

2.2. Description of the Media Selection Criteria

In order to successfully apply the AHP and VIKOR methods to solving the research problem, it is necessary to identify the criteria common to all the listed and considered media of mass communications and among which a selection of the best media for informing the population in situations of emergency will be conducted. (Nenadovic et al. 2016). Taking this into account, the following criteria are identified:

K_1 – The frequency of informing – This criterion is expressed by the number of the repetitions of informing through the amount of time in order to achieve as good reception as possible by as many individuals as possible.

K_2 – Territorial coverage – This criterion is expressed in percentages and represents the ability to receive information in real time throughout the territory of the municipality.

K_3 –Presence in a target group– This criterion is expressed in percentages and reflects the presence of a concrete medium in a concrete target group, or the other way round – it reflects the percentage of the target group 'consuming' a particular medium.

K_4 – The availability of the medium – This criterion represents the coverage of the Republic of Serbia's territory (by broadcasting or by distribution)[2] and it is described by linguistic descriptors given in Table 1.

Table 1. The descriptive scale of the linguistic criteria

Linguistic descriptors	Very poor	Poor	Medium	Good	Excellent
Assigned numerical value	1	2	3	4	5

K_5 – The medium access price – This criterion is expressed by cash units and accounts for the amount which is necessary to pay in order to make the content of a particular medium available.[3]

The characteristics of the listed criteria are presented in Table 2.

Table 2. The criteria characteristics

	ben[4].	*cost*[5]	Qualitative	Quantitative
K_1	+			+
K_2	+			+
K_3	+			+
K_4	+		+	
K_5		+		+

3. Applied Methods

The hybrid model used for the selection of the best media for informing the population in situations of emergency consists of the AHP and VIKOR methods. The AHP method is used to determine the weight coefficients of the identified criteria, while the VIKOR method is used to find a compromise solution, specifically for the selection of the optimal informing medium.

[2] When electronic media (the television and the radio) are concerned, it is significant whether they are the media with a national frequency or the media covering only a certain region in Serbia, whereas when the press (newspapers) is concerned, it is essential whether they are the media distributed throughout the territory or the media distributed locally.

[3] When speaking about electronic media, the total amount represents the sum of all expenses, such as purchasing a television set or a radio receiver, the costs of electricity, broadcasting costs, a special fee for using a public service, etc., whereas in the case of the press, it accounts for the amount which has to be paid for certain newspapers, magazines and so forth. For the internet and mobile communications, it is the price for those services.

[4] The subset of the criteria with the *benefit* characteristics, which means that a higher value of the criterion is preferable, i.e. better.

[5] The subset of the criteria with the *cost* characteristics, which means that a lower value of the criterion is preferable, i.e. better.

3.1. AHP

The AHP method developed by Thomas Saaty at the beginning of the 1970s is a tool used in decision analysis, created for the purpose of providing assistance to decision-makers in resolving complex decision-making problems in which many decision-makers participate, numerous criteria and in various time periods. This process is based on the balance concept used in order to determine the overall significance of the set of relative attributes, activities or criteria, and relates to the analyzed decision-making problem (Cupic & Suknovic, 2010). In the paper, this method is applied so as to determine the criteria weight coefficients regarding the selection of the media for informing the population in situations of emergency. Saaty's standard nine-level scale presented in Table 3 is applied in order to carry out a pairwise comparison (Saaty, 1980). Saaty's scale is applied by the decision-makers or the analysts performing comparisons in pairs on the basis of the semantic preferences from the left-hand column of Saaty's scale or by direct association. The numerical values stated in the columns 2 or 3 of Table 3, which correspond to the semantic preferences in the left-hand column, are entered into the square comparison matrix, Equation (1).

Table 3. Saaty's pairwise comparison scale

Definition	Standard values	Reciprocal values
Equal importance	1	1
Weak importance of one over another	3	1/3
Essential or strong importance	5	1/5
Demonstrated importance	7	1/7
Absolute importance	9	1/9
Intermediate values between the two adjacent judgments	2,4,6,8	1/2, 1/4, 1/6, 1/8

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{array} \tag{1}$$

Since it is true that $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$ for every $i,j = 1,2,\dots,n$, the matrix A is positive, symmetrical and reciprocal. When applying Saaty's classical scale, the relations in a pairwise comparison are strictly defined (Pamucar et al, 2016).

3.2. VIKOR

The VIKOR method was developed by Opricovic Serafim (Opricovic, 1998) based on the elements from compromise programming with the beginning at the "border" forms of Lp-metrics. These metrics represent the distance between the ideal point F^* and the point $F(x)$ in the space of the criteria functions (Petrovic et al. 2017).

The first step in the VIKOR method is the initial decision matrix:

$$\begin{array}{ccccc} X_1 & X_2 & X_3 & \cdots & X_n \\ W_1 & W_2 & W_3 & \cdots & W_n \end{array}$$

$$D = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & X_{13} & \cdots & X_{1n} \\ X_{21} & X_{22} & X_{23} & \cdots & X_{2n} \\ X_{31} & X_{32} & X_{33} & \cdots & X_{3n} \\ \cdots & \cdots & \cdots & \ddots & \vdots \\ X_{m1} & X_{m2} & X_{m3} & \cdots & X_{mn} \end{bmatrix} \quad (2)$$

By the decision matrix, the m alternatives and the n criteria are defined. Every criterion is associated with its weight coefficient w_i. The weight coefficients of the criterion should follow the next condition:

$$\sum_{i=1}^{n} w_i = 1 \quad (3)$$

After defining the decision matrix, the method is to be applied. The next step in the VIKOR method is the determination of x_i^* and x_i^-, which is conducted by the following equations:

$$x_i^* = \max (x_1, x_2, \ldots, x_n);\ i=1,2,\ldots, n; \quad (4)$$

$$x_i^- = \min (x_1, x_2, \ldots, x_n);\ i=1,2,\ldots, n; \quad (5)$$

The next step in the VIKOR method is the determination of the pessimistic (S_j) and the anticipated (R_j) solutions.

$$S_j = \sum_{i=1}^{n} w_i \quad (x_i^* - x_{ij}) \ /(x_i^* - x_i^-)\ ;\ j = 1,2,\ldots,m \quad (6)$$

$$R_j = \max_i [w_i \ (x_i^* - x_{ij}) \ / \ (x_i^* - x_i^-);\ j = 1,2,\ldots,m \quad (7)$$

After that, the next step is finding a compromise solution Q_j :

$$Q_j = v \frac{S_j - S^*}{S^- - S^*} + (1-v) \frac{R_j - R^*}{R^- - R^*};\ j=1, 2,\ldots, m \quad (8)$$

where

$$S^* = \min S_j \quad (9)$$

$$S^- = \max S_j \quad (10)$$

$$R^* = \min R_j \quad (11)$$

$$R^- = \max R_j \quad (12)$$

v – the weight of the strategy satisfied according to the majority of the criteria, $v \in \{0.25, 0.5, 0.75\}$.

The last step in the VIKOR method is the ranking of alternatives. A set of alternatives can be ranked by the value of the function of the criteria assigned to each alternative Q_j. The best alternative is the one that is the least distanced from the ideal value, i.e., the one that has the minimal $Q_j$value, and vice versa. As relevant, the rank list is taken for the value v = 0.5, but even though it is the first on the list, that action has to meet two more conditions (Petrovic et al. 2017), namely:

1) There has to be sufficient advantage (more than the "minimum sufficient advantage") related to the 2nd, 3rd, and other alternatives), which is established by applying the following expression:

$$Q(a') - Q(a'') \geq DQ \tag{13}$$

where:

$$DQ = \min(0.25, \frac{1}{m-1}) \tag{14}$$

where a' and a'' represent the values of the 1st and the 2nd alternatives, respectively, by $Q_j(v=0.5)$, and m represents the number of the alternatives. The minimum sufficient advantage is to be 0.25 in the cases when there is a small number of alternatives.

2) It has to have a sufficiently stable position, i.e. position no. 1, according to the rank list QS_j, or according to QR_j, or according to Q for $v = 0.25$ and $v = 0.75$ where (Petrovic et al. 2017):

$$QS_j = \frac{S_j - S^*}{S^- - S^*};\ j = 1, 2, \ldots, m \tag{15}$$

$$QR_j = \frac{R_j - R^*}{R^- - R^*};\ j = 1, 2, \ldots, m \tag{16}$$

4. Presentation of the Application of the Hybrid Model

As already stated, the hybrid model consists of the AHP and VIKOR methods. The weight coefficients of the criteria are calculated by applying the AHP method in the Expert Choice program package and the results of that process are shown in Tables 4 and 5.

Table 4. The criterion pairwise comparison according to Saaty's scale

	K_1	K_2	K_3	K_4	K_5
K_1	1.0	3.0	1/2	9.0	2.0
K_2		1.0	(4.0)	2.0	2.0
K_3			1.0	5.0	3.0
K_4				1.0	(3.0)
K_5					1.0
			CR=0.03		

Table 5: The values of the criteria weight coefficients

K_1	.300	
K_2	.092	
K_3	.406	
K_4	.051	
K_5	.151	
Inconsistency = 0.03 with 0 missing judgments.		

For the purpose of applying the VIKOR method, a total of 6 different alternatives were chosen (from A_1 to A_6), by which the initial decision matrix was defined, which is accounted for in Table 6.

The alternatives are as follows: Alternative A_1–Local television and radio station; Alternative A_2–National television and radio station; Alternative A_3–Early warning, informing and alerting system; Alternative A_4–Internet–social networks; Alternative A_5–Print media, and Alternative A_6–Mobile communications.

The details regarding the listed alternatives are not presented in the paper in order to avoid a decrease in their positions in the media space and favoring certain media, too.

Table 6. The initial decision matrix

Criterion	K_1	K_2[6]	K_3	K_4	K_5
Alternatives	0.300	0.092	0.406	0.051	0.151
A_1	600[7]	50	45	5	6
A_2	300	48	60	4	5
A_3	600	5	35	3	0.3
A_4	750	4	40	2	0.35
A_5	480	22	10	4	2.4
A_6	430	18	8	1	1.8
x_i^*	750	50	60	5	0.3
x_i^-	300	4	8	1	6
Characteristic of criterion	max	max	max	max	min

By solving the equations from 4 to 12, the final solutions are obtained and they are presented in Table 7.

Table 7. The final values of the alternatives

Alternatives	QSj	QRj	Qj (v=0.5)	Qj (v=0.25)	Qj (v=0.75)
A_1	0.463	0.252	0.357	0.305	0.410
A_2	0.353	0.576	0.465	0.520	0.409
A_3	0.040	0.156	0.098	0.127	0.069
A_4	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
A_5	0.938	0.936	0.937	0.936	0.937
A_6	1.000	1.000	1.000	1.000	1.000

According to the results obtained, the final ranking of the alternatives is as follows: **A_4, A_3, A_1, A_2, A_5** and **A_6.**

[6] According to the last analysis of the media market in Serbia, conducted by Ipsos Strategic Marketing Agency in 2015 (Regulatory Body for Electronic Media, 2015), the television is the leading medium, with a market share of 53%, the press accounts for 20%, and the radio accounts for 4% (the other media account for a market share of 23%).

[7] The number of repetitions in one day (i.e. 24 hours).

5. Sensitivity Analysis

When applying methods of multi-criteria decision-making, it is crucial to examine the sensitivity of the mathematical model applied, so that decision-makers could have some kind of guarantee according to the rationality and quality of the obtained solution (Pamucar et al. 2016). The analysis of the sensitivity of the results obtained by the hybrid model implies the examination of changes in the weights of criteria and on the consistency of the solution with respect to a change in the measurement scale (Pamucar et al. 2017).

When examining change in the weight of the criteria, a total of six scenarios were developed (Table 8) (A – the equal importance of all the criteria, B – the absolute dominance of K_1, C – the absolute dominance of K_2, D – the absolute dominance of K_3, E – the absolute dominance of K_4, F – the absolute dominance of K_5). Within the framework of the independence analysis regarding change in the measurement scale, a total of two scenarios were developed (Table 9). In the first scenario, the qualitative criterion (K_4) was given by the two different scales (S_1 and S_2) connected by a positive affine transformation ***(y = 2x – 1)***. In the second scenario, the quantitative criterion (K_5), which represents the media access cost, expressed in cash units is was given by the two different scales: (S_1) in RSD (Republic of Serbia's Dinar) and (S_2) in euros.

Table 8. The sensitivity analysis of change in the weights of the criteria

Scenario	A	B	C	D	E	F
Alternatives	Alternatives rank					
A_1	4	4	3	5	3	2
A_2	1	2	5	3	4	3
A_3	5	6	2	4	1	6
A_4	3	1	1	1	5	1
A_5	6	3	6	6	6	4
A_6	2	5	4	2	2	5

Table 9. The independence analysis of change in the measurement scale

Scenario	Scenario 1		Scenario 2	
	S_1	S_2	S_1	S_2
Alternatives	Alternatives rank			
A_1	5	5	5	5
A_2	3	3	3	3
A_3	2	2	2	2
A_4	1	1	1	1
A_5	5	5	5	5
A_6	6	6	6	6

6. Discussion and Conclusion

According to the results obtained by conducting a sensitivity analysis of the developed hybrid model for the purpose of the selection of the best medium for informing the population in situations of emergency and with respect to the research studies (Pamucar et al. 2018), a conclusion can be drawn that the hybrid AHP-VIKOR model is completely applicable in the cases of solving the treated problem and satisfies the set goal. The sensitivity analysis of change in the weights of the criteria shows that the hybrid model is sufficiently sensitive and that it keeps alternative priorities (in this particular case, Alternative A_4 is favored). Furthermore, checking the consistency of the solution by changing the measurement scale shows that the model is stable and that it generates sustainable solutions. By an analysis of all of the results obtained, it is possible to conclude that the application of the AHP and VIKOR methods can significantly help decision-makers to come to the necessary solution.

The proposed model examined in the paper represents an integration of the AHP and VIKOR methods, where the AHP method is used to determine the weight coefficients of criteria within the process of the selection of the best medium for informing the population in situations of emergency, whereas the VIKOR method is used to rank the obtained alternatives and find the optimal solution. The model has been verified through the media selection process inside the territory of a certain municipality by six different alternatives. The results obtained by the application of the model show that Alternative no. 4 is the best solution in all the scenarios with different values of the criteria. In comparison with the hybrid model, Alternative no. 4 has a priority engagement. Taking into consideration the fact that situations of emergency are concerned in this case, it is not only enough to depend on one single medium, but the competent staff in charge of situations of emergency will engage all available media. This means that informing the population would certainly be performed through the television, the radio, print media, and mobile communications. The early warning, informing and alerting system would be used for signal transmission. The sensitivity analysis has shown the stability of the results obtained by the application of the model in all of the considered scenarios.

The presented application of the hybrid model provides an unbiased aggregation of experts' choices by taking into consideration all the inconsistency and subjectivism of group decision-making. Apart from the expressed contribution, it is essential to emphasize the authors' attempt to apply this model in situations of emergency, which are characterized by uncertainty and a lack of time as well, the large amount of information and crisis decision making. The development of such models contributes to the literature in which the theoretical and practical application of multi-criteria techniques is subjected to review. The suggested model enables the evaluation of alternatives despite the imprecision and lack of quantitative information in the decision-making process. By applying the developed approach, problems concerning multi-criteria decision-making and the evaluation and selection of a medium for informing the population in situations of emergency can easily be dealt with. The model can be applied to making various decisions. It is also applicable in the process of decision-making within the staff in charge of situations of emergency in situations of emergency. The flexibility of the model is proven by the fact that its verification can be performed by applying any type of multi-criteria decision-making methods.

Further research studies regarding this paper should refer to the application of this and similar models in combination with other methods and the development of a new method, which would lead to the enrichment of this highly applicable scientific area.

Situations of emergency are the state of the endangerment of social stability with great implications for the life and health of people, the state of material goods and the environment. Therefore, every contribution to the improvement of the decision–making system of the staff in charge of situations of emergency is also a contribution to prevention and reaction in case a danger occurs.

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ACCIDENTS IN FACILITIES FOR STORING HAZARDOUS MATERIALS

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Abstract. *The vital elements of numerous industrial plants include the process equipment which, depending on the nature of the technological process, can be exposed to internal pressure in the general case of a variable size. The typical examples of process equipment are available at LPG stations (distribution centers), fuel tanks, gas boilers, combustion plants, etc. Practical experience and the analysis of the cause of accidents have shown that damage to process equipment is most often followed by the explosions of the tanks in which the flammable substances, such as LPG, petrol, diesel and jet fuel, oils, etc. are stored. The explosion of a tank cannot occur spontaneously, but only results from external factors. This means that the explosion of process equipment is preceded by the primary events whose harmful effects are manifested through the following phenomena: the weakening of the strength of a tank, an increase in pressure above the nominal value, or a combination of the two preceding cases.*

Key words: *risk assessment, accidents, hazardous materials, process equipment, domino effect, BLEVE.*

1. Introduction

The rapid industrial development of the world's leading economies requires the increasing use of hazardous substances and chemicals in many segments of social activities. Modern production conditions and strict market demands in achieving certain product properties require the presence of hazardous substances in many processes that emerge from the framework of the petrochemical industry with a relatively small product range, which has been the case in the past decades with developing countries. Today, hazardous substances are present in all social spheres,

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ranging from industrial plants, agriculture, and medicine to national security and everyday use in the household.

The inevitable followers of hazardous substances are their hazardous characteristics that can adversely affect human or animal health and the environment in a direct or indirect manner.

The distribution of accidents within the logistics system is based on the elementary structure of logistics subsystems and has five discrete states: production, storage, reloading, transport, and use (Tanackov et al. 2018). On the one hand, no direct risk modeling in the production, storage, handling and transport of hazardous substances can be performed. The concept of dangerous goods operations is heterogeneous, starting with a range of hazardous materials, transport supplies, installed equipment, traffic intensity, the distribution concept, employee training, etc., whereas on the other, it is indirectly possible within statistical probabilities, i.e. within data from accidental databases. These data are the expensively paid mistakes that are measured by human lives, great material damage and long-term environmental consequences. The databases such as MHIDAS, MARS, FACTS, MAHB, CARAT, ARIP, NEDIES, ECCAIRS, and IRDAT represent *a posteriori* significant data in risk modeling.

Accidents in the system of hazardous substances, such as a chemical release, a fire, an explosion or the BLEVE effect, may cause great catastrophic consequences not only for employees in their workplaces, but also for the residents and the environment. In addition, the financial losses caused by damage on objects (parts of production plants, tanks) are enormous, and rehabilitation and their re-entry into operation require a lot of time. These effects also result in other serious influences, such as, for example, the inability to provide sufficient quantities of raw materials to connected and/or related industries.

The development of the oil and chemical industry has caused the use of large and complex facilities in their plants, resulting in a large increase in the storage space (tanks of different shapes and dimensions). In the meantime, due to the use of land (a lack of space) and for economic reasons, the distances between installations and warehouses have become increasingly smaller. This branch of industry continues to develop in the direction of intensive and deep processing, chemical processes end up mainly through a series of physical and chemical reactions, and their main raw materials and products are in the liquid and gaseous states that are toxic, flammable and corrosive (Liu, Zhang, & Xu, 2013). Therefore, risk for oil and chemical plants has dramatically increased, in particular so when the risk of explosions and fires is concerned.

In the case of an accident (a fire or an explosion), and bearing in mind all of the foregoing, there may be a chain disaster, and therefore it may endanger human lives, environmental safety, and material assets, and may also cause high environmental pollution, as well as other secondary consequences (Yu & Guan, 2016), (Pasley & Clark, 2000), (Kim et al. 2009).

Accidents in the process industry are most frequently a result of the release of hazardous materials, fires and explosions of process installations (Hemmatian et al. 2014.). The effect of the technical-technological connection of process installations is such that the occurrence of an accident in one part of the plant may lead to the escalation and occurrence of a series of cascade accidents – a domino effect (Abdolhamidzadeh et al. 2011), (Dabra et al. 2011). The storage of eco-friendly substances, such as TNGs, is particularly characteristic from the aspect of the appearance of a domino effect and the escalation of the initial incidents. A domino effect is a very important phenomenon in the process industry and was specifically referred to in the first version of the Seveco Directive (European Council Directive 82/501/ECC). The modifications of this Directive prescribe that the dangers of a domino effect must be assessed differently, depending on whether they work on indoor or outdoor industrial plants and whether they are reflected in the application of Directive 96/82/EC and 96/82/EC, or not. The occurrence of fire within technological installations is predominantly preceded by a discharge of inflammable liquids, gases or vapors (Bariha et al. 2016). The explosions of process equipment are most often due to the BLEVE effect or a mechanical damage caused by the fragmentation of fragments (Eckhoff, 2014), (Sun et al. 2015). The phenomenon of the fragmentation of a tank is characterized by the cause-effect relationship between the cascading events in the accidental chain (Khan & Abbasi, 1999). The occurrence of critical pressure in process equipment can be due to a mechanical (physical) explosion, a cold or warm BLEVE effect, a closed explosion or uncontrolled chemical reactions.

Failures on the installations and a potential escalation of accidents due to the fragmentation of process equipment are characterized by a high degree of uncertainty (Khakzad et al. 2018). Therefore, the analysis of a domino effect implies a previously conducted assessment of the fragmentation risk since the subsequent fragmentation of damaged process equipment establishes a potential accidental chain. The intensive development of the modern processing industry is characterized by a considerable risk of large-scale domino effects. The prevention of potential accidents is conditioned by the use of fragmentation barriers (Landucci et al. 2016), (Kang et al. 2016), the identification of the fragmentation mechanism (Baker et al. 1983), and the basic characteristics of the primary fragments that are defined by the number, shape, velocity, and trajectory (CCPS, 1994). The procedure for predicting the number and the mass of the fragments of cylindrical storage tanks for LPG was proposed by Baker et al. (Baker et al. 1997). The results of their study were the basis for several recent research studies in the field of the fragmentation of tanks (Hauptmanns, 2001), (Hauptmanns, 2001a). The purpose of fragmentation analysis is to prevent the installations and equipment of process plants from potential fragment impacts (Sun et al. 2017). The escalation of a potential damage to process installations is prevented by using the fragmentation barriers first implemented in nuclear installations (Moore, 1967).

Risk assessment due to the fragmentation of pressure vessels requires adequate hazard modelling, and the creators of the first fragmentation models were Moore and Baker (Moore, 1967), (Baker et al. 1983). In 77% of accidents, fragmentation was a result of the explosions of the pressurized vessels generating from 1 to 9 fragments (Holden & Reeves, 1985). Holden found that 60% of the generated fragments covered a sectoral angle of ±30° on both sides of the tank (Holden, 1988). Some recent studies have been based on the results of these studies (Mébarki et al. 2009), (Mébarki et al.2009a). Mébarki et al. suggested an entropy model for estimating the number of generated fragments (Mébarki et al. 2009). The typical explosions of tanks following industrial accidents were related to the BLEVE phenomenon (Eckhoff, 2014), (Zhang et al. 2016). Risk assessment due to the fragmentation of a tank involves modelling the fragment flight, and in the literature a simplified model for fragmentation analysis has exclusively been applied (Mannan, 2012).

2. BLEVE Effect

Among different possible major accidents, Boiling Liquid Expanding Vapor Explosions (BLEVEs) keep occurring from time to time. A number of pieces of equipment and activities such as: steam boilers, liquefied gas storage tanks, road and rail tankers, etc. can originate them (Hemmatian et al. 2019). Boiling Liquid Expanding Vapor Explosions (BLEVEs) are a major accident which can have severe consequences; they occur from time to time, both in fixed plants and in the transportation of hazardous materials. Overpressure and the ejection of vessel fragments are the common effects of such an explosion; these can be followed by a fireball if the substance is flammable. If a tank containing liquid or a liquefied gas is subjected to thermal loading from a fire, an explosion of the tank is possible. Such an event is called a BLEVE (Boiling Liquid Expanding Vapour Explosion) (Marshall, 1987), (Baker et al. 1983). If a liquid or a liquefied gas is combustible, a fireball (a large-scale diffusion flame with strong thermal radiation) is formed. During the destruction of the tank, the shock waves of a high amplitude are produced. Accidents involving BLEVE are characterized by the severe destruction of the plant, with people being killed. Such accidents took place in Fazen, France (1966), Mexico (1984), and Alma-Ata, Kazakhstan (1989). The serious consequences of BLEVE and a damage to the vessels containing LPG subjected to fire have drawn the attention of many investigators. Impact failure (44.8%) and the human factor (30.3%) were the most common causes of BLEVEs (Hemmatian et al. 2019).

The fragmentation of a tank due to the BLEVE effect is usually followed by the generation of two or three fragments, and very rarely four or five fragments (Nguyen et al. 2009). The fragmentation of a tank due to the BLEVE effect is characterized by the obligatory fire occurrence in the case of the generation of a smaller number of fragments (Mishra, 2016). In the literature, the assessment of the number of generated fragments is carried out by means of the entropy model using accident data (Mébarki, 2009). The number of generated fragments in the explosion of a tank is usually up to five, and very rarely exceeds nine (Holden, 1985), (Holden,1988). Nguyen et al. state that, according to the scientific reports of the INERIS, typical explosions (BLEVE) of cylindrical tanks are most often followed by the generation of two or three primary fragments (Nguyen, 2006). The application of the entropy model requires the mandatory inclusion of accident data (Sun et al. 2012). The accidents accompanied by the explosion of a tank are distinguished by the three effects: a blast wave, thermal radiation and fragmentation. The fragmentation of a tank is followed by the generation of primary fragments, while the blast wave initiates the formation of secondary fragments. Thermal radiation is a result of the formation of a fireball, whose influence in the explosion of the LPG tank having a volume of about 50 m^3 is manifested at the distances of up to 170 m, whereas the effect of secondary fragments is intensely expressed at the distances of up to 125 m (Plans et al. 2015.). The most pronounced effect of the explosion of a tank relates to fragmentation, since the range of fragments can reach as far as 1.2 km (Tugnoli et al. 2014).

BLEVE affects the previous occurrence of an incident in the form of a fire in the immediate vicinity of the tank, most often due to a discharge of inflammable substances or as a result of some other cause. A thermal impact on the walls of the tank is manifested by a reduction in the resistance of the material (a tensile strength), so that the destruction of process equipment will follow a lower critical pressure than the normal value (a value corresponding to a no-fire effect). The temperature effect is exclusively reserved for the BLEVE effect as there is not enough time for the other types of explosion to transfer heat to the walls of the tank (for example, in an uncontrolled chemical reaction, etc.).

Each type of indoor explosion (a tank) must be accompanied by shock waves, and in the case of fire-extinguishing substances by the emergence of a fireball (thermal radiation), too. The amount of these energies depends on the type of the explosion and the type of the dangerous substance. The explosion of toxic substances with non-flammable substances is not accompanied by thermal radiation, but due to the dispersion of toxic substances, additional hazardous substances arise in the form of the contamination of the surrounding area. A hazard due to thermal radiation does not exceed 200 m for an explosion of about 50 m^3 of TNG, whereas a toxic hazard from the same volume with unfavorable meteorological conditions may be up to several kilometers (Djelosevic & Tepic, 2018).

3. The Domino Effect

In terms of production facilities and particularly refineries, it is necessary to focus (in terms of transport and production processes) on storage capacities. The storage capacities consisting of the tanks of different types, sizes and shapes are used for the permanent or temporary storage of different classes of dangerous substances (oil and oil derivatives, gas, high-pressure liquids, various corrosive substances, etc.). When an accident occurs in the production/processing or storage facilities, the physical effects of that particular accident very often lead to a damage to another surrounding equipment. Taking this into account, a relatively small incident can be said to have the ability to escalate into an event causing a damage to a much larger surface and leading to far severer consequences; in practice, it is called a domino effect. Such effects are usually created and caused by the physical effects of primary accidents, such as (Chen et al. 2012):

- overpressure,
- fragments (impact fragments)
- thermal radiation, and
- heat flux.

Darbra et al. (2010) analyzed 225 accidents with the consequences of the domino effect in the processing, storage and transport plants in the period since 1961. On this occasion, the following aspects were analyzed: the accident scenario, the type of the accidents, the class/type of the substance, the causes and the consequences, as well as the most frequent accidents sequences. The analysis established the fact that the most common causes were: the external losses of 31% and the mechanical errors of 29%. Even 35% of the domino-effect accidents happened in the storage area, whereas 28% of them occurred in the processing plants. The flammable substances included 89% of the accidents, most of which were LPG. In the largest number of the cases, the damaged equipment has no ability to resist, thus leading to a leakage and a loss of hazardous material and additional scenarios:

a) explosion → fire (27.6%),
b) fire → explosion (27.5%), and
c) fire → explosion (17.8%).

The definitions of a domino effect contain the following three concepts (Cozzani et al. 2006), (Antonioni et al. 2009), (Nguyen et al. 2014):

1. a "primary" event (fire, an explosion) that occurs in a certain unit;
2. the propagation of the accident towards one unit or a larger number of units or plants, in which "secondary" accidents are triggered as a result of the primary event;
3. an "escalation" effect leading to a general increase in consequences, with such secondary accidents being severer than the primary one.

The oil and chemical industry include many flammable and explosive chemicals for production and storage, and manufacturing processes are performed at high temperatures or high pressures. There are many different pieces of pressure equipment in industrial plants, such as tanks (cylindrical, elliptical, and torispherical) containing gas (LPG) or high-pressure liquids. When it reaches a critical level of high pressure, overheating or mechanical stress, the tank can suddenly explode and generate many fragments (one or more, depending on the critical pressure, the crack propagation, the type of the material and the connection of the basic mechanical components) that pose a threat to another equipment or other adjacent tanks. So, the fragments caused by the explosion of the tank have an effect on other tanks, and this effect is reflected in a partial or complete breakdown and/or damage to adjacent tanks and equipment. Fragments are of different shapes, sizes, initial speeds, and initial departure angles (horizontal and vertical). According to the INERIS expert reports, a typical explosion (BLEVE) of a cylindrical tank creates a limited number of massive fragments, mainly two or three, and very rarely more than four or five.

4. The Probability of a Domino Effect

The accidents characterized by an explosion of process equipment in an installation are usually followed by a sequential sequence of events (a domino effect); so, in order to analyze risk, it is necessary to know the probability of the occurrence of the primary and secondary events of the observed accident chain. In this context, the probability of the occurrence of a domino effect requires the knowledge of the probabilistic probabilities of the consequent-causal events of one cycle of the emergency chain. The probability of producing a domino effect is presented by (1), if the primary and secondary events are marked as PD and SD, respectively.

$$P(PD \cap SD) = P(PD) \cdot P(SD \mid PD) \tag{1}$$

As is known from the theory of probability, the formulation (6.10) shows that the realization of a secondary event is dependent on the realization of the primary event that is the first in an accidental chain. The primary event is an independent event in an accidental sequence and has the role of linking multiple sequential events into a unique accidental chain. The conditional likelihood of the occurrence of a secondary event, provided that the outcome of the primary one is completely certain, has the following form:

$$P(SD \mid PD) = \frac{P(PD \cap SD)}{P(PD)} \tag{2}$$

It is important to point out the fact that the analysis of a domino effect in research studies is based on a conceptual misinterpretation since it interprets the probability of an accidental sequence without the probabilistic probability of primary and secondary events. In this way, the independence of events in an accidental chain is established, which is contrary to logical and mathematical principles. The basic risk factor for a hazard that can be the generator of a domino effect encompasses the probability of its occurrence and, therefore, great attention is paid to this phenomenon for this very reason.

The occurrence of a chemical accident during the technological process in the industrial plant for the production (processing) of hazardous substances is illustrated by the principle of the Bajes network. In order to simplify the considered illustration, that there are only two causes in the occurrence of the accident, namely the human factor and the unreliability of equipment, will be assumed.

The variables representing the human factor and the reliability of equipment are indicated by *HU* (Human Factor) and *RE* (Reliability of Equipment), respectively. Assign an expert assessment of the potential causes of a chemical accident due to *HU* and *RE* the following probabilities: $P(HU = yes) = p$ or $P(RE = no) = q$, respectively. If chemical accidents are marked as *ChmA*, and if it is supposed that a) the organized HU behavior is in accordance with the prescribed procedure, and that b) the embedded process equipment works reliably, then the technological process takes place normally without any hint of a possible accident and the same is valid: $P(CA = yes \mid HU = no, RE = yes) = 0$. However, the probability of the occurrence of an accident due to unreliable process equipment reads as follows: $P(CA = no, RE = no) = ½$. Since *HU* manages the work of the technological process, any significant deviation from the procedure of working with dangerous substances inevitably leads to the occurrence of an accident. This may be a result of unintentional omissions due to the irresponsibility of *HU* (the management or direct executors) and the preplanned organized activities in the form of sabotage, regardless of the motives for such actions. The probability of the occurrence of an accident, if caused by the harmful effects of *HU*, regardless of the degree of the reliability of process equipment, is as follows:

$P(CA = yes \mid HU = yes, RE = yes) = 1$ and $P(CA = yes \mid HU = yes, RE = no) = 1$.

The probability of the occurrence of an accident may be expressed based on the previous analysis by applying the following equation:

$$\begin{aligned} P(CA = yes) &= \sum_{HU,RE} P(CA = yes, HU, RE) \\ &= \sum_{HU,RE} P(CA = yes \mid HU, RE) \cdot P(HU \mid RE) \cdot P(RE) \\ &= \sum_{HU,RE} P(CA = yes \mid HU, RE) \cdot P(HU) \cdot P(RE) \end{aligned} \tag{3}$$

where $P(HU \mid RE) = P(HU)$ as a consequence of the assumption of the independence of HU and RE events. Then, after developing the sum of (3), the following equation is obtained:

$$\begin{aligned}P(CA=yes) = {} & P(CA=yes \mid HU=no, RE=no)\cdot P(HU=no)\cdot P(RE=no) + \\ & P(CA=yes \mid HU=yes, RE=no)\cdot P(HU=yes)\cdot P(RE=no) + \\ & P(CA=yes \mid HU=no, RE=yes)\cdot P(HU=no)\cdot P(RE=yes) + \\ & P(CA=yes \mid HU=yes, RE=yes)\cdot P(HU=yes)\cdot P(RE=yes)\end{aligned} \tag{4}$$

$$\begin{aligned}P(CA=yes) & = \frac{1}{2}\cdot(1-p)\cdot q + 1\cdot p\cdot q + 0\cdot(1-p)\cdot(1-q) + 1\cdot p\cdot(1-q) \\ & = \frac{1}{2}\cdot q\cdot(1-p) + q\end{aligned} \tag{5}$$

where p and q represent, respectively:

the probability that the cause of the accident (CA) will be the human factor (HU = *yes*): $p = P(HU = yes)$, and the probability that CA will be equipment unreliability (RE = *no*): $q = P(RE = no)$.

These probabilities are a result of an expert assessment and can be obtained on the basis of statistical monitoring for HU, or according to the analysis of the reliability of process equipment in the real conditions of exploitation for RE. Adopting, for example, that $p = 0.10$ and $q = 0.15$, the probability of *ChmA* has the value $P(CA) = ½·q·(1-p)+q = ½·0.10·(1-0.10)+0.15=0.195$.

The obtained probability $P(CA) = 0.195$ represents the "*a priori*" probability of a chemical accident (CA) before observing any evidence.

$$\begin{aligned}P(HU=yes \mid CA=yes) & = \sum_{RE} P(HU=yes, RE \mid CA=yes) \\ & = \sum_{RE} \frac{P(CA=yes \mid HU=yes, RE)P(HU=yes)P(RE)}{P(CA=yes)}\end{aligned} \tag{6}$$

$$\begin{aligned}P(RE=no \mid CA=yes) & = \sum_{HU} P(HU, RE=no \mid CA=yes) \\ & = \sum_{HU} \frac{P(CA=yes \mid HU, RE=no)P(HU)P(RE=no)}{P(CA=yes)}\end{aligned} \tag{7}$$

By developing the sum in (6) and (7), and by replacing the concrete probability values, the following equation is obtained:

$$\begin{aligned}P(HU=yes \mid CA=yes) & = \frac{1\cdot p\cdot(1-q) + 1\cdot p\cdot q}{\frac{1}{2}\cdot q\cdot(1-p) + q} = \frac{2}{3-p} \\ & = \frac{2}{3-0{,}10} = 0{,}689\end{aligned} \tag{8}$$

$$\begin{aligned}P(RE=no \mid CA=yes) & = \frac{1\cdot p\cdot q + \frac{1}{2}\cdot(1-p)\cdot q}{\frac{1}{2}\cdot q\cdot(1-p) + q} = \frac{1+p}{3-p} \\ & = \frac{1+0{,}10}{3-0{,}10} = 0{,}379\end{aligned} \tag{9}$$

5. Theoretical Analysis of a Tank

Horizontal cylindrical tanks for TNG storage are responsible technical systems designed according to EN 13445-3 (EN 13445-3:2014). The projected exploitation characteristics and the achieved quality of production are checked by testing the tank according to EN 13445-5 (EN 13445-5:2014). The two-axis stress state of the tank indicates the longitudinal and radial deformation of the shell. The analysis of the stress state of the tank is an integral part of the design activities in terms of fulfilling exploitation requirements. A typical shape of the horizontal cylindrical tank discussed in the continuation of this paper is presented in Fig. 2. The construction of the tank consists of the supports (item 1), the cylinder segments (items 2-5), the elliptical end caps (item 6), and the lifting lugs (item 7). The tank is supplied with the filling and discharging system (FDT), the measure and control system (MCS), the inspection hatch (IH), and the safety valve (SV). The empty tank mass is 12.3 t and provides storage of up to 50 m³ of TNG.

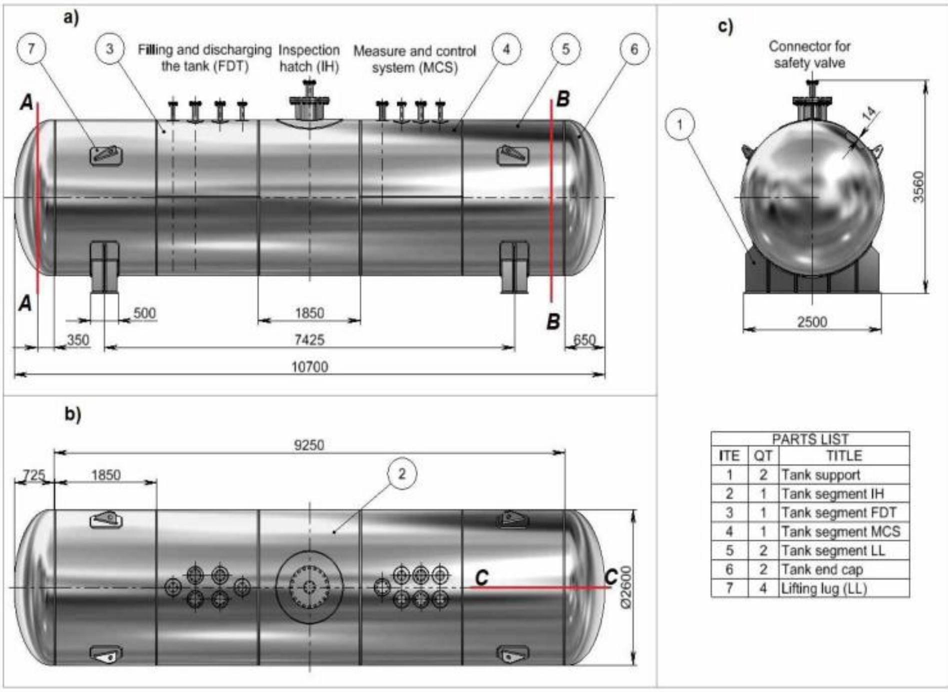

Figure 1. A horizontal cylindrical tank with the elliptical end caps according to DIN 28013

Horizontal cylindrical tanks have three critical cross-sections (Figure 1). The A-A critical cross-section is characteristic of tanks with torispherical end caps, whereas elliptical end caps influence the tank fracture at the B-B cross-section (Figure 1a). The fracture along the C-C cross-section exclusively occurs in tanks with spherical end caps (Figure 1b). The wall thickness of the tank is constant δ = 14 mm (Figure 1c). This condition is of great importance in the fragmentation model for the assessment of the initial velocity.

The critical zone of the tank in Fig. 1 corresponds to the passage of the cylinder into the elliptical end cap (B-B cross-section).

The critical zones of the cylindrical tank are estimated according to (10) and (11), derived from the basis of the substrate in (Ciarlet, 2000).

$$\sigma_{x,\max} = \sigma_x(x = 0.082m) = \left[1 + 0.292685 \cdot \left(\frac{D}{2h}\right)^2\right] \cdot \frac{D}{4} \cdot \frac{p}{\delta} \approx 100 \cdot p \quad (10)$$

$$\sigma_{\theta,\max} = \sigma_\theta(x = 0.195m) = \left[1 + 0.031418 \cdot \left(\frac{D}{2h}\right)^2\right] \cdot \frac{D}{2} \cdot \frac{p}{\delta} \approx 104 \cdot p \quad (11)$$

Authoritative stress for dimensioning the pressure vessel is given by (11). Permissible tress for the S355J2G3 (the tank material) is 195.83 MPa. The maximum operating pressure according to (11) is 1.88 MPa, whereas EN 13445-3 prescribes 2.12 MPa. The operating pressure of the LPG storage tank ranges from 16.4 to 16.9 bars (which is an average of 16.7 bars). Rationally designed tanks are characterized by a minimum difference $\sigma_{x,\max}$ and $\sigma_{\theta,\max}$, which is achieved by a D/2h ratio.

In the case under consideration, D/2h = 2; so, it follows $\sigma_{\theta,\max}/\sigma_{x,\max}$ = 4%. The critical zone is conditioned by the criterion (D/2h) = 2.086. The critical zone 1 is considered only if the tank head is elliptical. Then, it is always (D/2h) < 2; so, fragmentation is most often followed by the separation of the end cap from the tank cylinder due to the expansion of the fracture lines by circumference ($\sigma_\theta > \sigma_x$). The critical zone 3 dominates when $\sigma_\theta < \sigma_x$ (the hemisphere head); otherwise, the B-B cross-section is authoritative (Fig. 2). The estimation of critical zones according to (10) and (11) is limited to the generation of a smaller number of fragments due to the BLEVE effect.

The real stress of the tank varies between (10) and (11) due to the axial asymmetry. Therefore, the fragmentation of the tank generally requires the identification of real stress through software structural analysis. Figure 2 shows the critical areas of a cylindrical tank.

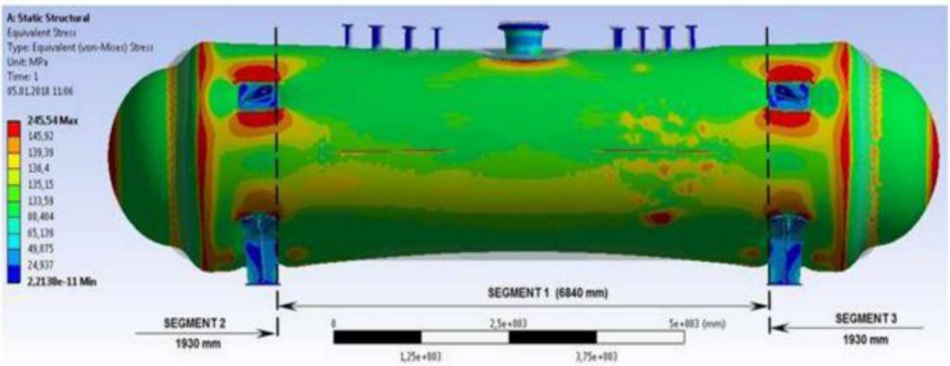

Figure 2. The software simulation of the critical zones of the tank (the pressure of 16.7 MPa)

When the crack spreads faster than the leakage of the fluid/liquid, an explosion of the tank occurs, where fragments are created, the size and velocity of which depend on the type of the cracks, i.e. the brittleness and flexibility of the material. The fragments projected due to the explosion of the tank can affect and damage adjacent objects and tanks in their surroundings. If these affected objects are, for example, pressurized containers, there is a risk that an explosion will occur, which would produce another set of projectiles/fragments. Such fragments can affect other devices and generate next explosions, thus leading to a scenario known as the "domino effect" (Ciarlet, 2000), (Cozzani et al. 2007), (Hauptmanns, 2001a), (Hauptmanns, 2001b), (Khan & Abbasi, 2001a), (Khan & Abbasi, 2001b), (Khan & Abbasi, 2001c), (Cozzani et al. 2009).

According to (Cozzani et al. 2007), (Baum, 1998a), (Baum, 1999b), (Baum, 2001c), (Cozzani, et al. 2006), when speaking about the reliability of industrial facilities and plants under possible explosions, it is necessary to observe and include the following development steps:

1. the analysis of conditional sources – the identification of the potentials of the plants/objects in which an explosion may occur, the knowledge of the conditions that may initiate/lead to an explosion, as well as the knowledge of the geometric dimensions, shapes, speed and frequency of the angles of the caused/generated projectiles;
2. the analysis of the influential term – the knowledge of the conditions that may cause/create the influence of other plants/facilities, the knowledge of the mechanical and geometric properties of the affected targets, the knowledge of impacts such as perforations or a partial penetration/break, as well as a possible creation of a new set of projectiles as a result of the failure/malfunction or explosion of the affected object/tank; and
3. the assessment of the reliability of the plants and facilities, and the consequences of the same.

Risk analysis in industrial plants often considers that random explosions generate the given categories and forms of structural fragments (Fig.3), i.e. standardize projectiles, the speed of which depends on the arbitrary ratio of the total energy. In addition, a detailed analysis is needed to assess the risk of the impact and the mechanical damage that may occur on the surrounding facilities and/or tanks.

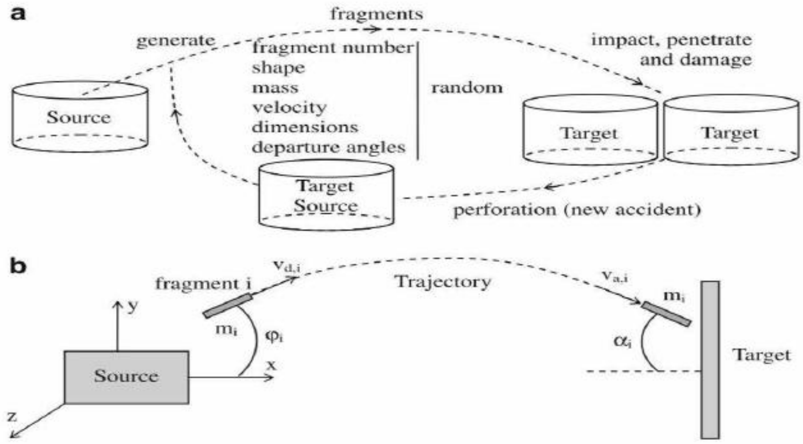

Figure 3. The projectile penetration, a residual resisting target thickness and the domino effect, a) a global view, b) a bi-dimensional model (Nguyen et al. 2009)

Fragments can be generated by various characteristics, such as the geometric shapes and dimensions, mass, velocity, and angles of the projection. If fragments affect the target (another tank), they can penetrate either completely or partially. The generated fragment penetrates partially or completely the second tank, which can cause an explosion of the adjacent tank (Fig.3).

Sophisticated mechanical models are necessary or may be required in order to analyze these dynamic effects and their consequences. Earlier reports (Gubinelli et al. 2004), (Yu, & Guan, 2016) show that there are generally three forms of generated fragments after industrial accidents or tank explosions, namely cylindrical, half-sphere, or plate (Fig.4).

In addition, the valve parts, as well as the tubular parts, may also be transformed into cylindrical shapes during the explosion. Obviously, the impact of a fragment may occur with any value of the angle between the fragment and the target, i.e. the second tank.

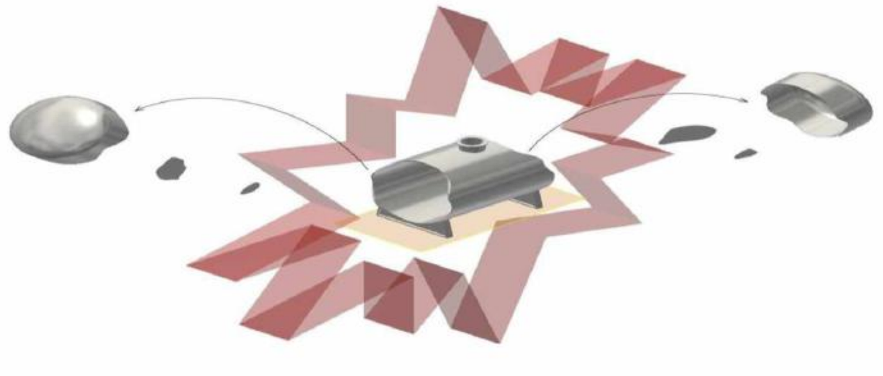

Figure 4. An illustration of fragmentation after a tank explosion

The equation of the motion of the generated fragments is presented below.

The vector form of the equation of motion of the fragment with mass m_{fr} and velocity v_{fr} is (Mébarki et al., 2009) is as follows:

$$m_{fr} \cdot \frac{d\vec{v}_{fr}}{dt} = \vec{W}_D + \vec{W}_L + \vec{G} \tag{12}$$

The force of air resistance in the fragment flight is as follows:

$$\vec{W}_D = -\left(\frac{1}{2}\rho_v C_D A_D v_{fr}\right) \cdot \vec{v}_{fr} \tag{13}$$

The lift force of the fragment in flight is as follows:

$$\vec{W}_L = -\left(\frac{1}{2}\rho_v C_L A_L v_{fr}\right) \cdot \vec{v}_{fr} \tag{14}$$

6. Conclusion

Critical infrastructures play a key role in the normal performance of economies and society. Many hazardous industrial activities provide society with indispensable goods and services. Some of these activities are considered as particularly critical, such as refining, oil and gas transport and distribution, or the production of rare specialty chemicals due to their criticality for ensuring human wellbeing and the smooth functioning of society. Over the past decades, the quantity and diversity of the critical infrastructure have grown rapidly and the interdependence between them has steadily increased. Therefore, an increasing number of the basic services depend on the continuous performance of one, two or more critical infrastructures, such as electricity and water supply, communications, etc.

Observing and reviewing the extreme events that have taken place over the past two decades have revealed that, although the interdependence between critical infrastructures is rapidly rising and becoming more complex, yet there is a huge gap between an increased risk and the actual readiness of the critical infrastructure to respond to extreme events such as accidents. It is also necessary to note that in addition to mechanical and technical causes, there are the external causes of accidents, i.e. natural disasters (e.g. earthquakes, tsunamis, etc.) that need to be analyzed given the fact their consequences are not negligible (e.g. Fukushima 2011).

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EVALUATION OF SUSTAINABLE RURAL TOURISM POTENTIAL IN BRCKO DISTRICT OF BOSNIA AND HERZEGOVINA USING MULTI-CRITERIA ANALYSIS

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Abstract. *For investment decisions to be made in tourism sector, it is necessary to determine tourism potential on the first place. Tourism potential is the ability of a particular location to attract and host tourists. Tourism development should be based on strengthening sustainability, and thus tourism will provide good effects. Since rural settlements have experienced recession in the past few decades, these areas need to be revitalized. This can be achieved through development of rural tourism. Sustainability of rural tourism potential in Brcko District of Bosnia and Herzegovina is in focus of this study. Based on sustainability criteria, we assessed the rural potential in Brcko District of Bosnia and Herzegovina for certain rural settlements. Assessment of the sustainability of rural tourism potential in Brcko District of Bosnia and Herzegovina was carried out with expert evaluation and used methods of FUCOM, ARAS and CRITIC, and a decision model will be created for this purpose. The findings from this study will provide guidelines for improvement of rural tourism in Brcko District of Bosnia and Herzegovina through examination of good and bad sides of the examined rural settlements. The model with certain corrections can also be used in determining sustainable tourism potential in other branches of tourism.*

Key words: *rural tourism, sustainable tourism, tourism potential, multi-criteria analysis, Brcko District Bosnia and Herzegovina*

1. Introduction

Tourism represents an economic branch which provides a basis for economic growth and development of the world economy. In some regions tourism contributes to the increase of employment and improvement of economy (Ullah, et al, 2010). Tourism development should be based on the principles of sustainability (Weaver,

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2014). Sustainability in tourism includes three basic criteria: economic, environmental and social. The assessment of these criteria is a requirement to improve tourism. In particular, this is significant in rural areas.

Tourism in rural areas is accepted as a tool for development of these areas (Rozman, et al, 2009). Rural tourism represents a form of tourism in rural areas, all in a natural environment where tourist are being offered various offers and activities (Jesus & Franco, 2016), all of it in an attempt to further develop that rural community and develop the living standard of that population. The main importance of rural tourism is to attract tourists on the basis of a rural tourist offer so that the population's income and living standard could increase, whilst using the already existing resources. Rural tourism attracts tourists that are searching for emotional experiences. The starting point of rural tourism has to be intercultural interaction and a way to bring the rural way of life to the tourists. Thus tourist won't just be passive consumers and the rural population won't be just powerless people who have had tourism imposed on them, instead, a social capital in tourism will develop (Steel, 2012).

The criteria of rural tourism potential can be different. Therefore, it is necessary to apply the principle of a complete evaluation of sustainable tourism potential. This evaluation is performed using the method of multi-criteria analysis. The aim of this paper is to research sustainable rural tourism potential in Brcko District of Bosnia and Herzegovina (hereinafter: Brcko District). This research was done using the decision model. In cooperation with the Government of Brcko District, three experts were engaged in evaluating sustainable rural tourism potential. Based on evaluation from the experts, good and bad side alternatives will be considered. The significance of this paper is to present the new model of research on sustainable rural tourism potential. In this study is presented the new research methodology using multi-criterion analysis methods.

Based on this, the following research objectives are set:

1. Create the model of sustainable rural tourism potential
2. Test the model on the example of the rural settlements of the Brcko District.

This paper will first present methods of multi-criteria analysis and it will explain the model and research methodology. Then, the results of the research will be presented that will be a basis for sensitivity analysis to examine these results. Finally, we will provide the conclusion from the study.

2. Multi-criteria analysis methods

The decision model used in this study is based on the application of the following multi-criteria analysis models: FUCOM, CRITIC and ARAS methods. The advantage of this model is that it takes advantage of these methods. The advantages of the FUCOM method are that it uses a simple algorithm, allows to obtain optimal values of weight coefficients with the ability to confirm the consistency of results, uses a simple mathematical apparatus that favors certain criteria, reduces subjective influence and inconsistency of experts' preferences, gets the same results as the BWM and AHP methods but with by performing a n-1 criterion comparison alone (Pamučar et al, 2018). The CRITIC method allows the criteria to be weighted in an objective manner without subjective evaluations. Criterion weighting using the CRITIC method is performed using statistical parameters standard deviation and correlation coefficient. The ARAS method allows you to determine the ranking of the utility function. This allows the ratio of the optimal alternative to be used in seeking to rank alternatives and to find ways to improve the alternative projects that were the subject of observation (Zavadskas and Turskis 2010). Based on these advantages, the model formation was performed. These methods will be explained below.

2.1. FUCOM method

The FUCOM (Full Consistency Method) method was developed by Pamučar, et al. (2018) for determining the weights of criteria. The FUCOM provides a possibility to validate the model by calculating the error size for obtained weight vectors, by determining the degree of consistency (Mujkanović, et al, 2019). The FUCOM method uses the following steps (Zavadskas, et al., 2018):

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria $C = \{C_1, C_2, \ldots, C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, from the most significant to the less significant.

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

If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of ">" between these criteria in the expression (1)

Step 2. Comparison of the ranked criteria is carried out and the comparative priority ($\varphi_{k/(k+1)}$, $k = 1,2,3,\ldots,n$, where k represents the rank of the criteria) of the evaluation criteria is determined.

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

Step 3. The final values of the weight coefficients of the evaluation criteria $(w_1, w_2, \ldots w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the following 2 conditions:

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

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

b) In addition to the Condition (2), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. $\varphi_{k/k+1} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/k+2}$. Since $\varphi_{k/k+1} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$ $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained.

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

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

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

$$\min \chi, \text{ s.t.}$$

$$\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| = \chi, \forall j$$

$$\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/k+1} \otimes \varphi_{(k+1)/(k+2)}\right| = \chi, \forall j \tag{5}$$

$$\sum_{j=1}^{n} w_j = 1, \forall j$$

$$w_j \geq 0, \forall j.$$

2.2. CRITIC method

The CRITIC method is used in order to determine weight values of objective criteria which include intensity and contrast of the conflict inherent in the structure of decision problem. It belongs to a class of correlation method and is based on analytical testing decision matrix in order to determine information contained in the criteria by which to evaluate the variants. In order to determine the contrast criteria, a standard deviation of normalized criterion is used, as well as value variants, by columns and the correlation coefficients of all pairs of the columns.

The CRITIC method steps are (Puška, et al., 2018a):

Step 1. There is a complex linear normalization. Thus, the initial matrix is converted into a matrix with the generic elements x_{ij}.

Step 2. Each vector has a standard deviation σ_j, which represents a measure of deviation values of variants for a given criterion of some average values. Standard deviation is, in fact, the size which is still used in this method.

Step 3. Then, a symmetrical matrix of dimension *m* x *m* with elements R_{JK} is constructed, which represents the coefficients of linear correlation vector X_J and X_K. The greater the discrepancy between the criterion (value) for (criteria) variants j and k, the lower the coefficient value R_{JK} is. The Spearman correlation coefficient can be used instead of Pearson correlation coefficient.

$$\sum_{k=1}^{m}\left(1-r_{jk}\right) \tag{6}$$

Step 4. The previous term is a measure of conflict criterion *j* in relation to the other criteria in the crucial situation (Milicevic & Zupac, 2011). The subsequent evaluation of the amount of information C_j which is contained or given in the criteria j, therefore it is determined by the combination of the above size and σ_j r_{jk} as follows:

$$C_j = \sigma_j \sum_{k=1}^{m}\left(1-r_{kj}\right) \tag{7}$$

Step 5. The objective criteria weights are obtained by normalizing the size *Cj*.

2.3. ARAS method

The Additive Ratio Assessment (ARAS) method is developed by Zavadskas and Turskis (2010). The process of solving decision making problems using the ARAS method, similarly to the other methods of MCDM, starts with forming the decision matrix and determining weights of criteria. After these initial steps, the remaining part of solving MCDM problem using the ARAS method can be precisely expressed using the following steps (Karabasević, et al., 2015):

Step 1. Determine the optimal performance rating for each criterion. In this step the decision maker sets the optimal performance rating for each criterion. If the decision maker does not have a preference, the optimal performance ratings are calculated as:

$$x_{0j} = \begin{cases} max_i\, x_{ij};\ j \in \Omega_{max} \\ min_i\, x_{ij};\ j \in \Omega_{min} \end{cases} \tag{8}$$

where x_{0j} denotes the optimal performance rating of *j*-th criterion, Ω_{max} denotes the benefit criteria, i.e. the higher the values are, the better it is; and Ω_{min} denotes the set of cost criteria, i.e. the lower the values are, the better it is.

Step 2. Calculate the normalized decision matrix.

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{\sum_{i=1}^{m} x_{ij}};\ j \in \Omega_{max} \\ \dfrac{1/x_{ij}}{\sum_{i=1}^{m} 1/x_{ij}};\ j \in \Omega_{min} \end{cases} \tag{9}$$

where r_{ij} denotes the normalized performance rating of *i*-th alternative in relation to the *j*-th criterion, $i = 0,1,...,m$.

Step 3. Calculate the weighted normalized decision matrix.

$$v_{ij} = w_j\, r_{ij}, \tag{10}$$

where v_{ij} denotes the weighted normalized performance rating of *i*-th alternative in relation to the *j*-th criterion, $i = 0,1,...,m$.

Step 4. Calculate the overall performance rating, for each alternative.

$$S_{ij} = \sum_{j=1}^{n} v_{ij} \tag{11}$$

where S_i denotes the overall performance rating of *i*-th alternative, $i = 0,1,...,m$.

Step 5. Calculate the degree of utility for each alternative. When evaluating alternatives, it is not only important to determine the best ranked alternative. It is also important to determine relative performances of considered alternatives, in relation to the optimal alternative.

$$Q_i = \frac{S_i}{S_0} \tag{12}$$

Where Q_i denotes the degree of utility of *i*-th alternative, and S_0 is the overall performance index of optimal alternative, $i = 1,2,...,m$.

Step 6. Rank alternatives and/or select the most efficient one. The considered alternatives are ranked by ascending Q_i , i.e. the alternative with the largest value of Q_i is the best placed.

3. Model and methodology

Evaluation of sustainable rural tourism potential requires assessment of alternatives by criteria of sustainability: environmental (C1), social (C2) and economic (C3) criteria. These criteria are the main criteria of the model. To see a sustainable rural tourism potential, each of these criteria is further developed into a sub-criterion. Identifying these sub-criteria was based on the following paper: Do & Chen, (2013), Zhou (2014), Zhou, et al. (2015), Mikulić, et al. (2016), Topolansky Barbe, et al. (2016), Peng & Tzeng (2019) and Yan et al. (2017) The model for sustainable rural tourism potential is presented in Figure 1. This model is formed to assess current sustainable tourist potential in the rural area of Brcko District. Four rural settlements make up a sample of four alternatives: Gornji Zovik (A1), Brezovo Polje (A2), Maoča (A3) and Bijela (A4).

To evaluate these alternatives we used expert evaluations. The experts were appointed in cooperation with the Government of Brcko District in the following way. First, we set the list of potential experts which was a basis for selection of experts. In order to conduct the study, three experts were appointed who visited selected areas. Furthermore, all the materials that the Government of the Brcko District has about these areas are presented and used by the experts. Based on this, the experts carried out an assessment of the sustainable rural tourism potential of the Brcko District.

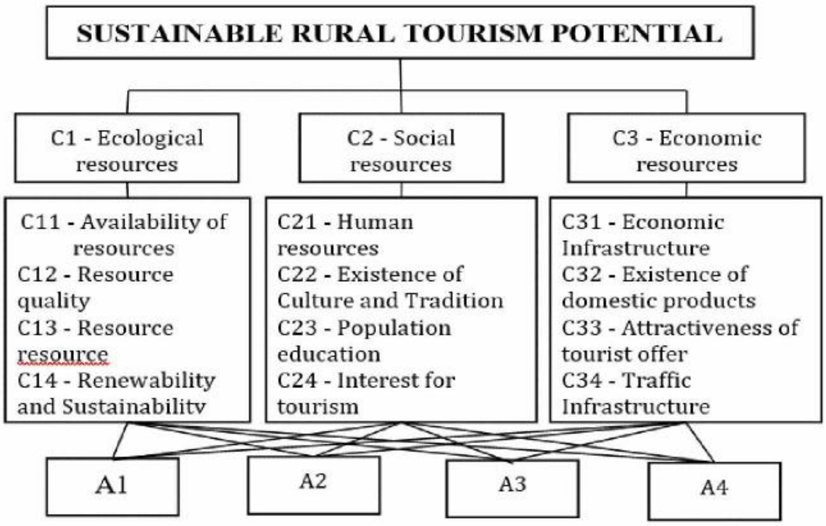

Figure 1. Model of sustainable rural tourism potential

The methodology of the study is presented in Table 1. Based on this methodology one can see how it will be used to particular methods of multi-criteria analysis.

- The FUCOM method will determine the weights of the main criteria;
- The CRITIC method will determine by the weight of sub criteria;
- The ARAS method will rank the alternatives.

Table 1. Methodology of the research

Research Phase	- The decision to study sustainable rural tourism potential. - Selection of criteria based on paper review. - Determining four rural settlements in cooperation with the Government of Brcko District. - Determining experts in tourism in cooperation with the Government of Brcko District.
Determining criteria and alternatives	- Expert evaluation of the weight main criteria using the FUCOM method. - Evaluation of sustainable rural tourism potential rural settlements of Brcko District - Application of the CRITIC - method for determining the weight of the sub criteria
Ranking alternatives	- Use of the ARAS method for ranking sustainable rural tourism potential of Brcko District. - Performing sensitivity analysis of the results.

Four rural settlements in Brcko District area have been used in this study. Each of selected rural settlements will be presented below.

Gornji Zovik is located in the southeastern part of Brcko District. This rural settlement has a variety of natural resources that are intact, preserved and pure, with a large number of potable water sources and uncultivated caves. Above this settlement is the hill Granaš which provides the possibility of applying mountain tourism. In the area of this settlement there are small gardens, decorated orchards and meadows. Nearby is the site of the Svatovsko cemetery with twenty-nine tombstones. In this settlement the sport-cultural and spiritual event called Zovik Summer has been organized. This area also has a large number of old houses dominated by Begova House.

Brezovo Polje is located on the banks of the Sava River. In this settlement is located the Aziza Mosque, which has been placed under the protection of the state. From the old buildings there is Nakic's Tower, which was a strategically military place. The resort is famous for its fishing activities and fishing tradition and is known for its gastronomic offer based on fish. It has swimming pools and swimming beaches. Nearby forests are full of wild game and birds, of which the well-known eagles are the Counts that were here before extinction. Every year, a seven-day event is organized under the name Brezovo Polje Summer of Culture.

Maoča is located below the slopes of Majevica Mountain. Through the settlement flow two rivers along which there are plenty of picnics locations and pine forests. Along the river is the Nožin-agina mosque that has been rearranged to be the museum. This area has rich evergreen and deciduous forests giving clean air. Above

Maoča, there is a locality of Dovište, where they used to learn prayers for rain during the dry days. Residents of this settlement care about customs and traditions. At the end of this village there are rocks with caves, and the area above Maoča is attractive for development of mountain tourism. Every year, the traditional manifestation Trešnjarevo is held, when a wine picking has been organized.

Bijela is located on the Tinja River, which is rich with fish. The local streams that contain two ancient watermills are poured into this river. The famous monument of Beg's tower is known, which is currently being reconstructed and preserved. Above Bijela are the wooded slopes of Majevica. There is the Katina cave, and on the other side are the Dark Caves that are unclean. Above the hamlet of Kalajdžija is the hill Kukavičluk, which springs from the fields of the Ivory Coast. The terrain above Bijela is attractive for development of mountain tourism.

4. Results

For this paper, the FUCOM method for determining the weighting of the criteria was applied.

Step 1. The criteria were ranged from the defined set of criteria, which is shown in the Table 1. Ranking of the criteria according to its significance was carried out by three experts.

Table 2. Rank of criteria

Expert	Rank
E1	C2>C3>C1
E2	C2>C1=C3
E3	C2>C1>C3

Step 2. Comparison of the ranked criteria was done and comparative significance of the evaluation criteria was determined. Expert evaluation of comparative significance is shown in Table 3.

Table 3. Comparative significance of criteria

Expert	Rank		
E1	C2	C3	C1
	1	2	2.3
E2	C2	C1	C3
	1	2.7	2.7
E3	C2	C1	C3
	1	2	2.5

Step 3. Following the steps the FUCOM method and using the Lingo 17 software, the results for the main criteria were obtained. The results are presented in Table 4. The results have shown that the experts favored the social criterion in relation to the other two sustainability criteria. At least importance is given to economic criterion.

Table 4. Weight coefficients of criteria

Expert	w_1	w_2	w_3	DFC (x)
E1	0.225	0.517	0.258	0.000
E2	0.213	0.574	0.213	0.000
E3	0.263	0.526	0.211	0.000
Average	0.234	0.539	0.227	-

After having determined the weights of the main criteria, the alternatives were evaluated according to the sub-criteria. The results of evaluation of the alternative are presented in Table 5. The experts evaluated alternatives ranging from 1 to 7. The score 1 represents the lowest rating, while 7 represents the highest rating.

Table 5. Expert evaluation of the alternative

DM1	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	5	6	5	4	2	2	3	2	4	5	4	7
A2	4	5	6	3	3	3	3	2	5	5	6	7
A3	4	5	5	5	3	2	3	2	5	4	3	5
A4	5	4	6	5	4	3	3	4	5	5	6	7
DM2	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	5	5	6	5	2	2	3	5	3	4	5	4
A2	5	4	5	4	3	3	3	5	4	5	5	6
A3	4	3	4	4	4	4	5	3	5	6	4	5
A4	5	5	5	4	3	3	4	4	4	4	5	6
DM3	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	5	5	6	5	3	3	4	6	4	4	6	4
A2	4	4	5	4	4	4	4	6	5	5	6	6
A3	4	4	5	4	5	4	5	4	5	5	5	4
A4	5	4	5	4	4	4	4	5	5	4	6	6

After evaluating the alternatives by sub-criteria it is necessary to match the evaluation of the experts, since group decision-making was used where there were three tourism experts. This will be done by the applied aggregate geometric mean on an initial matrix of decision-making. The initial decision matrix is presented in Table 6. This matrix was used to determine the weight sub-criteria with the CRITIC method, and was used for ranking the alternate with the ARAS method.

Table 6. Initial decision matrix

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	5.00	5.31	5.65	4.64	2.29	2.29	3.30	3.91	3.63	4.31	4.93	4.82
A2	4.31	4.31	5.31	3.63	3.30	3.30	3.30	3.91	4.64	5.00	5.65	6.32
A3	4.00	3.91	4.64	4.31	3.91	3.17	4.22	2.88	5.00	4.93	3.91	4.64
A4	5.00	4.31	5.31	4.31	3.63	3.30	3.63	4.31	4.64	4.31	5.65	6.32

Before alternating ranking was performed, it was necessary to determine the weight of the sub-criteria using the CRITIC method. All weight sub-criteria were calculated for the main criteria using the steps CRITIC method. First, normalization of the initial decision matrix was performed. Second, standard deviation values and correlation coefficients were calculated. Third, the values $(1-r_{jk})$ were calculated and these values were compiled. Fourth, these values were multiplied with the standard deviation. Fifth, normalization of weight sub-criteria was performed. Finally, weights of sub-criteria were multiplied by the weights of the main criteria and the final weight was formed.

Table 7. Steps of CRITIC method

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
Normalized decision matrix	1.00	1.00	1.00	1.00	0.59	0.69	0.78	0.91	0.73	0.86	0.87	0.76
	0.86	0.81	0.94	0.78	0.84	1.00	0.78	0.91	0.93	1.00	1.00	1.00
	0.80	0.74	0.82	0.93	1.00	0.96	1.00	0.67	1.00	0.99	0.69	0.73
	1.00	0.81	0.94	0.93	0.93	1.00	0.86	1.00	0.93	0.86	1.00	1.00
σ_j	0.10	0.11	0.07	0.09	0.18	0.15	0.10	0.14	0.12	0.08	0.15	0.15
r_{jk}	1.00	0.72	0.83	0.50	1.00	0.89	0.75	-0.39	1.00	0.65	-0.21	0.24
	0.72	1.00	0.86	0.51	0.89	1.00	0.37	-0.05	0.65	1.00	-0.29	0.00
	0.83	0.86	1.00	0.15	0.75	0.37	1.00	-0.78	-0.21	-0.29	1.00	0.90
	0.50	0.51	0.15	1.00	-0.39	-0.05	-0.78	1.00	0.24	0.00	0.90	1.00
$(1-r_{jk})$	0.00	0.28	0.17	0.50	0.00	0.11	0.25	1.39	0.00	0.35	1.21	0.76
	0.28	0.00	0.14	0.49	0.11	0.00	0.63	1.05	0.35	0.00	1.29	1.00
	0.17	0.14	0.00	0.85	0.25	0.63	0.00	1.78	1.21	1.29	0.00	0.10
	0.50	0.49	0.85	0.00	1.39	1.05	1.78	0.00	0.76	1.00	0.10	0.00
$\sum_{k=1}^{m}(1-r_{jk})$	0.95	0.91	1.16	1.83	1.75	1.79	2.65	4.22	2.31	2.64	2.60	1.86
$\sigma_j\sum_{k=1}^{m}(1-r_{jk})$	0.10	0.10	0.09	0.17	0.32	0.26	0.27	0.60	0.27	0.20	0.38	0.27
w_j	0.21	0.23	0.19	0.37	0.22	0.18	0.19	0.41	0.24	0.18	0.34	0.24
Final w_j	0.049	0.053	0.045	0.087	0.118	0.098	0.101	0.222	0.055	0.041	0.077	0.055

After calculating the weights for sub-criteria, ranking of the alternatives was performed using the ARAS method. First, normalization of the initial decision matrix was performed (Table 8). Second, the decision-making matrix was made more difficult and S_0 values were determined (Table 9). The third ranking was formed (Table 10).

Table 8. Normalized decision matrix

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	0.273	0.298	0.270	0.275	0.174	0.190	0.228	0.261	0.203	0.232	0.245	0.218
A2	0.235	0.241	0.254	0.215	0.251	0.274	0.228	0.261	0.259	0.270	0.280	0.286
A3	0.218	0.219	0.222	0.255	0.298	0.263	0.292	0.192	0.279	0.266	0.194	0.210
A4	0.273	0.241	0.254	0.255	0.277	0.274	0.251	0.287	0.259	0.232	0.280	0.286
S_0	0.273	0.298	0.270	0.275	0.298	0.274	0.292	0.287	0.279	0.270	0.280	0.286
w	0.049	0.053	0.045	0.087	0.118	0.098	0.101	0.222	0.055	0.041	0.077	0.055

Table 9. Weighted normalized matrix

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
A1	0.014	0.016	0.012	0.024	0.021	0.019	0.023	0.058	0.011	0.009	0.019	0.012
A2	0.012	0.013	0.011	0.019	0.030	0.027	0.023	0.058	0.014	0.011	0.021	0.016
A3	0.011	0.012	0.010	0.022	0.035	0.026	0.029	0.043	0.015	0.011	0.015	0.012
A4	0.014	0.013	0.011	0.022	0.033	0.027	0.025	0.064	0.014	0.009	0.021	0.016
S_0	0.014	0.016	0.012	0.024	0.035	0.027	0.029	0.064	0.015	0.011	0.021	0.016

The results of the ARAS method have shown that the best alternative is A4 which is the rural settlement of Bijela, while the worst ranked rural settlement is A1 which is Gornji Zovik.

Table 10. Results and ranking alternatives

	S_i	K_i	Rank
A1	0.237	0.834	4
A2	0.254	0.896	2
A3	0.240	0.846	3
A4	0.269	0.949	1
S_0	0.284	1.000	

Table 10 shows the summary results of the research conducted, which were obtained on the basis of a compromise of all criteria and sub-criteria used in the study. In order to gain a better understanding of the results, an alternative ranking will be made by major criteria. These results are shown in Table 11. The results of the analysis by the main criteria show the following. When looking at environmental resources, alternative A1 shows the best results, while alternative A2 shows the worst results. This shows that the best environmental resources are in rural settlement Gornji Zovik. The reason for this is the fact that it is located on the slopes of Majevica and that there are many natural beauties in the area that are not contaminated. However, it can be seen from the results that other rural settlements have good results with this criterion, so it can be concluded that all have good ecological resources, since the results are close to 1. Looking at social resources, one can see that A4 has the best results, while A1 has the worst results. Thus, rural settlement Bijela has the best social resources over other rural settlements observed. It can be observed that no rural settlement has a value of 1 that is best in all sub-criteria within social resources. Considering only economic resources, the best alternative is A2, while the worst alternative is A4. These results show that rural settlement Brezovo Polje invests most in tourism compared to other rural settlements.

Table 11. Results of partial analysis according to the main criteria

	Ecological resources			Social resources			Economic resources		
	S_i	K_i	Rank	S_i	K_i	Rank	S_i	K_i	Rank
A1	0.279	1.000	1	0.223	0.774	4	0.226	0.809	4
A2	0.233	0.835	4	0.255	0.886	2	0.275	0.983	1
A3	0.233	0.836	3	0.247	0.857	3	0.232	0.829	3
A4	0.256	0.917	2	0.276	0.958	1	0.268	0.959	2
S_0	0.279	1,000		0.288	1.000		0.279	1.000	

The following conclusions are drawn from the results obtained. Alternative A1 - Gornji Zovik must work on social and economic resources. More investment in tourism is needed to create a better environment in this area for the population to remain in the countryside and to engage in tourism. Thus, with the strengthening of economic infrastructure, social resources will also improve. Alternative A2 - Brezovo Polje must work on ecological resources. It must use the location of the Sava River flowing past this village to make up for the lack of mountains, hills and pastures located near to other rural settlements in the Brcko District. Alternative A3 - Maoča must empower the most of all resources and, above all, economic resources, because these resources have the worst results of all. Alternative A4 must work on environmental and economic resources. This research has shown that in rural settlements, there are certain potentials that need to be upgraded. The Brcko District Government should pay greater attention to rural tourism and invest more in tourism in order to exploit the tourism potential available in these areas.

5. Sensitivity analysis

In the framework of the sensitivity analysis, a change in the weights of the criteria is made, and the effect on the result of the analysis is examined (Puška, et al., 2018b). The main objective of the sensitivity analysis is not to consider the impact of different criteria on changing the value of alternatives, but also to consider the impact of these changes on the overall rating of alternatives (Maksimović, & Puška, 2015).

Table 12. Sensitivity analysis scenarios

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34
Scenario 1	0.45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 2	0.05	0.45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 3	0.05	0.05	0.45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 4	0.05	0.05	0.05	0.45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 5	0.05	0.05	0.05	0.05	0.45	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 6	0.05	0.05	0.05	0.05	0.05	0.45	0.05	0.05	0.05	0.05	0.05	0.05
Scenario 7	0.05	0.05	0.05	0.05	0.05	0.05	0.45	0.05	0.05	0.05	0.05	0.05
Scenario 8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.45	0.05	0.05	0.05	0.05
Scenario 9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.45	0.05	0.05	0.05
Scenario 10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.45	0.05	0.05
Scenario 11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.45	0.05
Scenario 12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.45

In this study, the total weight was evaluated so that a sub-criterion will be taken and given greater importance in relation to other sub-criterion and it will be assigned a weight of 0.45 while the other criterion will assign the importance of 0.05. In this way, it will be examined how each criterion has an influence on ranking the alternatives, taking into account other criterion. Thus, 12 different scenarios were obtained in the sensitivity analysis. The weights of each scenario are shown in Table 12. In the first scenario, criterion C11 gained a weight of 0.45, while the other criteria gained a weight of 0.05. In the second scenario, criterion C12 gained a weight of 0.45, while other criteria gained a weight of 0.05. In the 12th scenario, criterion C34 gained a weight of 0.45, while other criteria gained a weight of 0.05. The sensitivity analysis results are shown in Figure 2.

The results of the sensitivity analysis show that in most scenarios, the best results were obtained by A4 alternative - Bijela. Other alternatives have the best results in one scenario. Alternative A1 performed best in scenario 2 in which is ranked at the first place. This shows that alternative A1 has the best performance under C12 - Resource quality criteria, and when this criterion is given with highest priority, alternative A1 is the best. However, in five scenarios, alternative A1 shows the worst results (scenarios 5,6,7,9 and 10). Alternative A2 shows the best results for scenario 10. This indicates that the alternative has the best results for criteria C32 - Existence of domestic products. However, in scenario 4, alternative A2 shows the worst results. Alternative A3 shows the best results in scenario 7, while worst case results in scenarios 1, 2, 3, 8, 11 and 12. Alternative A4 has the best results in scenarios 1, 3, 4, 5, 6, 8, 9, 11 and 12. However, the alternative A4 did not take the last place in either scenario. It had the worst results in scenario 10 in which is ranked at the third place. The results of the sensitivity analysis show that the A4 alternative is least sensitive to the application of different scenarios, while other alternative indicators are more sensitive for different scenarios. This points out that the alternative A4 - Bijela has the best indicators of sustainable rural tourism potential in Brcko District.

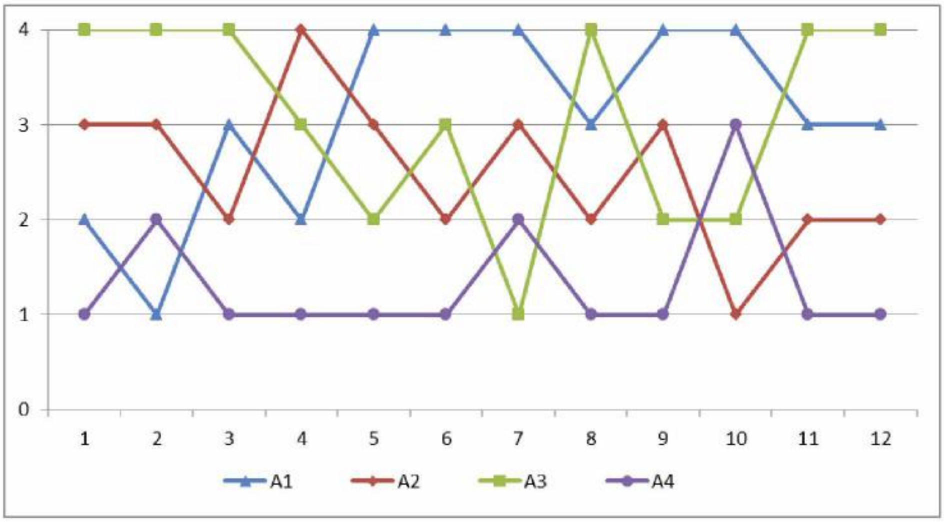

Figure 2. Sensitivity analysis

6. Conclusion

This paper reviews sustainability of rural tourism potential of Brcko District. For this purpose, expert decision-making was used by different methods of multi-criteria analysis. A unique decision-making model and an innovative methodology for this research were formed. The FUCOM method was used to calculate the weights of the main criteria, the CRITIC was calculated by the weight of the sub-criteria, and the

ARAS method was used to rank alternatives. Three experts were engaged to evaluate the four alternatives. The results of this analysis have shown that the best-ranked is the rural settlement of Bijela. Sensitivity analysis has confirmed these results.

The advantage of the model is in the following. Weight for the main criteria was subjectively determined using the advantages of the FUCOM method. The experts compared three criteria, and had to compare 2 pairs. The alternatives were evaluated for sub-criteria. The experts did not have to determine the weight of the sub-criteria, but it is rather determined by using the CRITIC method. In this way the questionnaire completed by the experts was reduced, their task was simplified and the ranking was accelerated using the ARAS method. The questionnaire consisted of two parts. The part one was intended for the subjective determination of the weights of the main criteria (table with one row and three columns); the second section was for evaluating alternatives by sub criteria (table with twelve rows and four columns). In this way, the experts filled only 13 columns. The model used in this way reduced the number of lines in the questionnaire and facilitated the work of experts. The model used took full advantage of the methods used and showed very good flexibility. Thus, the set goals of the research were achieved.

The flipchart of this study is that only four alternatives have been taken. In future research it is necessary to increase the number of settlements that determine sustainability of tourism potential of Brcko District. This would give the overall rating of rural tourism potential. In addition, the lack of this study is that no linguistic values are used that are closer to human thinking.

In the following research it is necessary to extend this model and methodology to other methods using fuzzy logic. It is also necessary to apply this model and methodology in other areas of tourism. In this way, the method and methodology used in this research would be of multiple benefits for future research.

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SELECTION OF A LOCATION FOR THE DEVELOPMENT OF MULTIMODAL LOGISTICS CENTER: APPLICATION OF SINGLE-VALUED NEUTROSOPHIC MABAC MODEL

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Abstract. *Logistics center (LC) is unique technological, spatial, organizational and economic unity that brings together different providers and users of logistics services. By selecting the optimal LC location, transport costs are reduced and business performance, competitiveness and profitability are improved. In order to achieve the overall optimum, it is necessary to perform adequate evaluation and selection of the optimal location for the construction of a LC. In this paper is performed the evaluation of potential locations based on new approach in the field of logistics. Weight coefficients of criteria are determined using objective model integrated in Single-Valued Neutrosophic (SVNN) Multi-Attributive Border Approximation Area Comparison (MABAC) model. In order to determine the stability of the model, the SVNN MABAC model is compared with other representative multi-criteria models. In the final part of the model validation, statistical correlation between the SVNN MABAC model and other MCDM approaches (SVNN WASPAS, SVNN VIKOR, SVNN TOPSIS and SVNN CODAS) is performed.*

Key words: *single-valued neutrosophic sets, MABAC, logistics center, multi-criteria decision making.*

1. Introduction

A logistics center (LC) location selection presents the process of selecting one of several possible solutions. A large number and heterogeneity of location factors clearly indicate that location issues are interdisciplinary and often require the application of complex procedures when searching for a solution. There are numerous methodologies and procedures that are available concerning this issue (Kaboli et al, 2007; Lai et al, 2010; Sun, 2012; Zare at al, 2013; Rahmaniani et al, 2013). The problem

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of location selection for the development of a logistics center can be considered as a special case within general facility location problem.

There are different studies associated with location selection decisions that have been commonly carried out by using multi-criteria decision-making (MCDM) techniques, such as distribution centre selection with weighted fuzzy factor rating system (Ou & Chou, 2009), selection of distribution centres with three-stage hierarchy of selection (Vinh & Devinder, 2005), distribution location problem with QFD (Chuang, 2002), location problem with fuzzy-AHP (Kaboli et al, 2007), location problem with MOORA and COPRAS method (Rezaeiniya et al, 2012), select distribution centers for a firm and location choice of distribution centers with PROMETHEE method (Fernández-Castro and Jiménez, 2005), logistic centre selection with dynamic dual-diamond model (Cao Yunzhong, 2009), logistics distribution location based on genetic algorithms and fuzzy comprehensive evolution (Shao et al, 2009), intermodal freight hub location decision with multi-objective evaluation model (Sirikijpanichkul & Ferreira, 2005; 2006), location selection of logistics centre based on fuzzy AHP and TOPSIS (Wang & Liu, 2007), selection of logistics centre location with fuzzy TOPSIS based on entropy weight (Chen & Liu, 2006), facility or plant location selection with multiple objective decision making (Farahani & Asgari, 2007), facility location selection with AHP and ELECTRE (Yang & Lee, 1997), convenience store location with fuzzy-AHP (Kuo et al, 2002), port selection with AHP and PROMETHEE (Ugboma et al, 2006), reverse logistics location selection with MOORA (Kannan et al, 2008), selecting a site for a logistical centre on factor and methods (Chen & Liu, 2006), logistic centre selection with fuzzy-AHP and ELECTRE Method (Ghoseiri & Lessan, 2008) and multi-modal hub location (Ashayeri & Kampstra, 2002).

The research shown in the previous section show that in the process of selecting a LC location, MOORA, COPRAS, TOPSIS, ELECTRE and PROMETHEA methods are often used in fuzzy or crisp environment. However, multi-criteria decision-making models that contain qualitative or quantitative attribute values can not always be expressed with crisp numbers. In traditional multi-criteria models (MCDM), the weight of every attribute and rank of alternatives are presented with crisp numbers. Though, in reality a decision maker may prefer attribute assessment using linguistic variables, instead of crisp values, due to partial knowledge of attributes or lack of information from the domain of the problem. A fuzzy set presented by Zadeh (1965) is one of the tools used to present such imprecision in mathematical form. Nevertheless, a fuzzy set can not present the degree of non-affiliation and the degree of imprecision of imprecise parameters.

In order to partially overcome the difficulties in defining imprecise parameters Atanassov (1986) introduced Intuitionistic fuzzy sets (IFS) characterized with the degree of affiliation and non-affiliation simultaneously. However, in the IFS, the sum of the degree of affiliation and the degree of non-affiliation of the imprecise parameter is less than a unity. That is why Smarandache (1999) presented the concept of neutrosophic sets (NS) in order to deal with unspecified or inconsistent information that usually exist in reality. The concept of neutrosophic set is a general platform that extends the concepts of classic sets, fuzzy sets (Zadeh, 1965), Intuitionistic fuzzy sets (Atanassov, 1986) and interval valued Intuitionistic fuzzy sets (Atanassov and Gargov, 1989).

Unlike Intuitionistic fuzzy sets and interval valued Intuitionistic fuzzy sets, in neutrosophic set uncertainty is explicitly characterized. The neutrosophic set (NS) has three basic components: (1) the truth function T, (2) the indeterminacy function I and

(3) the falsity function *F*. Each of these components in the neutrosophic set is defined independently. However, so defined neutrosophic set hardly finds application in real scientific and engineering field. That is why Wang and others developed the concept of interval-valued neutrosophic sets (IVNS) (Wang et al, 2005) and the concept of single-valued neutrosophic sets (SVNS) (Wang et al, 2010). Due to the large presence of uncertainty, imprecision and inconsistency in subjective assessments, and due to simple application in practical problems, IVNS and SVNS have quickly become widely applied in reality (Ye, 2013).

In this paper, the LC location selection is performed by using Single-Valued Neutrophic Multi-Attributive Border Approximation Area Comparison (MABAC) method (SVNN MABAC). Within the SVN MABAC algorithm, objective approach has been implemented to determine weight coefficients of criteria based on single-valued neutrosophic numbers (SVNN). This paper has several goals. The first goal is to develop new multi-criteria model that integrates the SVNN concept with objective approach for determining weight coefficients and the MABAC method and improves the field of multi-criteria decision making. The second goal of the paper is to form completely new methodology to enable decision-makers to evaluate potential locations for a LC development in the case of partially known values and uncertain values of the decision attributes.

The paper is organized in the following way. After the introduction, in the second section is presented single-valued neutrosophic concept and basic arithmetic operations with the SVNN. The model for evaluating potential locations for LC development using the SVNN MABAC model is formed in the third section. The fourth section shows the application of the SVNN MABAC model and validation of the results obtained. Finally, the fifth section provides final conclusions.

2. Single-valued neutrosophic set

According to the definition of neutrosophic set, neutrosophic set A is universal set X characterized by membership function used to describe truth (truth-membership function) $T_A(x)$, membership function used to describe indeterminacy (indeterminacy-membership function) $I_A(x)$ and membership function used to describe falsity (falsity-membership function) $F_A(x)$, where $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard or non standard subsets ranging in the interval $[^-0,1^+]$, so that each of the three neutrosophic components meets the condition where $T_A(x) \rightarrow [^-0,1^+]$, $I_A(x) \rightarrow [^-0,1^+]$ and $F_A(x) \rightarrow [^-0,1^+]$.

The set $I_A(x)$ can be used not only to present indeterminacy, but also to present uncertainty, inaccuracy, imprecision, error, contradiction, undefined, unknown, incomplete, redundancy, etc.. (Ghaderi et al, 2012; Biswas et al, 2016). In order to cover all the unclear information, indeterminacy-membership degree can be divided in subcomponets, such as "contradiction", "uncertainty" and "unknown" (Smarandache, 2005).

Sum of these three membership functions of the neutrosophic set $T_A(x)$, $I_A(x)$ and $F_A(x)$ should meet the following condition (Biswas et al, 2016) $^-0 \le T_A(x) + I_A(x) + F_A(x) \le 3^+$. The component of the neutrosophic set A for all the values of $x \in X$ is determined with A^C so that $T_A^c(x) = 1^+ - T_A(x)$, $I_A^c(x) = 1^+ - I_A(x)$ and $F_A^c(x) = 1^+ - F_A(x)$. Neutrosophic set A is contained in another neutrosophic set B (respectively $A \subseteq B$) if and only if for every value $x \in X$ the following conditions are met: $\inf T_A(x) \le \inf T_B(x)$, $\sup T_A(x) \le \sup T_B(x)$, $\inf I_A(x) \ge \inf I_B(x)$, $\sup I_A(x) \ge \sup I_B(x)$, $\inf F_A(x) \ge \inf F_B(x)$ and $\sup F_A(x) \ge \sup F_B(x)$.

The SVNS are a special case of neutrophysic sets that can be successfully used in real scientific and engineering applications. The following section provides some basic definitions, operations and properties of the SVNS (Deli and Şubaş, 2017).

Definition 1. Let X be universal point (objects) space with generic element X marked with *x*. Then, single-valued neutrosophic set $\tilde{N} \subset X$ is presented with $T_{\tilde{N}}(x)$ truth membership function, $I_{\tilde{N}}(x)$ indeterminacy membership function and $F_{\tilde{N}}(x)$ falsity membership function with the condition $T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x) \in [0,1]$ for every $x \in X$.

Next we can mark SVNS in a simplified manner as

$$\tilde{N} = \left\{ \langle x, T(x), I(x), F(x) \rangle \mid x \in X \right\} \tag{1}$$

In this paper, for the sake of simplicity the SVNS $\tilde{N} = \left\{ \langle x, T(x), I(x), F(x) \rangle \mid x \in X \right\}$ will be presented with the simplified expression $\tilde{N} = \left\{ \langle T(x), I(x), F(x) \rangle \mid x \in X \right\}$.

The sum of truth membership function $T_{\tilde{N}}(x)$, indeterminacy membership function $I_{\tilde{N}}(x)$ and falsity membership function $F_{\tilde{N}}(x)$ of SVNS meets the following relation

$$0 \le T_{\tilde{N}}(x) + I_{\tilde{N}}(x) + F_{\tilde{N}}(x) \le 3,\ \forall x \in X \tag{2}$$

When *X* is continuous object space, then single-valued neutrosophic set $\tilde{N}$ can be presented as

$$\tilde{N} = \int_x \left\langle T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x) \right\rangle \mid x,\ \forall x \in X \tag{3}$$

When X is discrete object space, then single-valued neutrosophic set $\tilde{N}$ can be presented as

$$\tilde{N} = \sum_x \left\langle T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x) \right\rangle \mid x,\ \forall x \in X \tag{4}$$

Therefore, final SVNC can be presented as follows

$$\tilde{N} = \left\{ \left(\left\langle x_1, T_{\tilde{N}}(x_1), I_{\tilde{N}}(x_1), F_{\tilde{N}}(x_1) \right\rangle \right), \ldots, \left(\left\langle x_n, T_{\tilde{N}}(x_n), I_{\tilde{N}}(x_n), F_{\tilde{N}}(x_n) \right\rangle \right) \right\}; \quad \forall x_i \in X, i = 1, 2, \ldots, n \tag{5}$$

Definition 2. Let $\tilde{A} = \left\{ \left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x) \right\rangle \right\}$ and $\tilde{B} = \left\{ \left\langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \right\rangle \right\}$ present two SVNS, and then the following operations can be defined on the mentioned SVNS (Wang et al, 2010):

(1) $\tilde{A} \subseteq \tilde{B}$ if and only if for every value of $x \in X$ are met the following conditions $T_{\tilde{A}}(x) \le T_{\tilde{B}}(x)$, $I_{\tilde{A}}(x) \ge I_{\tilde{B}}(x)$, $F_{\tilde{A}}(x) \ge F_{\tilde{B}}(x)$.

(2) $\tilde{A} = \tilde{B}$ if and only if for every value of $x \in X$ is met that $\tilde{A} \subseteq \tilde{B}$ and $\tilde{B} \subseteq \tilde{A}$.

(3) $\tilde{A}^c = \left\{ x \mid \left\langle F_{\tilde{A}}(x), 1 - I_{\tilde{A}}(x), T_{\tilde{A}}(x), \right\rangle \mid x \in X \right\}, \forall x \in X$.

(4) $\tilde{A} \cup \tilde{B} = \left\langle \max\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \min\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \min\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\right\rangle, \forall x \in X$.

(5) $\tilde{A} \cap \tilde{B} = \left\langle \min\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \max\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \max\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\right\rangle, \forall x \in X$.

Let $\tilde{A} = \left\{\left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\right\rangle\right\}$ and $\tilde{B} = \left\{\left\langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\right\rangle\right\}$ present two SVNS, and then the operations with $\tilde{A}$ and $\tilde{B}$ are defined with the following expressions (Smarandache, 2016):

(1) Addition SVNS "+"

$$\tilde{A} + \tilde{B} = \left\langle \begin{array}{l} T_{\tilde{A}}(x) + T_{\tilde{B}}(x) - T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), \\ I_{\tilde{A}}(x) + I_{\tilde{B}}(x) - I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), \\ F_{\tilde{A}}(x) + F_{\tilde{B}}(x) - F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x) \end{array} \right\rangle \tag{6}$$

(2) Subtraction SVNS "−"

$$\tilde{A} - \tilde{B} = \left\langle \frac{T_{\tilde{A}}(x) - T_{\tilde{B}}(x)}{1 - T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x)}{I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x)}{F_{\tilde{B}}(x)} \right\rangle \tag{7}$$

where $T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)$, $T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \in [0,1]$ with the limitation of $T_{\tilde{B}}(x) \neq 1$, $I_{\tilde{B}}(x) \neq 0$ and $F_{\tilde{B}}(x) \neq 0$.

(3) Multiplication SVNS "×"

$$\tilde{A} \times \tilde{B} = \left\langle T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x) \right\rangle \tag{8}$$

(4) Division SVNS "÷"

$$\tilde{A} \div \tilde{B} = \left\langle \frac{T_{\tilde{A}}(x)}{T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x) - I_{\tilde{B}}(x)}{1 - I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x) - F_{\tilde{B}}(x)}{1 - F_{\tilde{B}}(x)} \right\rangle \tag{9}$$

where $T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)$, $T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \in [0,1]$ with the limitation of $T_{\tilde{B}}(x) \neq 0$, $I_{\tilde{B}}(x) \neq 1$ and $F_{\tilde{B}}(x) \neq 1$.

(5) Scalar multiplication SVNS where $k > 0$

$$k \times \tilde{A} = \left\langle 1 - \left(1 - T_{\tilde{A}}(x)\right)^k, \left(I_{\tilde{A}}(x)\right)^k, \left(F_{\tilde{A}}(x)\right)^k \right\rangle \tag{10}$$

(6) SVNS power, where $k > 0$

$$\tilde{A}^k = \left\langle \left(T_{\tilde{A}}(x)\right)^k, 1 - \left(1 - I_{\tilde{A}}(x)\right)^k, 1 - \left(1 - F_{\tilde{A}}(x)\right)^k \right\rangle \tag{11}$$

Definition 3 (Euclidean distance). Let

$\tilde{A} = \left\{\left(\left\langle x_1, T_{\tilde{A}}(x_1), I_{\tilde{A}}(x_1), F_{\tilde{A}}(x_1)\right\rangle\right), \ldots, \left(\left\langle x_n, T_{\tilde{A}}(x_n), I_{\tilde{A}}(x_n), F_{\tilde{A}}(x_n)\right\rangle\right)\right\}$ and

$\tilde{B} = \left\{\left(\left\langle x_1, T_{\tilde{B}}(x_1), I_{\tilde{B}}(x_1), F_{\tilde{B}}(x_1)\right\rangle\right), \ldots, \left(\left\langle x_n, T_{\tilde{B}}(x_n), I_{\tilde{B}}(x_n), F_{\tilde{B}}(x_n)\right\rangle\right)\right\}$ be two SVNS where $\forall x_i \in X$ $(i = 1, 2, \ldots, n)$. Then, Euclidean distance between the two SVNS $\tilde{A}$ and $\tilde{B}$ is defined as follows:

$$d_{Eu}(\tilde{A},\tilde{B})=\sqrt{\sum_{i=1}^{n}\left\{\left(T_{\tilde{A}}(x_i)-T_{\tilde{B}}(x_i)\right)^2+\left(I_{\tilde{A}}(x_i)-I_{\tilde{B}}(x_i)\right)^2+\left(F_{\tilde{A}}(x_i)-F_{\tilde{B}}(x_i)\right)^2\right\}} \tag{12}$$

Normalized Euclidean distance between two SVNS $\tilde{A}$ and $\tilde{B}$ is obtained with the application of the following expression

$$d_{Eu}^{n}(\tilde{A},\tilde{B})=\sqrt{\frac{1}{3n}\sum_{i=1}^{n}\left\{\left(T_{\tilde{A}}(x_i)-T_{\tilde{B}}(x_i)\right)^2+\left(I_{\tilde{A}}(x_i)-I_{\tilde{B}}(x_i)\right)^2+\left(F_{\tilde{A}}(x_i)-F_{\tilde{B}}(x_i)\right)^2\right\}} \tag{13}$$

Definition 4. Let $\tilde{A}=\left\{\left\langle T_{\tilde{A}}(x),I_{\tilde{A}}(x),F_{\tilde{A}}(x)\right\rangle\right\}$ be single valued neutrosophic number, and then the score function $S(\tilde{A})$ can be determined as crisp value by applying the following expression (Zavadskas et al, 2015)

$$S(\tilde{A})=\frac{3+T_{\tilde{A}}(x)-2I_{\tilde{A}}(x)-F_{\tilde{A}}(x)}{4} \tag{14}$$

where the score function is defined in the interval $S(\tilde{A})\in[0,1]$. Such defined score function allows obtaining crisp values ranging in the same interval as $\tilde{A}$.

Definition 5. Let $\tilde{A}=\left\{\left\langle T_{\tilde{A}}(x),I_{\tilde{A}}(x),F_{\tilde{A}}(x)\right\rangle\right\}$ and $\tilde{B}=\left\{\left\langle T_{\tilde{B}}(x),I_{\tilde{B}}(x),F_{\tilde{B}}(x)\right\rangle\right\}$ be any of the SVNS. Then, if the condition $S(\tilde{A})<S(\tilde{B})$ is valid, single valued neutrosophic number $\tilde{A}$ is smaller than single valued neutrosophic number $\tilde{B}$, respectively $\tilde{A}<\tilde{B}$.

Definition 6. The fuzzification of the SVNS $\tilde{N}=\left\{(x\,|\left\langle T_{\tilde{N}}(x),I_{\tilde{N}}(x),F_{\tilde{N}}(x)\right\rangle)\,|\,x\in X\right\}$ can be defined as the process of mapping $\tilde{N}$ in the fuzzy set $\tilde{F}=\left\{x\,|\,\mu_{\tilde{F}}(x)\,|\,x\in X\right\}$, respectively $f=\tilde{N}\rightarrow\tilde{F}$ for $x\in X$. Representative degree of membership to the fuzzy function $\mu_{\tilde{F}}(x)\in[0,1]$ of the vector $\left\{(x\,|\left\langle T_{\tilde{N}}(x),I_{\tilde{N}}(x),F_{\tilde{N}}(x)\right\rangle)\,|\,x\in X\right\}$ is defined as follows

$$\mu_{\tilde{F}}(x)=1-\sqrt{\left\{\left(1-T_{\tilde{N}}(x)\right)^2+\left(I_{\tilde{N}}(x)\right)^2+\left(F_{\tilde{N}}(x)\right)^2\right\}\Big/3} \tag{15}$$

3. Single valued neutrosophic MABAC method

Step 1. Forming initial decision-making matrix (*N*). The evaluation of alternatives by criteria is performed by *m* experts $\{E_1,E_2,...,E_m\}$ with the assigned weight coefficients $\{\varpi_1,\varpi_2,...,\varpi_m\}$, $0\le\varpi_e\le1,\ (e=1,2,...,m)$, $\sum_{e=1}^{m}\varpi_e=1$. With the aim of final ranking of alternatives $a_i\in A$ ($i=1,2,..,b$), every expert E_e ($e=1,2,...,m$) evaluates alternatives by the defined set of criteria $C=\{c_1,c_2,...c_n\}$. Therefore, for every expert is formed related initial decision-making matrix

$$N^{(e)}=\left[\eta_{ij}^{(e)}\right]_{b\times n}=\begin{bmatrix}\eta_{11}^{(e)} & \eta_{12}^{(e)} & \cdots & \eta_{1n}^{(e)}\\ \eta_{21}^{(e)} & \eta_{22}^{(e)} & \cdots & \eta_{2n}^{(e)}\\ \vdots & \vdots & \ddots & \vdots\\ \eta_{b1}^{(e)} & \eta_{b2}^{(e)} & \cdots & \eta_{bn}^{(e)}\end{bmatrix}$$
$$=\begin{bmatrix}\left\langle T_{\eta 11}^{(e)},I_{\eta 11}^{(e)},F_{\eta 11}^{(e)}\right\rangle & \left\langle T_{\eta 12}^{(e)},I_{\eta 12}^{(e)},F_{\eta 12}^{(e)}\right\rangle & \cdots & \left\langle T_{\eta 1n}^{(e)},I_{\eta 1n}^{(e)},F_{\eta 1n}^{(e)}\right\rangle\\ \left\langle T_{\eta 11}^{(e)},I_{\eta 11}^{(e)},F_{\eta 11}^{(e)}\right\rangle & \left\langle T_{\eta 22}^{(e)},I_{\eta 22}^{(e)},F_{\eta 22}^{(e)}\right\rangle & \cdots & \left\langle T_{\eta 2n}^{(e)},I_{\eta 2n}^{(e)},F_{\eta 2n}^{(e)}\right\rangle\\ \vdots & \vdots & \ddots & \vdots\\ \left\langle T_{\eta b1}^{(e)},I_{\eta b1}^{(e)},F_{\eta b1}^{(e)}\right\rangle & \left\langle T_{\eta bn}^{(e)},I_{\eta bn}^{(e)},F_{\eta bn}^{(e)}\right\rangle & \cdots & \left\langle T_{\eta bn}^{(e)},I_{\eta bn}^{(e)},F_{\eta bn}^{(e)}\right\rangle\end{bmatrix} \quad (16)$$

where the elements of the matrix $N^{(e)}$ ($\eta_{ij}^{(e)}$) present SVN numbers from the predefined neutrosophic linguistic scale. Final aggregated decision-making matrix N is obtained by averaging the elements $\eta_{ij}^{(e)}=\left\langle T_{\eta ij}^{(e)},I_{\eta ij}^{(e)},F_{\eta ij}^{(e)}\right\rangle$ of the matrix (16) by applying the expression (18).

$$N=\left[\eta_{ij}\right]_{b\times n}=\begin{bmatrix}\eta_{11} & \eta_{12} & \cdots & \eta_{1n}\\ \eta_{21} & \eta_{22} & \cdots & \eta_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \eta_{b1} & \eta_{b2} & \cdots & \eta_{bn}\end{bmatrix}$$
$$=\begin{bmatrix}\left\langle T_{\eta 11},I_{\eta 11},F_{\eta 11}\right\rangle & \left\langle T_{\eta 12},I_{\eta 12},F_{\eta 12}\right\rangle & \cdots & \left\langle T_{\eta 1n},I_{\eta 1n},F_{\eta 1n}\right\rangle\\ \left\langle T_{\eta 11},I_{\eta 11},F_{\eta 11}\right\rangle & \left\langle T_{\eta 22},I_{\eta 22},F_{\eta 22}\right\rangle & \cdots & \left\langle T_{\eta 2n},I_{\eta 2n},F_{\eta 2n}\right\rangle\\ \vdots & \vdots & \ddots & \vdots\\ \left\langle T_{\eta b1},I_{\eta b1},F_{\eta b1}\right\rangle & \left\langle T_{\eta bn},I_{\eta bn},F_{\eta bn}\right\rangle & \cdots & \left\langle T_{\eta bn},I_{\eta bn},F_{\eta bn}\right\rangle\end{bmatrix} \quad (17)$$

where the elements $\eta_{ij}=\left\langle T_{\eta ij},I_{\eta ij},F_{\eta ij}\right\rangle$ are obtained by applying the SVNN weighted average operator (SWNSWAA) , with the expression (18)

$$\eta_{ij}=SVNSWAA(\eta_{ij}^{(1)},\eta_{ij}^{(2)},...,\eta_{ij}^{(m)})=\sum_{b=1}^{m}\varpi_e\eta_{ij}^{(1)}$$
$$=\left\langle 1-\prod_{b=1}^{m}\left(1-T_{\eta ij}^{(e)}\right)^{\varpi_e},\prod_{b=1}^{m}\left(I_{\eta ij}^{(e)}\right)^{\varpi_e},\prod_{b=1}^{m}\left(F_{\eta ij}^{(e)}\right)^{\varpi_e}\right\rangle \quad (18)$$

where ϖ_e the weight coefficients, $0\le\varpi_e\le 1,\ (e=1,2,...,m)$, $\sum_{e=1}^{m}\varpi_e=1$.

Step 2. Normalization of initial decision-making matrix (N). By normalization of the matrix elements (17), it is obtained the matrix $\hat{N}=\left[\hat{\eta}_{ij}\right]_{b\times n}=\left[\left\langle T_{\hat{\eta} ij},I_{\hat{\eta} ij},F_{\hat{\eta} ij}\right\rangle\right]_{b\times n}$. The elements of the matrix $\hat{N}$ are obtained by applying the expression (19)

$$\eta_{ij}=\begin{cases}\left\langle T_{\eta ij},I_{\eta ij},F_{\eta ij}\right\rangle, & if\ \ c_j\in B;\\ \left\langle F_{\eta ij},1-I_{\eta ij},T_{\eta ij}\right\rangle, & if\ \ c_j\in C;\end{cases} \quad (19)$$

where B and C, respectively, present the sets of criteria of benefit and cost type.

Step 3. Determining weight coefficients' values. Determining weight coefficients values is based on maximum deviation model (MDM). After the normalization of expert correspondent matrices, aggregated normalized decision-making matrix is obtained $\hat{N}=\left[\hat{\eta}_{ij}\right]_{b\times n}=\left[\left\langle T_{\hat{\eta}ij},I_{\hat{\eta}ij},F_{\hat{\eta}ij}\right\rangle\right]_{b\times n}$. Aggregated normalized decision-making matrix $\hat{N}$ is further transformed into the weighted matrix $N^{*}=\left[\eta_{ij}^{*}\right]_{b\times n}$, $\eta_{ij}^{*}=w_j\cdot\eta_{ij}$.

In the matrix N can be calculated the degree of elements' deviation η_{kj} ($1\le k\le b$) in relation to other elements η_{ij} within the criteria c_j ($j=1,2,...,n$)

$$\varphi_{ij}(w_j)=\sum_{k=1}^{b}d(\eta_{kj}^{*},\eta_{ij}^{*})=\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{20}$$

Where $d(\eta_{kj},\eta_{ij})$ present the distance between η_{kj} ($1\le k\le b$) and η_{ij} ($j=1,2,...,n$). From the expression (19) it can be clearly noted that for higher values of $D_{ij}(w_j)$ the alternative a_i ($i=1,2,...,b$) is better.

The MDM model is based on the following starting points: (1) In case there are small deviations between the value of η_{kj} ($1\le k\le b$) and the value of η_{ij} within the criterion c_j ($j=1,2,...,n$), then the criterion has low influence to the rank of alternatives and small value of the weight coefficient w_j; (2) Contrary to the mentioned, if there are significant deviations between the value of η_{kj} ($1\le k\le b$) and the value of η_{ij} within the criterion c_j ($j=1,2,...,n$), then the criterion has high influence to the rank of alternatives and large value of the weight coefficient w_j; (3) If all the values of η_{ij} are identical within the criterion c_j ($j=1,2,...,n$), then the criterion has no influence to the rank of alternatives and has the value of the weigh coefficient $w_j=0$. After that, it is calculated the degree of deviation between all the elements within the observed criterion c_j ($j=1,2,...,n$).

Step 3.1. Calculation of the degree of deviation between all the elements within the observed criterion c_j ($j=1,2,...,n$)

$$\varphi_{j}(w_j)=\sum_{i=1}^{b}\varphi_{ij}(w_j)=\sum_{i=1}^{b}\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{21}$$

Respectively, calculation of total deviation of all alternatives by criteria

$$\varphi(w)=\sum_{j=1}^{n}\varphi_{j}(w_j)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{22}$$

Step 3.2. The weight coefficients w_j are obtained by solving optimization model which is based on maximum deviation

$$\begin{aligned}&\max D(w)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{u=1}^{b}d(\eta_{ij},\eta_{uj})w_j\\&s.t.\\&\begin{cases}\sum_{j=1}^{n}w_j^2=1;\\0\le w_j\le 1;\ \ j=1,2,...,n\end{cases}\end{aligned} \tag{23}$$

With the aim of solving the model (23), it is introduced the Lagrange function

$$L(w,p)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{u=1}^{b}d(\eta_{ij},\eta_{uj})w_j+\frac{\lambda}{2}\left(\sum_{j=1}^{n}w_j^2-1\right) \tag{24}$$

After partial deviation by w, and then by p are obtained two equations $D(w)+pw_j=0$ i $\sum_{j=1}^{n}w_j^2=1$, where

$$w_j=\frac{\sum_{i=1}^{b}\sum_{u=1}^{b}\left\{\frac{1}{3}\left[\left|f\left(s_{pij}\right)-f\left(s_{p_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-q_{ij}}\right)-f\left(s_{t-q_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-r_{ij}}\right)-f\left(s_{t-r_{uj}}\right)\right|^{\varphi}\right]\right\}^{\frac{1}{\varphi}}}{\sqrt{\sum_{j=1}^{n}\left(\sum_{i=1}^{b}\sum_{u=1}^{b}\left\{\frac{1}{3}\left[\left|f\left(s_{pij}\right)-f\left(s_{p_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-q_{ij}}\right)-f\left(s_{t-q_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-r_{ij}}\right)-f\left(s_{t-r_{uj}}\right)\right|^{\varphi}\right]\right\}^{\frac{1}{\varphi}}\right)^2}} \tag{25}$$

Step 3.3. Calculation of final values of weight coefficients. By normalization of the values (25) are obtained final values of weight coefficients.

$$\omega_j=\frac{w_j}{\sum_{j=1}^{n}w_j} \tag{26}$$

where ω_j present optimal values of weight coefficients.

Step 4. Calculation of the elements of the border approximate area matrix (*G*). The elements of the matrix $G=\left[g_j\right]_{1\times n}$ are obtained by applying the expression (27)

$$g_j=\prod_{i=1}^{b}\left(d_{ij}\right)^{1/b}=\left\langle\prod_{i=1}^{b}\left(T_{dij}\right)^{1/b},1-\prod_{i=1}^{b}\left(1-I_{dij}\right)^{1/b},1-\prod_{i=1}^{b}\left(1-F_{dij}\right)^{1/b}\right\rangle \tag{27}$$

Step 5. Calculation of the matrix of the distance of alternatives from the border approximate area (*S*). The elements of the matrix $S=\left[s_{ij}\right]_{b\times n}$ are obtained by applying the expression (28)

$$s_{ij}=\begin{cases}d_{Eu}(d_{ij},g_j), & if\ d_{ij}>g_j;\\ 0, & if\ d_{ij}=g_j;\\ -d_{Eu}(d_{ij},g_j), & if\ d_{ij}<g_j.\end{cases} \tag{28}$$

where the distance d_{Eu} is determined by applying the expression(13).

Step 6. Ranking alternatives. Based on the values of the criteria functions of alternatives Q_i ($i=1,2,...,b$), it is performed ranking of alternatives. Criteria functions are obtained by applying the expression (29),

$$Q_i=\sum_{j=1}^{n}s_j,\ \ i=1,2,...,b;\ j=1,2,...,n. \tag{29}$$

Rank of alternatives is determined based on the value Q_i, where it is more favorable for alternative to have as high as possible value of the criteria function Q_i.

4. Application of the SVNN MABAC model

In this paper, a case study of location selection for a multimodal LC is presented. As an example, eight potential locations for the development of a multimodal LC on the Danube River in the territory of Serbia are considered. Based on the recommendations of Zecevic (2006), nine criteria are identified based on which the selection of the location of a multimodal LC is done, as in the Table 1.

Table 1. Criteria for the evaluation of multimodal LC locations

Mark	Criteria name	Criteria description
C1	Connectivity to multimodal transport	The criterion presents traffic and logistic characteristics of the environment and the connection of the location with other modes of transport. This criterion expresses the possibility of approach, accepting and dispatching of the means of external transport. It belongs to the group of "benefit" criteria.
C2	Assessment of infrastructure construction	This criterion shows the regulation of infrastructure to adequately serve the demands of goods flows in the LC. Every location has certain limitations, some of which can be eliminated by investing material resources, while some present limiting factors for the development and exploitation of the LC. The criterion belongs to the group of "benefit" criteria.
C3	Influence to the environment	This criterion is descriptive and presents the impact of the location to environmental pollution through the emission of gases, noise and vibration. It belongs to the group of "cost" criteria.
C4	Compliance with spatial plans and economic development strategy	The criterion shows the compliance of the LC development with spatial plans and the strategy of economic development. It belongs to the group of "benefit" criteria.
C5	Existing intermodal transport units	This criterion is an estimate of the existing transport flows towards the LC. It is expressed through an estimate of the number of ITUs per year (ITU / year). It belongs to the group of "benefit" criteria.
C6	Loading capacities of the LC	This criterion presents the loading capacities of the LC. The LC loading capacities express the maximum number of ITUs that can be unloaded within one hour (ITU / h). It belongs to the group of "benefit" criteria.
C7	Available area for future development and LC capacity expansion	Based on the requirements of material flows and preliminary estimation of the required area for certain subsystems, it is determined the minimal required total area for the development of the LC. When designing, additional area is planned for the expansion and development of terminals in the future. The criterion belongs to the group of "benefit" criteria.
C8	Distance of the users from the LC	The criterion is descriptive and presents an estimate of the distance of the LC location from the potential users of services. It belongs to the group of "cost" criteria.
C9	Traffic safety	The criterion presents the regulation of the location of the LC from the aspect of traffic safety (regulation of traffic signalization, number of traffic accidents on access roads, regulation of road and rail crossings). The criterion is descriptive and belongs to the group of "benefit" criteria.

In model testing participated four experts from the field of transport which are assigned weight coefficients w_{e1}=0.2864, w_{e2}=0.2741, w_{e3}=0.2170 and w_{e4}=0.1673.

Table 2. Aggregated initial decision-making matrix

Crit	A1	A2	A3	A4	A5	A6	A7	A8
C1	(0.54,0.3,0.28)	(0.53,0.34,0.35)	(0.52,0.37,0.28)	(0.5,0.33,0.29)	(0.41,0.33,0.29)	(0.63,0.37,0.38)	(0.52,0.29,0.23)	(0.59,0.34,0.47)
C2	(0.51,0.29,0.24)	(0.53,0.31,0.25)	(0.5,0.34,0.26)	(0.56,0.31,0.39)	(0.47,0.33,0.4)	(0.55,0.46,0.3)	(0.49,0.38,0.35)	(0.51,0.36,0.3)
C3	(0.47,0.27,0.33)	(0.57,0.4,0.34)	(0.46,0.32,0.31)	(0.5,0.27,0.26)	(0.49,0.34,0.29)	(0.59,0.38,0.42)	(0.41,0.3,0.19)	(0.45,0.28,0.24)
C4	(0.44,0.27,0.25)	(0.47,0.34,0.35)	(0.37,0.25,0.15)	(0.41,0.34,0.15)	(0.63,0.42,0.48)	(0.51,0.32,0.35)	(0.39,0.4,0.19)	(0.33,0.24,0.24)
C5	(0.41,0.28,0.23)	(0.52,0.31,0.29)	(0.44,0.19,0.34)	(0.52,0.33,0.36)	(0.56,0.75,0.47)	(0.62,0.33,0.44)	(0.53,0.35,0.32)	(0.58,0.42,0.41)
C6	(0.51,0.33,0.31)	(0.48,0.24,0.28)	(0.51,0.36,0.36)	(0.52,0.41,0.4)	(0.45,0.32,0.28)	(0.5,0.31,0.31)	(0.52,0.31,0.3)	(0.43,0.25,0.25)
C7	(0.56,0.3,0.44)	(0.53,0.39,0.31)	(0.55,0.27,0.36)	(0.54,0.32,0.37)	(0.53,0.39,0.41)	(0.58,0.37,0.37)	(0.5,0.32,0.38)	(0.49,0.29,0.32)
C8	(0.59,0.4,0.43)	(0.6,0.49,0.41)	(0.55,0.43,0.32)	(0.56,0.39,0.36)	(0.47,0.3,0.26)	(0.57,0.42,0.25)	(0.48,0.42,0.39)	(0.61,0.41,0.33)
C9	(0.61,0.42,0.37)	(0.66,0.47,0.43)	(0.58,0.35,0.48)	(0.62,0.42,0.4)	(0.65,0.5,0.44)	(0.45,0.38,0.35)	(0.47,0.28,0.31)	(0.48,0.29,0.38)

Experts evaluated the criteria by applying linguistic scale: Very important – VI (0.90,0.10,0.10); Important – I (0.75,0.25,0.20); Medium – M (0.50,0.50,0.50); Unimportant – UI (0.35,0.75,0.80); Very unimportant – VU (0.10,0.90,0.90).

Step 1: In the first step, the experts evaluated eight alternatives (locations) in relation to the nine evaluation criteria marked with C1 to C9. Thus, for every expert, one correspondent matrix is formed. Evaluation of the alternatives is made using predefined set of the SVN linguistic variables. Therefore, for every expert, a correspondent initial decision-making matrix is defined, which by using SWNSWAA (18) is aggregated into the initial decision-making matrix, as in the Table 2.

Table 3. Deviations between the criteria in the initial decision-making matrix

Criteria	A1	A2	A3	A4	A5	A6	A7	A8
C1	0.693161	0.729263	0.711873	0.673599	0.64468	0.854589	0.670868	0.873455
C2	0.658016	0.678004	0.661235	0.7689	0.726337	0.80292	0.721386	0.691708
C3	0.649877	0.812623	0.656083	0.646737	0.669801	0.866943	0.590643	0.604452
C4	0.620961	0.728282	0.548415	0.614471	1.016261	0.743172	0.654049	0.545849
C5	0.639613	0.718458	0.681562	0.750361	1.218171	0.889591	0.75045	0.872205
C6	0.675299	0.623921	0.72922	0.80159	0.626706	0.658559	0.673925	0.589811
C7	0.779089	0.738575	0.715328	0.717412	0.779176	0.777315	0.701796	0.665741
C8	0.843699	0.894391	0.769733	0.772811	0.672498	0.770101	0.769027	0.818187
C9	0.839894	0.942952	0.857972	0.860605	0.95581	0.731635	0.689946	0.725356
Sum	5.851	5.709	5.497	5.471	6.520	5.379	5.874	6.310

Step 2:

In the second step by applying the expression (19) it is normalized the aggregated matrix, which is further in the step three used for determining objective values of the weights of criteria.

Step 3:

After determining normalized initial decision-making matrix, by applying the expressions (20)-(24) are calculated the deviations between the elements of the aggregated matrix. Thus, for the criteria (C1-C9) are obtained the deviations presented in the Table 3.

By applying the expressions (25) and (26) are obtained optimal values of the weigh coefficients of criteria

$w_j = (0.1100, 0.1073; 0.1033; 0.1028; 0.1225; 0.1011; 0.1104; 0.1186; 0.1241)$.

Step 5:

The calculation of the elements of border approximate area matrix (BAA). By applying the expression (27) are obtained the elements of border approximate area matrix, as in the Table 4.

Table 4. Border approximate area matrix

Criteria	BAA
C1	(0.10,0.11,0.12)
C2	(0.11,0.11,0.13)
C3	(0.13,0.12,0.10)
C4	(0.17,0.12,0.12)
C5	(0.08,0.13,0.15)
C6	(0.14,0.10,0.10)
C7	(0.08,0.11,0.08)
C8	(0.06,0.09,0.08)
C9	(0.07,0.09,0.11)

Step 6:

The calculation of the matrix of alternatives distance from border approximate area. By applying the expression (28) is determined the distance of alternatives from the BAA, as in the Table 5.

Table 5. Distance of alternatives from border approximate area

Criteria	A1	A2	A2	A4	A3	A6	A4	A8
C1	0.833	-0.500	-0.500	0.500	-0.333	-0.667	0.167	0.500
C2	0.500	0.500	-0.500	0.667	-0.333	0.333	-0.667	0.333
C3	0.167	-0.333	0.500	0.833	0.500	0.667	0.833	0.167
C4	0.167	-0.167	0.333	-0.667	0.333	-0.500	0.333	0.167
C5	-0.333	-0.500	0.333	0.667	-0.100	-0.167	0.500	0.333
C6	0.333	0.500	0.500	0.833	-0.333	0.333	-0.667	0.167
C7	-0.333	-0.500	-0.333	-0.833	-0.500	0.500	-0.833	0.667
C8	0.500	-0.667	0.333	0.833	0.500	0.333	-0.667	0.833
C9	-0.667	0.167	0.500	-0.833	-0.667	0.667	0.167	0.333

Step 7:

Ranking alternatives. Based on the distance of alternatives from border approximate area (Table 5), by applying the expression (29) are obtained final values of the criteria functions of alternatives and final rank of alternatives, as in the Table 6.

Table 6. Criteria functions and rank of alternatives

Alternative	Qi	Rank
A1	1.167	4
A2	-1.500	8
A3	1.160	5
A4	2.000	2
A5	-0.933	7
A6	1.499	3
A7	-0.834	6
A8	3.500	1

The validation of the SVNN MABAC model is carried out in this part. The validation of the SVNN MABAC model is made by comparison with other multi-criteria SVNN models from bibliography. For these purposes, the following methods are used: SVNN WASPAS (Zavadskas et al, 2015), SVNN VIKOR (Pouresmaeil et al. 2017), SVNN TOPSIS (Pouresmaeil et al. 2017) i SVNN CODAS (Peng & Dai, 2018).

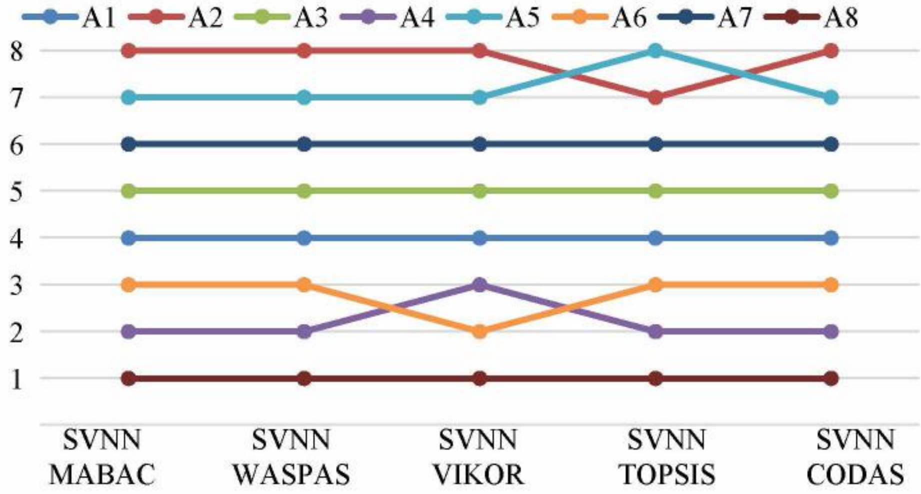

Figure 1. Comparison of the results of the SVNN MABAC model with other MCDM models

The Figure 1 shows that the eighth location is the best solution in all scenarios formed, respectively, in the application of all the other methods mentioned above. The location four in four models is in the second position, using SVNN MABAC, SVNN WASPAS, SVNN TOPSIS and SVNN CODAS, while using the SVNN VIKOR model it is in the third place. This is due to the significant differences between the SVNN VIKOR methodology and other MCDM models considered. The second location is on the eighth position four times, while in the SVNN TOPSIS model it is in the seventh position. Considering these are only the worst alternatives, these changes in ranks have no impact on the final decision. Since there is no complete consensus in the results between the models considered, statistical comparison of the ranks is performed in the following part and the correlation of the ranks is done using Spearman's coefficient (Tian et al., 2018; Pamucar et al., 2019). In the table 7 it is presented Spearman's coefficient of rank correlation between the models observed.

Table 7. Spearman's coefficient of correlation for rank location using different methods

Methods	SVNN MABAC	SVNN WASPAS	SVNN VIKOR	SVNN TOPSIS	SVNN CODAS
SVNN MABAC	1.000	1.000	0.999	0.999	1.000
SVNN WASPAS	-	1.000	0.999	0.999	1.000
SVNN VIKOR	-	-	1.000	0.997	0.999
SVNN TOPSIS	-	-	-	1.000	0.999
SVNN CODAS	-	-	-	-	1.000

Based on the total calculated statistical coefficient of correlation (0.990), it can be concluded that the ranks are in high correlation in all formed scenarios. Observing the overall ranks and correlation coefficients, it can be concluded that the model obtained is very stable, and that the ranks are in high correlation. Since all the values are significantly greater than 0.90, according to Pamucar et al. (2018) these present very high correlation of ranks.

5. Conclusion

This paper presents the application of the SVNN MABAC model in the process of selecting the location of multimodal logistic center on the Danube River. The SVNN MABAC model additionally enriches the field of multi-criteria decision making. The model presented allows making more objective decisions through respecting subjectivity and uncertainty in the decision-making process. The third contribution of the paper is the improvement of the methodology for evaluating and selecting optimal location for the development of multimodal LC through new approach to dealing with imprecision, since the application of this or similar approach has not been observed in the literature that examines the subject area.

With the application of the developed approach, it is possible to consider the evaluation of a LC construction sites systematically, which have significant impact on the efficiency achievement of the entire supply chain. The SVNN MABAC model is also applicable for solving other logistic problems, such as supplier evaluation, selection of means of transport in other areas. The flexibility of the model is reflected in the fact that its upgrade can be carried out by integrating other methods of multi-criteria decision-making.

The results of the research shown in this paper indicate that the SVNN MABAC model presents a useful and reliable tool for rational decision-making. Basic recommendation for further use of this method is simple mathematical apparatus, stability (consistency) of the solution, as well as the possibility of combining it with other methods, especially concerning the determination of the weights of criteria.

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THE SELECTION OF THE LOGISTICS DISTRIBUTION FRUIT CENTER LOCATION BASED ON MCDM METHODOLOGY IN SOUTHERN AND EASTERN REGION IN SERBIA

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Abstract. *Location selection for the logistics distribution center is often one of the most critical elements in a supply chain's management success. Decision making in location selection domain is a complex process due to the fact that a wide range of diverse criteria, stakeholders and possible solutions are embedded into this process. This paper focuses on the application of some multi-criteria decision-making (MCDM) approaches for the logistics distribution fruit center location selection in the Southern and Eastern Serbia region. An Analytic Hierarchy Process (AHP) and a Weighted Aggregated Sum-Product Assessment (WASPAS) have been implemented in this process for evaluation and location selection.*

Key words: *location selection problem, logistics distribution center, MCDM, AHP, WASPAS.*

1. Introduction

The location selection problem (Owen & Daskin, 1998; Farahani & Hekmatfar, 2009; Zak & Weglinski, 2014) consists in determining proper placement of an infrastructural component (ground, site, facility, etc.) in a considered area, taking into account the decision maker's preferences and existing constraints. It has a universal character and may refer to different categories of sites (Farahani & Hekmatfar, 2009; Farahani, et al, 2010; Zak & Weglinski, 2014). The location selection problem plays a crucial role in logistics, where it refers to find the most desirable location for logistics facilities.

The main goal of this paper is to show the usage of multi-criteria decision-making (MCDM) methodology on the location selection problem which refers to an installment of the logistics center for storing and distribution of fruits on the territory of Southern and Eastern region in Serbia.

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As a key component in a supply chain, the distribution center, plays the vital role of obtaining materials from different suppliers, performing value-added activities, and assembling (or sorting) products to fulfil customer orders and offer a high level of service (Baker, 2007, 2008; Parkih & Meller, 2008; Vieira et al., 2017).

To improve every aspect of the supply chain and satisfy all relevant involved factors for the most suitable logistics center location, a multi-criteria decision-making problem (MCDM) methodology has been used.

To solve problems related to decision-making, Ćojbašić et al. (2018) say that several optimization methods are used in practice. But, in the case where decision activities are based on similar options, it becomes critical to analyze various factors, alternatives with similar category, involving a set of different and opposite criteria.

When MCDM methods are applied for solving the location selection problem, they can help decision-maker with objective and systematic evaluation of alternatives on multiple criteria.

Two MCDM methods, which are applied on the practical example (the location selection of the logistics distribution center), are classical MCDM method - Analytic Hierarchy Process (AHP) method and hybrid MCDM method - Weighted Aggregated Sum Product Assessment (WASPAS) method. The first method, the AHP method, was used for the determination of the criteria weights, and, furthermore, for the evaluation of the alternatives. The second method, the WASPAS method, was only used for the evaluation of the alternatives while using the criteria weights determined by the AHP method.

The location selection of the logistics distribution fruit center is being determined inside the Southern and Eastern Serbia region (alternative solutions are region's districts with their govern cities). By the defined criteria set, alternatives are evaluated with the help of the mentioned MCDM methods (Section 4).

The final result of this paper should be, respectively to the previously emphasized distribution center importance, the best possible location for its installment. This location will be proposed to the responsible authorities of the Southern and Eastern region, as well as the Ministry of Agriculture, Forestry and Water Management.

2. The location selection problem – Literature Preview

The location selection problem is a worldwide "phenomenon", which is widely discussed in transportation and logistics circles.

This problem (Owen & Daskin, 1998; Chen, et al., 2007; Daganzo, 1996; Ozcan, et al., 2011) refers to the selection of specific locations of such facilities as: warehouses, distribution centers, transportation hubs, passenger and cargo terminals, material inventory, parking lots and many others (Van Thai & Grewal, 2005; Drezner & Hamacher, 2002; Fierek, et al, 2007; Zak & Weglinski, 2014).

The focus of this paper is location selection for the logistics distribution center and Gutjahr & Dzubur (2015) said that in the literature on facility location, much attention has been devoted to the optimal choice of facilities or distribution centers where customers are supplied with products, commodities or services of a different kind.

Logistics distribution centers have evolved from traditional warehouses. The main difference between distribution centers and warehouses is in the fact that a warehouse is designed to store goods for longer periods. Distribution centers are facilities with the primary purpose of logistic coordination. Beside manipulative activities (loading, unloading, load transfer), constantly adapting to new market demands, continuous automation and computerization, there is a development in trade, delivery and transport functions in logistics systems on all levels (Pupavac et al., 2014).

Choosing the most suitable location for the logistics distribution center is a complex decision which involves the consideration of multiple factors including: politics, economics, infrastructure, environment, competition, development strategy, product features, logistic costs, and customers service levels (Rao et al., 2015).

The complexity of the problem increases with the increase of the possible solutions and number of the criterion which affects them. Choosing the most suitable location for the logistics distribution center becomes the MCDM problem.

MCDM methods can help decision-maker with objective and systematic evaluation of possible solutions-locations, on multiple criteria involved. To find the best alternative the location selection models have been designed. Over the past decades, those models have increased significantly (Kazemi & Amiri, 2017). These models are principally mathematical models that can be categorized into two groups: static and deterministic and dynamic and stochastic (Cheng at al., 2005). But, the most recent models contain both quantitative and qualitative values with the concentration on decision-makers' behavior (Hashemkhani et al., 2013). Some classical and hybrid models are included in MCDM methodology, as presented in this research.

Multiple criteria facility location problems were presented by Farahani et al. (2010), while the study on location selection started more than a century ago when researchers were trying to find the most suitable location of the warehouse in order to have minimum distance with the customer (Cheng et al., 2005). Chou et al. (2008) utilized mathematical programming in order to process the facility model for a distribution center.

Stevic et al. (2015) and Bagum & Rashed (2014) used classical AHP method on the selection of the logistics distribution center location. The same method was used by Tomić et al. (2014) in order to find the best locations for the distributive center on the Balkan Peninsula. Burnaz et al., (2006) applied the MCDM approach for the evaluation of retail locations. Ozcan et al. (2011) proposed a comparative analysis of MCDM methods (TOPSIS, ELECTRE and Grey Theory) on a warehouse location selection problem. Selection of a similar problem was done combining AHP and DEA methodology (Korpela et al., 2007). The selection of the logistics center location based on the ELECTRE III/IV method was carried away in Poland (Zak & Weglinski, 2014). ELECTRE methods were also used by Wang & Triantaphyllou (2008) for ranking irregularities while evaluating alternatives.

Nowadays, more and more popular are fuzzy variants of MCDM methods and He et al., (2017) used fuzzy TOPSIS and fuzzy EW+AHP for sustainable decision making for joint distribution center location selection. Fuzzy optimization has been applied for locating and distributing centers in a supply chain network (Chen et al., 2007). Sanayei et al. (2010) proposed VIKOR MCDM method under the fuzzy environment in the selection process. Steep-fuzzy AHP+TOPSIS method has been developed for evaluation and selection of thermal power plant location (Choudhary et al., 2012).

3. Multi-criteria decision-making (MCDM) methods

Multi-criteria analysis methods have been developed as mathematical tools to support decision-makers involved in the decision-making process (Madić et al., 2015). Those methods are gaining importance as potential tools for analyzing and solving complex real-time problems due to their inherent ability to evaluate different alternatives concerning various criteria for possible selection of the best alternative (Chakraborty et al., 2015).

They are based on scientific principles that enable an effective and efficient way of determining the "optimal" solution. Some methods have many common features or a similar application procedure, while others are different, but most of them, are based on quantitative calculations. Each method has some of its unique characteristics, logic, advantages, and disadvantages, depending on a decision-making problem (Madić et al., 2015; Petrović et al., 2018).

The choice of the method which will be in use for solving the specific multi-criteria analysis problem depends on: the nature of the problem, the availability of information concerning a problem, the number of alternatives, as well as the knowledge, previous experience and preferences of the decision-maker.

When a particular MCDM method is finally chosen for a specific application, it is observed that its solution accuracy and ranking performance are seriously influenced by the value of its control parameter (Chakraborty et al., 2015).

Proposed MCDM methods for solving this paper's decision-making problem, the location selection problem, are: Analytic Hierarchy Process (AHP) and Weighted Aggregated Sum-Product Assessment (WASPAS).

In order to evaluate the overall effectiveness of the candidate alternatives (locations), rank and select the most suitable location, the primary objective of an MCDM methodology is to identify the relevant location selection criteria, assess the alternatives information relating to those criteria and develop methodologies for evaluating the significance of criteria (Ćojbašić et al., 2018).

The weights of relevant location selection criteria are calculated by the AHP method, while, the same method and WASPAS method are furthermore used for evaluation of alternatives (locations).

3.1. Analytic Hierarchy Process (AHP) method

The Analytic Hierarchy Process (AHP) method was originally proposed by Thomas Saaty (1977, 1980). It represents one of the best known and the most commonly used MCDM method.

The AHP can be implemented in a few simple consecutive steps:

Step 1: Computing the vector of criteria weights. The vector of criteria weights can be computed by creating a *pairwise comparison matrix* $\boldsymbol{A}$ where each element a_{ij} of the matrix $\boldsymbol{A}$ represents the importance of the i^{th} criterion relative to the j^{th} criterion. The comparisons between two elements are assembled, using the values from 1 to 9 from fundamental Saaty scale. Final determination of criteria weights w_j is based on the geometric mean method as shown by the following equation:

$$GM_i = \left(\prod_{i=1}^{n} a_{ij}\right)^{1/n}, \; w_i = \frac{GM_i}{\sum_{i=1}^{n} GM_i}, \quad (1)$$

where GM_i is geometric means of each row and n is the number of considered criteria.

Step 2: Testing the consistency of results. The pairwise comparisons made by AHP method are subjective and this method tolerates inconsistency through the amount of redundancy in the approach. The value that measures the consistency of the subjective comparisons is *consistency index CI*:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the *pairwise comparison matrix* $\boldsymbol{A}$.

Finally, the ratio CI/RI, that is termed the *consistency ratio CR,* should be less than 0.1. In Eq. 3 RI is the *Random Index* (Table 1), i.e. the consistency index when the entries of matrix $\boldsymbol{A}$ are completely random.

$$CR = \frac{CI}{RI} \tag{3}$$

Table 1. Values of a Random Index (RI) depending on the number of criteria

Number of criteria	3	4	5	6	7	8	9	10
RI	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Step 3: Comparison of alternatives concerning each criterion. This step implies the determination of pairwise alternative comparison matrix $\boldsymbol{B}_j$, where elements of this matrix b_{kl} represent the preference of the k^{th} alternative relative to the l^{th} alternative according to criterion j. The comparisons have to be done using the values from 1 to 9 from Saaty scale in the same way as described in Step 1.

Step 4: Synthesize global ratings. The final step is the multiplication of local priorities by the weight of the respective criterion and the results are summed up to produce the overall priority of each alternative (global ratings).

3.2. Weighted Aggregated Sum Product Assessment (WASPAS) method

Weighted Aggregated Sum Product Assessment (WASPAS) method was proposed by Zavadskas et al. (2012). The WASPAS method is a unique combination of two well-known MCDM approaches, i.e. Weighted Sum Model (WSM) and Weighted Product Model (WPM) (Chakraborty et al., 2015).

The WASPAS can be implemented in a few simple consecutive steps:

Step 1: Determine the decision matrix:

$$X = \left[x_{ij}\right] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

where x_{ij} represents the performance of i-th alternative with respect to j-th criteria; m is the number of alternatives and n is the number of the criteria.

Step 2: Determine the normalized decision matrix computing its elements by one of the formulas:

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \text{ for maximal criterion,} \tag{5}$$

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \text{ for minimal criterion,} \tag{6}$$

where $\bar{x}_{ij}$ is the normalized value of x_{ij}.

Step 3: The first criterion of optimality is similar to WSM method. The total relative importance of the *i*-th alternatives is determined by the formula:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} \cdot w_j \,, \tag{7}$$

where w_j is the weighted coefficient of the *j*-th criteria.

Step 4: The second criterion of optimality is similar to WPM method. The total relative importance of the *i*-th alternatives is determined by the formula:

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{x}_{ij}^{w_j} \,. \tag{8}$$

Step 5: A joint importance is based on the contribution of WSM and WPM:

$$Q_i = \frac{Q_i^{(1)} + Q_i^{(2)}}{2}. \tag{9}$$

To increase ranking accuracy and effectiveness of the decision-making process, in WASPAS method, a more generalized equation for determining the total relative importance of *i*-th alternative is developed as below (Saparauskas et al., 2011; Zavadskas et al., 2012):

$$Q_i = \lambda \cdot Q_i^{(1)} + (1-\lambda) \cdot Q_i^{(2)} = \lambda \cdot \sum_{j=1}^{n} \bar{x}_{ij} \cdot w_j + (1-\lambda) \cdot \prod_{j=1}^{n} \bar{x}_{ij}^{w_j} \,,$$
$$\lambda = 0, 0.1, \ldots, 1. \tag{10}$$

Now, the candidate alternatives are ranked based on the Q values, i.e. the best alternative would be that one having the highest Q value.

4. Case study – The selection of the logistics distribution fruit center location

The Southern and Eastern Serbia is one of five statistical regions of the Republic of Serbia. This region covers the area of 26 255 km^2, which makes 29.71% out of the whole country's area. In this region live 1 559 281 citizens, this makes 21.5% out of the entire population (by the 2011 Census, Statistical Office of the Republic of Serbia).

Southern and Eastern Serbia consists of 9 districts (every district has administrative center): Bor District (Bor), Braničevo District (Požarevac), Jablanica District (Leskovac), Nišava District (Niš), Pčinja District (Vranje), Pirot District (Pirot), Podunavlje District (Smederevo), Toplica District (Prokuplje), Zaječar District (Zaječar) (Figure 1).

Alternatives (locations) are administrative centers form A_1 to A_9 respectively ordered by Districts, as in the previous passage, and shown in Figure 1 and 2, and in decision matrix in Table 2.

Figure 1. Southern and Eastern Serbia region's districts.

By the Agricultural Census from 2012 (Statistical Office of the Republic of Serbia), there are 187 744 registered agricultural holdings in the Southern and Eastern region, this makes 29.75% out of all registered agricultural holdings. 97 401 registered agricultural holdings are registered as the fruit growing holdings, on the total area of 43 372 ha.

Mentioned number of agricultural holdings grow a wide selection of fruits, such as apples, pears, peaches, apricots, plums, quinces, different sorts of nuts (walnuts, hazelnuts, almonds, etc.), as well as the berry fruits (raspberry, strawberry, blackberry, blueberry, etc.).

This paper shows the usage of MCDM methodology as a reliable tool in the decision-making process, and that the result of this process should be a proposal for construction of logistics distribution fruit center in one of the 9 Districts inside the Southern and Eastern Serbia Region. Designed logistic distribution center should be used to store fruit products, as well as their further distribution inside the region, inside the country and abroad.

The selection of the location for the logistics distribution center has become a key concern in logistics and supply chain management practice and design.

The proposed MCDM methods from Section 3 have been used for logistics distribution fruit center location evaluation and selection.

The working model for location selection of the logistics distribution fruit center in Southern and Eastern Serbia region is presented in the Figure 2.

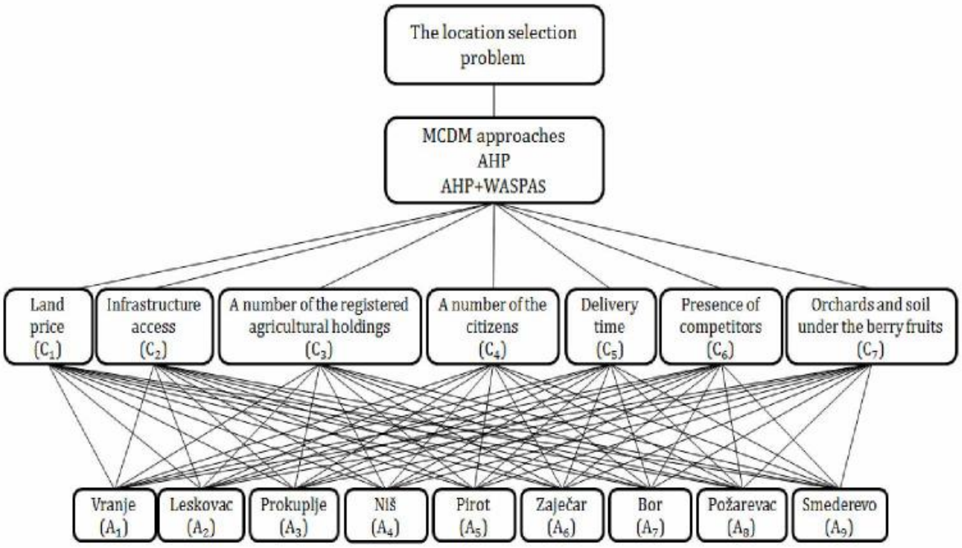

Figure 2. A model for the location selection problem.

A well-considered logistic distribution center will reduce the logistics cost, improve the efficiency of transport flows, improve a citizen's living condition, sustain the city's economic vitality and can contribute to the harmonious development of the economy, environment, and society. However, a poorly designed logistic distribution center can cause a series of negative externalities and external costs, such as greater traffic congestion, increased emission, road safety, and damaged urban image (Rao et al., 2015).

This paper's criteria set consist of 7 criterions. Those criteria have been based on the factors that affect the problem, of the location selection, the most. The criteria set have been chosen on the previous authors' experience – literature preview, type of the problem (location selection problem), as well as the current fruit growing situation in the Region.

C_1 – Land price is the minimization criterion defined on the basis of grades. Land price is a very important factor for logistics distribution center construction because it directly affects the increase of the investment costs. Besides the required amount of land which is necessary for the logistics distribution center, there must be enough additional surrounding space available for future development.

C_2 – Infrastructure access is the maximization criterion defined on the basis of grades. Transportation is the essence of logistics distribution, and logistics distribution center must have a variety of possible means of transport (highways, railroads, river ports, airports) in order to facilitate transit.

C_3 – A number of the registered agricultural holdings is also the maximization criterion which represents the total number of the agricultural holdings which are oriented in growing fruits by the District (Agricultural Census 2012, Statistical Office of the Republic of Serbia).

C_4 – A number of the citizens is the maximization criterion which represents the total number of the citizens by the District (by the 2011 Census, Statistical Office of the Republic of Serbia). The number of citizens dictates the number of customers and available label workers.

C_5 – Delivery time is the minimization criterion, and it is very important that delivery must be on time, especially, because of the product's type. This criterion is in relation to criterion C_2 – Infrastructure access, and it also depends on the delivery destination.

C_6 – Presence of competitors is the minimization criterion defined on the basis of grades. This criterion refers to the level of competitors' presence in the Districts. The less competitive environment, the better the result is.

C_7 – Orchards and soil under the berry fruits is maximization criterion which represents the total amount of soil under fruits by the District (Agricultural Census 2012, Statistical Office of the Republic of Serbia).

Criteria C_1, C_2, C_5, and C_6 are evaluated by the group of experts on the basis of the Saaty's scale for pair-wise comparison of 9 numerical values. After the evaluation of the criteria, mean values were taken into account. On the other hand, for the criteria C_3, C_4 and C_7, real values were taken.

Decision matrix has been formed and presented in Table 2 and based on the described alternatives (locations) and defined criteria.

Table 2. Location's performance ratings – decision matrix

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Alternative	min	max	Max	Max	min	Min	Max
A_1	4.8	5.0	12609	158717	5.6	7.4	3874.6
A_2	7.4	7.2	16669	216304	2.4	7.0	6819.08
A_3	4.0	4.6	12625	90600	2.4	3.6	9828.69
A_4	8.2	8.8	15400	373404	1.4	6.8	5527.7
A_5	3.0	4.4	7519	92277	2.8	6.4	1874.85
A_6	4.0	3.6	8501	119967	4.0	4.4	3603.94
A_7	2.6	4.0	4804	124992	5.8	2.6	1529.34
A_8	4.2	5.0	12461	183625	3.4	5.0	4019.88
A_9	8.4	7.4	6813	199395	2.2	7.8	6294.35

The team of experts has also evaluated the significance of the defined criteria by creating a pairwise comparison matrix (Table 3).

Table 3. Evaluation of criteria – pairwise comparison matrix

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	1.000	0.294	0.263	5.200	0.278	7.200	2.200
C_2	3.400	1.000	2.200	7.400	0.417	8.600	3.400
C_3	3.800	0.455	1.000	5.200	0.313	7.600	2.600
C_4	0.192	0.135	0.192	1.000	0.122	3.600	0.455
C_5	3.600	2.400	3.200	8.200	1.000	8.800	5.200
C_6	0.139	0.116	0.132	0.278	0.114	1.000	0.238
C_7	0.455	0.294	0.385	2.200	0.192	4.200	1.000

Table 4. Criteria weights obtained using AHP MCDM method

Criteria weights	C_1	C_2	C_3	C_4	C_5	C_6	C_7
AHP	0.113	0.234	0.171	0.039	0.354	0.021	0.068

To ensure the objectivity of the calculated criteria weights the consistency index (CR) has been calculated and its value is 0.087, while the maximal allowed value of this index is 0.1.

AHP method and hybrid combination of the MCDM method (AHP+WASPAS) were used for the complete assessment for the logistics distribution fruit center location in Southern and Eastern Serbia region. The application of the proposed methods gives a complete range of location selection, as shown in Table 5 and Figure 3.

Table 5. Complete rankings of the locations according to different MCMD approaches

Log. Distr. center location	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
AHP	0.082 (7)	0.123 (2)	0.108 (4)	0.164 (1)	0.095 (6)	0.079 (8)	0.075 (9)	0.097 (5)	0.109 (3)
AHP+WASPAS	0.443 (7)	0.671 (2)	0.615 (3)	0.842 (1)	0.487 (6)	0.425 (8)	0.371 (9)	0.528 (5)	0.584 (4)

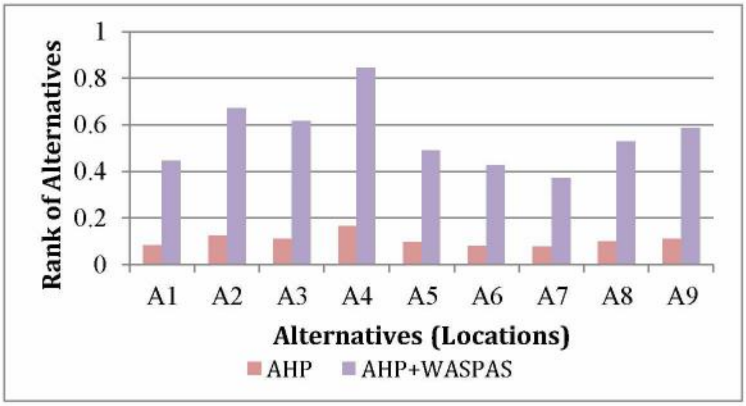

Figure 3. Complete rankings of the locations according to different MCDM approaches.

In accordance with those table and figure, it can be seen that ranks are of the same importance in both methods. In both cases (AHP and AHP+WASPAS) the best alternative solution is the alternative A_4, i.e. the best location for the logistics distribution fruit center is the administrative center, the city of Niš (Nišava District). On the other hand, in both cases too, the worst alternative solution is the alternative A_7, i.e. the worst location for the logistics distribution center is the administrative center, the city of Bor (Borski District).

The only difference in the results of those two MCDM approaches is for the alternative A_3 (Administrative Center of Prokuplje – Toplica District) and A_9 (Administrative Center of Smederevo – Podunavlje District).

In the case of classic MCDM approach (AHP method), alternative A_3 has a rank 4, while alternative A_9 has a rank 3.

In the case of hybrid MCDM approach (AHP+WASPAS), alternative A_3 has a rank 3, while alternative A_9 has a rank 4.

5. Conclusion

This research has demonstrated the applicability of classic MCDM approach (AHP method) and a hybrid MCDM approach (AHP+WASPAS) in the location selection for logistics distribution fruit center in Southern and Eastern Serbia region.

In the case of logistics center location both considered approaches give insignificant variation in the final ranking scores. Both approaches selected alternative A_3 (administrative center, the city of Niš (Nišava District)) as the best choice.

The authors of this paper belong to a narrow group of researches (e.g. Daganzo, 1996; Zak & Weglinski, 2014) who have realized that the logistics distribution center must be considered as a hierarchical problem, a two-level problem.

The first level represents a macro analysis of the one wider area, which has been described in this paper. The selection of the best location for the logistic distribution fruit center was done by observing the whole Southern and Eastern Serbia region. In the macro-region analysis potentials and advantages of the Districts was observed to construct a logistics center of this type.

The second level represents a microanalysis for described logistics center inside the previously chosen location in the first level of study. The main goal of further research is to find the best possible location (exact location) of the logistics distribution center inside the chosen District.

The most important future endeavors regarding the usage of the MCDM methodology are directed to the development of an expert and intelligent decision-making system.

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APPLICATION SOLUTION TO THE STAGE OF AGGREGATION METHOD FOR ASSESSING THE QUALITY OF SERVICE PROVIDED

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Abstract. *Formed FAM4QS (Fuzzy Aggregation Method for Quality Service (software), FAM4QS), has been created with modification of LSP (Logical scoring of preferences) methods and SSSI (Six-Step Service Improvement method used LSP (Logical scoring of preferences) algorithms. This had imposed a need for the support of the appropriate software Given that FAM4QS is a new and unique approach to this issue, the proposed software provides unique computer support for this method. With the support of FAM4QS, it is possible for the decision-maker to better demonstrate its own subjective preferences in multi-criteria decision-making. An overview of a large number of results allows numerous analyzes of the application of this decision-making method, as well as an increase in the efficiency of the decision-making process itself. This makes it easier to analyze and consider their solutions, while at the same time it provides managers to use this method in deciding in easy way.*

Key words: *FAM4QS, software quality, software services*

1. Introduction

Companies in the modern market face global competition, but also with demands for increasing profits, which is happening in times of constant change. In order for companies to accomplish their task in relation to the mentioned challenges, it is necessary to invest certain resources in reliable information technologies and in specific software solutions for the given industrial branch. This also means reorganizing own business with minimal changes when it comes to profitability and transparency. (Gajic, 2013). End-user expectations for software services are increasing.

It is common knowledge that today's society is developing into an information society. This technology becomes an instrument in the service of information, so information is knowledge, power, and money.

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The speed and success of the application of information technology will become the basic factor of the strength and usability of today's managers (Ilić et al. 2017). Managers who decide on a day-to-day basis determine and choose ways to solve the problems they face, which will be in line with the set aims of the organization, but also taking into account the circumstances in which the business takes place. On that case, managers use all available sources of information and quality-processed data on the problem or the conditions in which they need to be addressed, while in the absence of the necessary information they rely on intuition and experience.

Professor Oldcorn in his book states that "managers must make decisions - that is their responsibility", according to which the decision-making phases are the following (Oldcorn, 1998):

1. Identify the problem that needs to be solved
2. Discover the facts and find the cause
3. Develop some of the possible solutions to the problem
4. Narrow the choice of the alternative direction of action
5. Make a decision
6. Implement the decision made
7. Analyze the consequences of this solution.

The rapid development of information systems and computer technology, introducing the decision making in the presence of a larger number of the most often conflicting criteria. The specific approach to the application of information systems in decision-making has imposed a decision support system that, together with expert systems, provides support for decision-making.

Practical managerial problems set different and diverse requirements, often with different relative significance, differently sensitive to changes in input and output sizes. Therefore, managerial decision-making requires the application of multi-criteria decision-making methods. A number of different and diverse criteria provide a more comprehensive and objective picture in accordance with the requirements that the decision-maker sets. Criteria can appear in different units, often with different relative significance and different requirements for maximizing or minimizing. This method makes it possible to better understand the underlying causes of specific service behavior. Understanding the behavior of service is a key prerequisite for improving services. The method encapsulates a systematic approach in a comparative analysis of the defined parameters of each service, with the same parameters of other services that belong to the same ranking.

In order to remain competitive, it is very important to constantly improve the quality of software services and be able to meet new needs faster (to be more agile) (Tomašević, 2017). Below is proposed a software solution FAM4QS that can be used in continuous improvement of quality.

2. The Method

Formed FAM4QS (Fuzzy Aggregation Method for Quality Service (software), FAM4QS), has been created with modification of LSP (Logical scoring of preferences) methods (Dujmović and Dujmović, 2016; Dujmović, 2018) and SSSI (Six-Step Service Improvement method used LSP (Logical scoring of preferences) algoritama (Marković and Maksimović, 2012). This had imposed a need for the support of the appropriate software (Tomaseivć et al. 2018). The FAM4QS mathematical model for assessing the quality of the service provided is based on operations with fuzzy numbers (Tomašević, 2017; Tomaseivć et al. 2018). By formulating the FAM4QS method, a more accurate assessment of the quality of the service is done, choosing different values for degrees in the aggregation used to estimate the parameters, or groups of system parameters, and the service itself. Also contributing to a better assessment, which is conditioned by the different nature of the parameters. That difference implies more or less disjunctively, that is, the conjugacy of the form of the chosen aggregation function (greater r disjunctive form, less r more conjunctive form).

Instead of standard real numbers, the model looks at fuzzy numbers and corresponding operations defined over them shown in (Stević, 2017; Puška et al. 2018; Stević et al. 2018; Stević et al. 2019; Chatterjee et al. 2019). Justification for the introduction, i.e. replacing crisp numbers with fuzzy numbers consists of the fact that the estimates of the parameters considered in the system are either vague (imprecise) or can range in a range.

Below is a shown in detail of how to calculate the quality of service using FAM4QS.

In experimental data processing, the use of the fuzzy method includes the following steps:

- • data fuzzification;
- • processing the fuzzy data;
- • defuzzification the results.

The first step shows that data which is vague, for example, about 20% fuzzification, i.e. we present the fuzzy set (fuzzy number) (Klement et al. 2000). The second step is to work with these fuzzy objects, for example, the addition of two fuzzy numbers (Klir et al. 1995). The result of the second step is the fuzzy number, and it is usually required to answer to the solution of problem be a crisp number, and in the third step, it is performed defuzzification of that number, that is, assigned a crisp value.

Depending on the nature of the data, i.e. professional assessments (whether precisely determined or not) are applied fuzzy numbers and the fuzzy operations of them, for imprecisely determined or not accurately estimated weights w_i on the following way:

$$\hat{E} = \left(\hat{w}_1 \cdot (\hat{e}_1)^r + \ldots + \hat{w}_n \cdot (\hat{e}_n)^r \right)^{\frac{1}{r}}. \tag{1}$$

The parameter estimation is first calculated $P_j, j = 1 \ldots m$ using equation (2):

$$\hat{e}_j = \left(\sum_{q=1}^{k} \hat{w}_{jq} \cdot \left(\hat{e}_{jq} \right)^{r_j} \right)^{\frac{1}{r_j}}. \tag{2}$$

by each of the fuzzy numbers $\hat{w}_{jq} = (l_{w_{jq}}, m_{w_{jq}}, r_{w_{jq}})$ joins its α section according to (Tomašević, 2017): $\left[w^{*}_{jq}, w^{**}_{jq}\right]$, and each of fuzzy number $\hat{e}_{jq} = (l_{e_{jq}}, m_{e_{jq}}, r_{e_{jq}})$ joins its section according to (Tomašević, 2017): $\left[e^{*}_{jq}, e^{**}_{jq}\right]$.

Now α section of $\hat{e}_j$ can be calculated by the following way:

$$^{\alpha}\hat{e}_j = \left(\sum_{q=1}^{k}\left[w^{*}_{jq}, w^{**}_{jq}\right]\cdot\left[e^{*}_{jq}, e^{**}_{jq}\right]^{r_j}\right)^{\frac{1}{r_j}}, \tag{3}$$

After that we using equation (4):

$$^{\alpha}\hat{e}_j = \left[e^{*}_j, e^{**}_j\right] = \left[\left(\sum_{q=1}^{k} w^{*}_{jq}, (e^{*}_{jq})^{r_j}\right)^{\frac{1}{r_j}}, \sum_{q=1}^{k} w^{**}_{jq}, (e^{**}_{jq})^{r_j}\right)^{\frac{1}{r_j}}\right]. \tag{4}$$

By applying previous equations formule (1) assessment of service is calculated as fuzzy value, so the final assessment of service in form of section is:

$$^{\alpha}\hat{E} = \left(\sum_{j=1}^{k}\left[w^{*}_j, w^{**}_j\right]\cdot\left[e^{*}_j, e^{**}_j\right]^{r}\right)^{\frac{1}{r}} \tag{5}$$

In analogy to the previous use of the rules for working with intervals, we get:

$$^{\alpha}\hat{E} = \left[E^{*}, E^{**}\right] = \left[\left(\sum_{j=1}^{k} w^{*}_j \cdot \left(e^{*}_j\right)^{r}\right)^{\frac{1}{r}}, \left(\sum_{j=1}^{k} w^{**}_j \cdot \left(e^{**}_j\right)^{r}\right)^{\frac{1}{r}}\right]. \tag{6}$$

Especially if $\hat{e}_j$ is crisp value equal to e_j:

$$^{\alpha}\hat{E} = \left[E^{*}, E^{**}\right] = \left[\left(\sum_{j=1}^{k} w^{*}_j \cdot e^{r}_j\right)^{\frac{1}{r}}, \left(\sum_{j=1}^{k} w^{**}_j \cdot e^{r}_j\right)^{\frac{1}{r}}\right]. \tag{7}$$

With the FAM4QS method, the ranking of the service from the lowest C, middle B and highest rank A was done according to the following criterion:

Observing the mean value interval $\left[E^{*}, E^{**}\right], i = 1, \ldots n$:

$$E = \left[\frac{1}{n}\sum_{i=1}^{n} E^{*}_i, \frac{1}{n}\sum_{i=1}^{n} E^{**}_i\right], \tag{8}$$

Adding for example. $\pm 10\%$ or $\pm 5\%$ (UCL 1.05, LCL 0.95) on left and right border of interval:

$$UCL = \left[1.1 \cdot \frac{1}{n} \sum_{i=1}^{n} E_i^{*}, 1.1 \cdot \frac{1}{n} \sum_{i=1}^{n} E_i^{**} \right],$$

$$LCL = \left[0.9 \cdot \frac{1}{n} \sum_{i=1}^{n} E_i^{*}, 0.9 \cdot \frac{1}{n} \sum_{i=1}^{n} E_i^{**} \right], \quad (9)$$

getting the criterion of choosing whether a service belongs to the highest-ranking (A) or the lowest (C) is obtained. Those services that have a core (dots) (ie α section for $\alpha = 1$) higher than the right border UCL have the highest-ranking (A), and those services that have a core less than the left-hand LCL have the lowest ranking (C). Services with a core within the left-hand LCL and right-hand side of UCL are middle-level services (B).

3. FAM4QS Implementation

FAM4QS is written in the programming language C#. Defined operators facilitate basic operations with fuzzy numbers and alpha cross-sections (Figure 1).

```
public static AlphaSection FromFuzzy(FuzzyNumber fuzzy)
{
    var alpha = new AlphaSection();
    alpha.Start = AlphaValue * fuzzy.Middle + (1 - AlphaValue) * fuzzy.Left;
    alpha.End = AlphaValue * fuzzy.Middle + (1 - AlphaValue) * fuzzy.Right;
    return alpha;
}
public static AlphaSection operator +(AlphaSection a1, AlphaSection a2)
{
    return new AlphaSection(a1.Start + a2.Start, a1.End + a2.End);
}
public static AlphaSection operator +(AlphaSection a, FuzzyNumber f)
{
    var alpha = FromFuzzy(f);
    return alpha + a;
}
public static AlphaSection operator +(FuzzyNumber f, AlphaSection a)
{
    return a + f;
}
public static AlphaSection operator -(AlphaSection a1, AlphaSection a2)
{
    return new AlphaSection(a1.Start - a2.Start, a1.End - a2.End);
}
public static AlphaSection operator *(AlphaSection a1, AlphaSection a2)
{
    return new AlphaSection(a1.Start * a2.Start, a1.End * a2.End);
}
public static AlphaSection operator *(AlphaSection a, FuzzyNumber f)
{
    var alpha = FromFuzzy(f);
    return a * alpha;
}
public static AlphaSection operator *(FuzzyNumber f, AlphaSection a)
{
    var alpha = FromFuzzy(f);
    return a * alpha;
}
public static AlphaSection operator *(AlphaSection a, double d)
{
    return new AlphaSection(a.Start * d, a.End * d);
}
public static FuzzyNumber operator *(FuzzyNumber fuzzy, double score)
{
    var res = new FuzzyNumber();
    res.Left = fuzzy.Left * score;
    res.Middle = fuzzy.Middle * score;
    res.Right = fuzzy.Right * score;
    return res;
}

public static FuzzyNumber operator +(FuzzyNumber f1, FuzzyNumber f2)
{
    return new FuzzyNumber(f1.Left + f2.Left, f1.Middle + f2.Middle, f1.Right +
                       f2.Right);
}
```

Figure 1. Basic operations with alpha sections and fuzzy numbers

Basic operations include: addition, subtraction and multiplication. For example, the addition of an alpha cross-section with a fuzzy number is done by converting the first fuzzy number into an alpha cross-section, and then the operation of the addition of two alpha cross-sections is performed, which collects the initial boundaries of the interval with the initial, that is shown in Figure 2.

```
public static AlphaSection operator *(FuzzyNumber f1, FuzzyNumber f2)
{
    AlphaSection res = new AlphaSection();
    res.Start = f1.Left * f2.Left + AlphaSection.AlphaValue * (f1.Left * f2.Middle - 2.0
    * f1.Left * f2.Left + f2.Left * f1.Middle) + Math.Pow(AlphaSection.AlphaValue, 2.0)
    * (f1.Middle - f1.Left) * (f2.Middle - f2.Left);
    res.End = f1.Right * f2.Right + AlphaSection.AlphaValue * (f1.Middle * f2.Right -
    2.0 * f1.Right * f2.Right + f1.Right * f2.Middle) +
    Math.Pow(AlphaSection.AlphaValue, 2.0) * (f1.Middle - f1.Right) * (f2.Middle -
    f2.Right);
    return res;
}
public static AlphaSection operator ^(AlphaSection alpha, double pow)
{
    return new AlphaSection(Math.Pow(alpha.Start, pow), Math.Pow(alpha.End, pow));
}

public static FuzzyNumber operator ^(FuzzyNumber fuzzy, double pow)
{
    var res = new FuzzyNumber();
    res.Left = Math.Pow(fuzzy.Left, pow);
    res.Middle = Math.Pow(fuzzy.Middle, pow);
    res.Right = Math.Pow(fuzzy.Right, pow);

    return res;
}
```

Figure 2. Complex operations with alpha cross-sections and fuzzy numbers

```
private void CalculateFAM4QS()
{
    CollectScores();
    var subgroups = Groups.Keys.Where(x => !x.Equals(Const.MainGroupName)).ToList();
    foreach (var subgroupName in subgroups)
    {
        var subgroup = Groups[subgroupName];
        var selectedR = subgroup.RList.Where(x => x.IsSelected).ToList();
        if (selectedR.Count <= 0)
        {
            ...
            return;
        }

        var services = subgroup.Services;
        foreach (var service in services.Values)
        {
            service.KrispCalculation.Clear();
            service.FuzzyCalculations.Clear();
            foreach (var r in selectedR)
            {
                if (subgroup.WeightType == NumberType.Krisp)
                {
                    KrispWeightCalc(service, r, subgroup.Weights);
                }
                else
                {
                    FuzzyWeightCalc(service, r, subgroup.Weights, subgroup.ScoreType);
                }
            }
        }
    }
    List<List<string>> combinations = new List<List<string>>();
    foreach (var group in Groups.Values)
    {
        combinations.Add(group.RList.Where(x => x.IsSelected)
                                    .Select(x => x.DisplayName)
                                    .ToList());
    }
    Console.WriteLine(combinations);
    var product = combinations.CartesianProduct();
```

Figure 3. Calculation of FAM4QS method

Method Calculate FAM4QS () calculating imprecise data in a way that *CollectScores ()* collecting the values of the ratings entered by the user in the rating table (Figure 3). *var subgroups = Groups.Keys.Where(x => !x.Equals(Const.MainGroupName)). ToList();* is a code that filters all the groups and only names the subgroups. With these names, *for* loops, it goes through all subgroups. First, check whether the user has selected *r* values for each subgroup. If not, the error message is printed and the code execution is stopping.
If the check *r* value is passed, the code continues by going through all the services, using the other *for* the loops. First, all previous calculations are canceled. Then, the third *for* loop goes through all the selected *r* values.
Depending on the selected weight type (Crisp or Fuzzy), the estimation of each subgroup is calculated. By calling the *CartesianProduct method ()*, combinations of selected *r* values are obtained for all groups.

```
using (SaveFileDialog saveDialog = new SaveFileDialog())
{
    saveDialog.Filter = "FAM4QS Data|*.tfcd";
    saveDialog.Title = "Save data to file";
    saveDialog.ShowDialog();

    //if (saveDialog.FileName != null)
    if (!string.IsNullOrEmpty(saveDialog.FileName))
    {
        //if location is valid, save data as blob
        var fs = (FileStream)saveDialog.OpenFile();
        Tools.SaveObject(Data, fs);
        fs.Close();
    }
}
                                    ...

Stream myStream = null;
OpenFileDialog openDialog = new OpenFileDialog();

openDialog.InitialDirectory = "c:\\";
openDialog.Filter = " FAM4QS Data|*.tfcd";
openDialog.FilterIndex = 2;
openDialog.RestoreDirectory = true;
if (openDialog.ShowDialog() == DialogResult.OK)
{
    try
    {
        if ((myStream = openDialog.OpenFile()) != null)
        {
            using (myStream)
            {
                Data = Tools.LoadObject<DataHolder>(myStream);
            }
        }
    }
    catch (Exception ex)
    {
        MessageBox.Show("Error: Could not read file from disk. Original error: " +
                        ex.Message);
    }
}
                                    ...
```

Figure 4. Save and loading data

The standard way of storing objects in a file in the C # programming language is specified in the Windows Forms environment, as well as loading them from files (Figure 4).

The first step defines the number of services that are evaluated and the percentage accuracy of the results is entered (Figure 5).

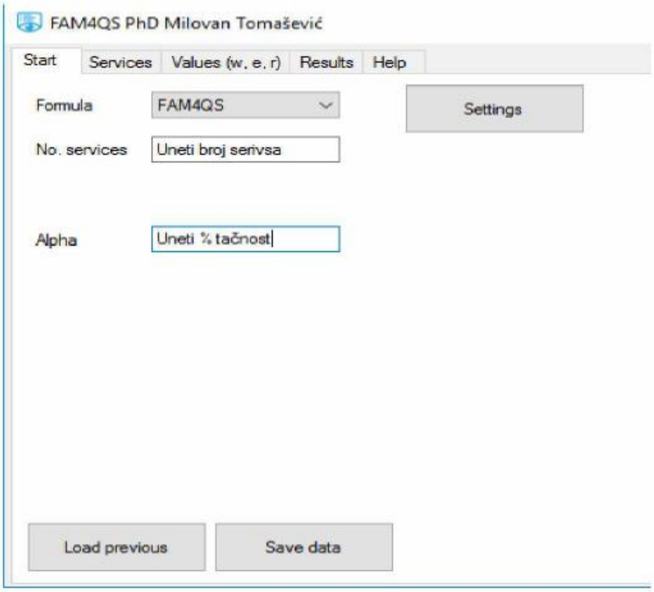

Figure 5. Entering initial data

In the example, it is shown case for three services and a probability of accuracy of 90% (Figure 6).

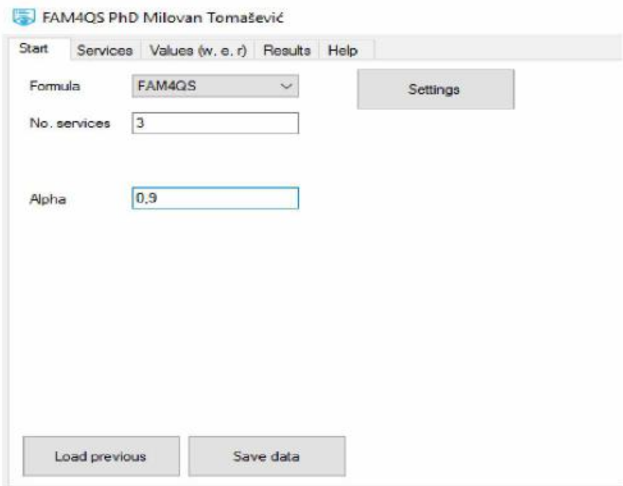

Figure 6. Example of entering data

In step 2 (Figure 7) we enter the names of the services we want to compare.

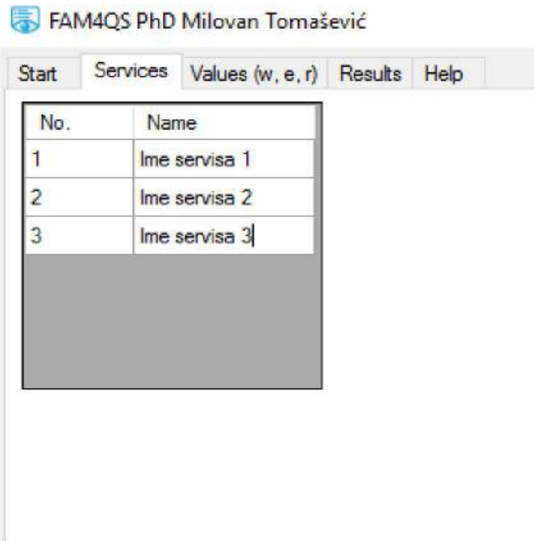

Figure 7. Entering the names of the services

In step 3 (Figure 8), the parameter values for the groups are selected, whether the correct value or the fuzzy number.

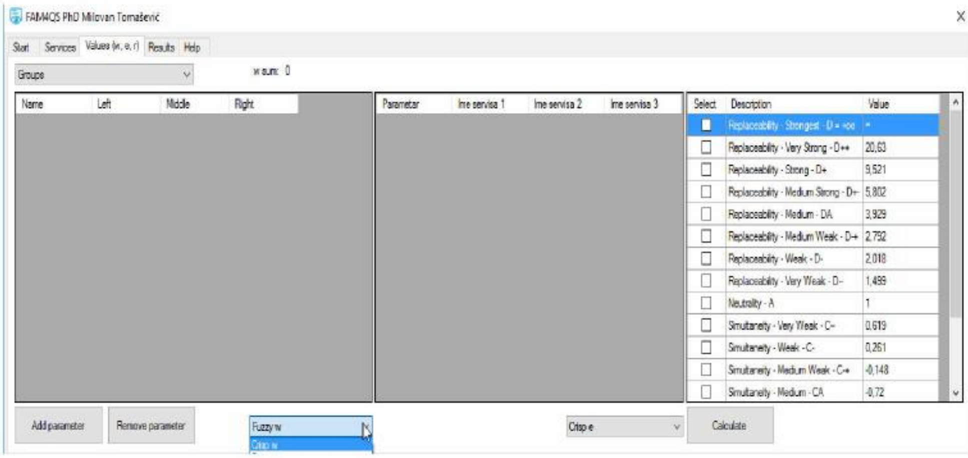

Figure 8. Selection of the parameter type

In step 4 (Figure 9), group parameters are entered.

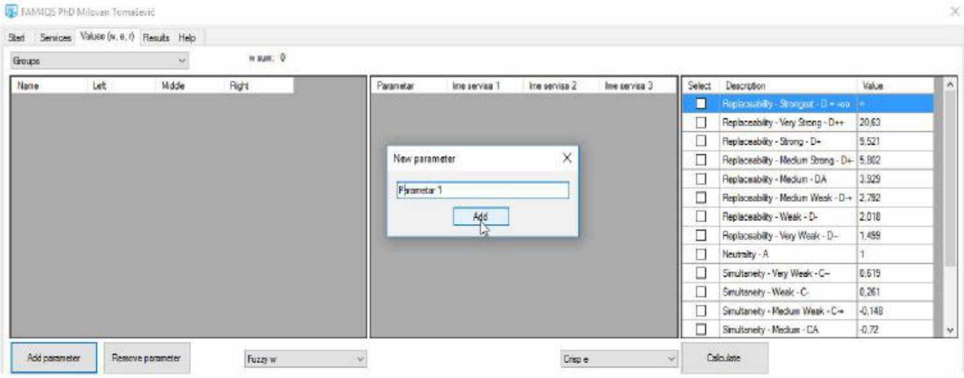

Figure 9. Entering parameters for groups

In step 5 (Figure 10), values for the parameters are entered.

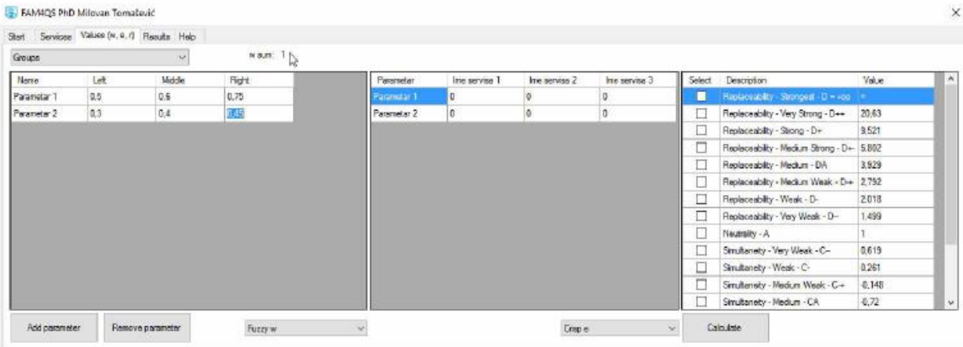

Figure 10. Entering values for parameters

In step 6 (Figure 11), a parameter is selected for entering data into subgroups.

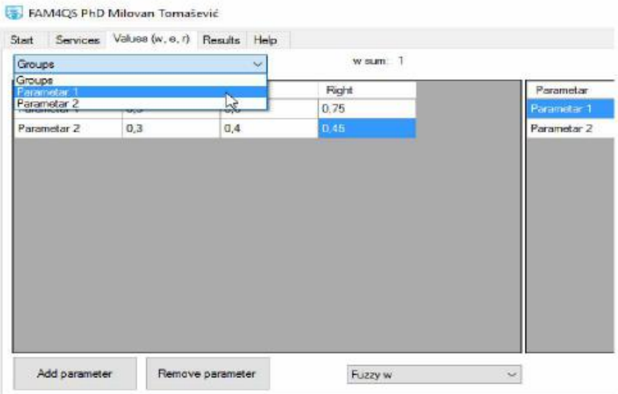

Figure 11. Selection a parameter for entering data into subgroups

In the seventh step (Figure 12), the selection of the type of parameter in the subgroup is made.

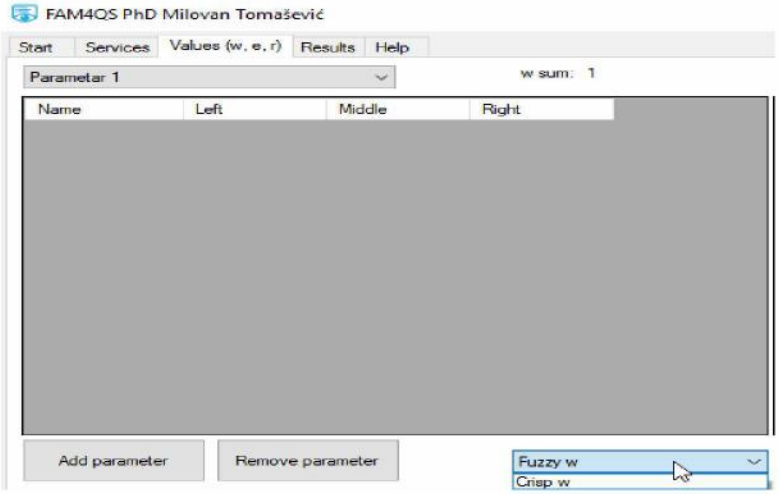

Figure 12. Selection the type of parameters in the subgroup

In the eighth step (Figure 13) subgroup parameters and assign values are entered (Figure 14):

- • weight coefficients for parameters,
- • each service is evaluated by this parameter and
- • values for r are selecting.

The values for r are taken from the nature of the data, which is explained in more detail in the previous section.

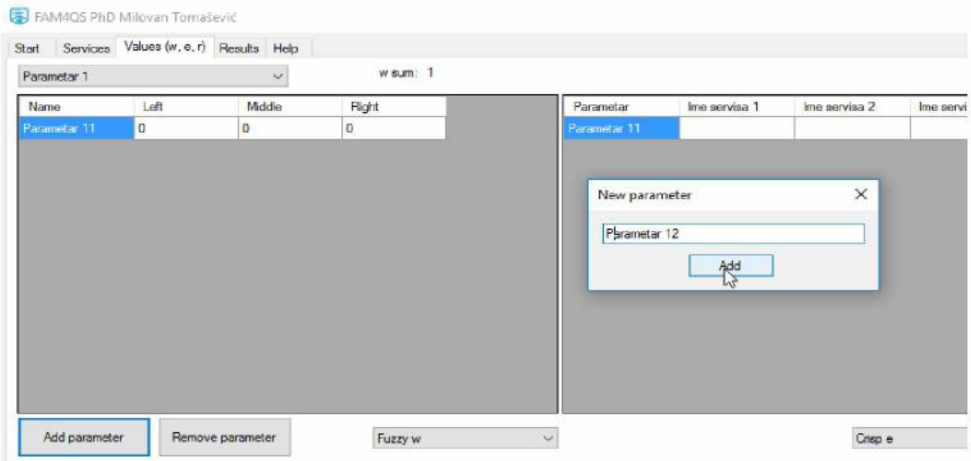

Figure 13. Entering parameters in a subgroup

Application solution to the stage of aggregation method for assessing the quality of service provided

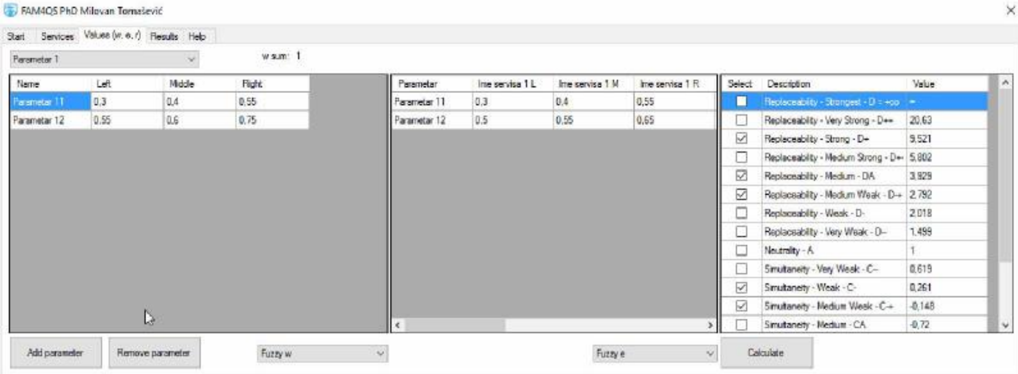

Figure 14. Assigning values to parameters from a subgroup

This process (step seven and eight) is repeated for other groups of parameters. When finished, click the *Calculate* button. In the ninth step, results are obtained as all combinations of selected values for r. In relation to the data type, results, fuzzy numbers (Figure 15) or intervals are obtained (Figure 16). The mean value of the fuzzy number is the mean value - crisp.

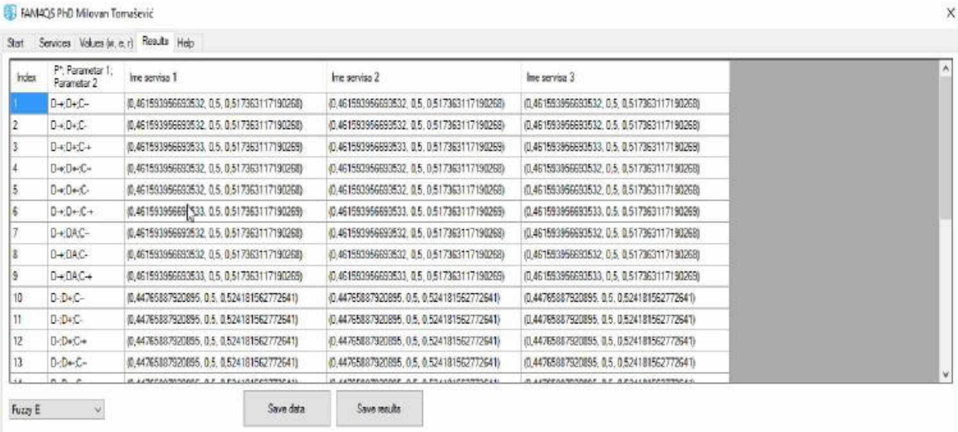

Figure 15. Results – fuzzy number

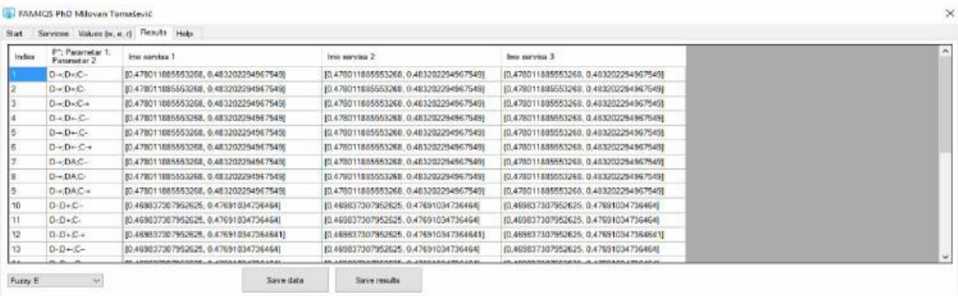

Figure 16. Results - interval

In step ten:

- • Ranking services by quality, showing them graphically,
- • Services are evaluated and
- • Analyze the best and the worst.

4. Discussion

Unlike LSP (Logical scoring of preferences), in the newly introduced model here, instead of the standard real numbers, the fuzzy numbers and the corresponding operations defined over them are observed. Justification for the introduction, i.e. replacing crisp numbers with fuzzy numbers consists of the fact that the estimates of the parameters considered in the system are either vague (imprecise) or can range in a range.

Similar to the LSP, where individual parameters are evaluated, as well as the entire service, and here it is taken into account that each of the individual parameters does not participate equally in the overall assessment, and therefore assign different weights which are in this model triangular fuzzy numbers. And for the estimates for individual parameters, the triangular fuzzy numbers are taken, which finally gives the assessment of the service that is the fuzzy number (it does not have to be necessarily triangular). For the purpose of this calculation, the apparatus fuzzy arithmetic was used, ie the display of the results as an alpha cross-section (closed interval), rather than a crisp number.

By selecting an alpha the degree of confidence in the assessment of the experts for a particular parameter is chosen, and depending on this, the result obtained is vague. The final result is mainly corrected by $\pm 5\%$ (or 10% depends on the nature of the parameters themselves) and the obtained interval values (UCL and LCL) that determine the rank (quality) of the service.

The nature of the results determines the choice of the rank of the service, that is, if the core is the fuzzy number corresponding to the estimated service, less than the left limit UCL is assigned the worst rank, and if it is higher than the right limit, the LCL is the highest ranking. All observed values of service ranges that are between these borders are of the middle rank.

Number r which occurs in the formula for estimating parameters as well as the entire service and determines whether the given rating is more or less pessimistic or optimistic, which is determined by the nature of the parameters.

In a model developed for parameter estimation, a fuzzy-aggregation function is actually used, which in its nature works with imprecise data and generates a new average value from more than one value. Therefore, this apparatus can be used to model a decision that represents some sort of averaged value from several individual imprecision decisions made, in any similar decision making where imprecise data enters. The disadvantage of this model is that the result is not precise, but it is also a result of the imprecision of the experts judgment.

5. Conclusions

Forming FAM4QS, imposed a need for the implementation of the appropriate software for its support, which was the goal of the software application of this work as well as the improvement of the support system for multi-criteria decision-making.

The software developed in this paper had the basic goal of automating the FAM4QS-based calculation based on aggregation functions. In this way, a qualitatively new approach to the FAM4QS budget is provided, and at the same time an analysis of the solutions obtained by this software solution. In addition to the calculation, the software provides a display of comparative results obtained by changing the parameters *r* over certain groups and subgroups of the given service. This enables the analysis obtained based on different parameter values r (whether the given rating of a particular service is more or less pessimistic or optimistic, which is also determined by the nature of the parameters).

The contribution of this application solution is reflected in a more faithful reflection of reality and increasing the quality of decisions made, making this process faster and more efficient. Also, the software solution is reflected in the possibility of direct application of the developed software and providing new information for the scientific and professional public, which can represent a quality basis for further development of the model for decision making.

The presented solution is general and with certain settings and a higher level of integration can be applied in different decision areas.

Research has shown that there are certain constraints that require attention and should be the subject of further research in the future:

1) Extension and testing of methods with a larger number of parameters
2) Application of neural networks
3) Developing a web system that would make it easier to make a decision, or whose result would not be a number, but a clear report based on a large projection of parameters and knowledge base (the current state - the standard).

In a mathematical view, the given model can be changed in several directions:

- By changing the aggregation function - one can observe a function that depends not only on one parameter r, but more than that of which we can adjust the criteria for evaluating the service.
- Presenting values not as triangular but as trapezoidal fuzzy numbers.

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