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RANKING THE LIBYAN AIRLINES BY USING FULL CONSISTENCY METHOD (FUCOM) AND ANALYTICAL HIERARCHY PROCESS (AHP)

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Abstract. *Performance measurement and evaluation of the airlines are a key point for improving their performance. This evaluation can help achieving the airline targets. The aim of this paper is to evaluate and compare the performance of four Libyan airlines by considering five main areas of performance; the airline reliability, employees, management, customer's satisfaction and tangibles. In this work, a hybrid method which combined the Full Consistency Method (FUCOM) and Analytical Hierarchy Process (AHP) in one system has been used to assess the four Libyan airlines. In the AHP method, the number of the required pairwise comparisons are increases dramatically with the number of the elements to be compared. The more the comparisons are the higher is the likelihood that the decision maker will introduce erroneous data. In this regard, the problem has been solved by means of using integer, decimal values from the predefined scale for the pairwise comparison of the criteria. The results show that the reliability is the most important performance area followed by satisfaction. Among the four investigated airlines, Libyan Wings were ranked first with a total 0.392 score.*

Key words: *Libyan airlines, AHP, FUCOM, MCDM.*

1. Introduction

In today's competitive market within the airline industry, delivering high-quality service has become a global marketing need. One of the key elements for airline modern industry is the evaluation of performance and effectiveness. This can support achieving the company objectives, and compare their performance with the similar best practices' businesses. In order to achieve these higher-quality levels,

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airlines need to develop a methodology to make this measurement in a profitable manner.

The air transport industry plays an important role in Africa, while it provides the essential links for the economic and physical integration in the continent. The network of the other transportation service could be inadequate. Despite the great potential and the rapid growth of air transport, Africa's share in the global air transport industry stills insignificant. The state of air transport industry in Africa is about 2.85% and 2% of global revenue passenger kilometer and global airport income respectively, and about 1% of global airlines' cargo (Njoya, 2016). Furthermore, only around 20% of intercontinental traffic between Africa and the rest of the world is controlled by African airlines. (Amankwah-Amoah, 2018).

There are many internal and external elements that lead to the limited competitiveness of the African airlines. Some of these external factors are slow implementation of the YD and protection of state-owned airlines, which have leads to the unfair competition. Furthermore, the internal factors such as limited economies of scale and quality of service have affected the ability of competition of some airlines (Amankwah-Amoah, 2018).

None of the above-mentioned studies have considered Libyan airlines in their investigation. This study responds to this need by using a list of Key Performance Indicators to assess a number of aspects of airline's performance. The aim of this work is to use a set of key performance indicators to measures and evaluate the performance of Libyan airlines. A questionnaire survey was used to gather expertise opinions across Libya. The responses to the questionnaire were then analyzed and studied with a new method which companies the Analytic Hierarchy Process (AHP) methodology and Full Consistency Method (FUCOM) in one system. The FUCOM technique was used to determine the relative weight of the KPIs and then ranked the Libyan airlines using AHP according to their KPIs.

The paper is organized as follows. Section 2 presents a literature review on MCDM Methods. Section 3 presents the Full Consistency Method FUCOM. In section 4, the case study is presented and discussed, where sixteen indicators were used to determine the performance of the airlines. Section 5 presented the determination of the weights using FUCOM method and compares it to results obtained by the AHP method, and ranks the Libyan airlines using AHP method. Finally, Section 6 presents the conclusion remarks that emerged from the analysis of the case study.

2. Literature review

Multi Criteria Decision Making MCDM methods are gaining more popularity in many fields such as logistics, supply chain management, energy, urban development, waste management, and passenger satisfaction measurement (Pamučar and Ćirović, 2015); (Tsafarakis et al., 2018, Milosavljević et al., 2018); (Petrović and Kankaraš, 2018); (Liu et al., 2018); (Vesković et al., 2018); (Pamučar et al., 2018a). MCDM methods generally work as a decision support tool to the problems containing multiple and conflicting objectives.

One of the most popular methods in MCDM techniques is Analytic Hierarchy Process (AHP) (Zietsman and Vanderschuren, 2014), which introduced by Thomas L. Saaty in 1977 (Saaty, 1980). According to (Mardani et al., 2016), AHP and its modified forms are the most commonly used methods for evaluating of transportation systems. AHP is based on the following four main components:

- Define the problem and determine the type of information required
- Structure the problem as a hierarchy
- Conduct pairwise comparisons among all criteria at every level within the hierarchy
- Compute the relative weights of the criteria

Barros and Wanke (Barros and Wanke, 2015) used two-stage TOPSIS method and neural networks to analyses the African airlines efficiency. Because of its location, Libya has a good opportunity to be a strategic air transport hub. Maertenz et al (Maertens et al., 2014) focused on the traffic between Africa and Europe and evaluates the prospects of an air transport operation in Libya. They developed a weighted average distance penalty (WADP) indicator and applied it to Tripoli airport as a potential hub location. Recently, Eshtaiwi et al. (Eshtaiwi et al., 2018) developed a set of KPI's to evaluate the performance of the Libyan airports. The grey theory model has been used to evaluate the Libyan airports (Eshtaiwi et al., 2017). Mahtani and Garg (Mahtani and Garg, 2018) adopts a multi-criteria decision making (MCDM) approach based on the technique of fuzzy Analytical Hierarchy Processing (AHP). The results indicate that that financial factors are the most critical and categorized as a major influence on the commercial stability of the airlines. Results also show that annual inflation and GDP growth rate in the country has a major influence on the sustainability of the airlines in India. Karman and Akman (Karaman and Akman, 2018) used the Analytical Hierarchical Process (AHP) to Turkish airline industry to assess and weigh the CSR program criteria among multiple alternatives. Questionnaires based on the pairwise comparison, answered by a number of experts working in different major airline companies, are used to assess the relative importance of related factors. Then, fuzzy linguistic variables are adopted to rank the selected CSR programs of airliner companies. The results indicate that CSR paradigm in the airline industry is envisaged within a restricted economic realm besieging social and environmental dimensions, rather than within the totality of systemic efforts towards multi-faceted issues.

High-quality service has become a requirement in the market among air carriers, and helps companies to gain and maintain customer loyalty. It also leads to creating competitive pressure among air carriers (Chen et al., 2011). Tsafarakis et al. (Tsafarakis et al., 2018) suggested a model for airline passenger satisfaction measurement and service quality improvement. In this context, no research has been done regarding the airline's performance measurements in Libya.

3. The Full Consistency Method FUCOM

FUCOM (Pamučar et al., 2018b) is a new MCDM method for determination criteria weights. The problems of multi-criteria decision-making are characterized by the choice of the most acceptable alternative out of a set of the alternatives presented on the basis of the defined criteria. A model of multi-criteria decision-making can be presented by a mathematical equation

$\max\left[f_1(x), f_2(x), ..., f_n(x)\right]$, $n \geq 2$, with the condition that $x \in A = \left[a_1, a_2, ..., a_m\right]$; where *n* represents the number of the criteria, *m* is the number of the alternatives, *fj* represents the criteria ($j = 1, 2, ..., n$) and *A* represents the set of the alternatives a_i ($i = 1, 2, ..., m$). The values f_{ij} of each considered criterion f_j for each considered alternative a_i are known, namely $f_{ij} = f_j(a_i), \quad \forall(i, j); \; i = 1, 2, ..., m; \; j = 1, 2, ..., n$. The relation shows that each value of the attribute depends on the j^{th} criterion and the i^{th} alternative.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions:
(1) that the ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

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

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

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

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

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

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

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

4. The case study

Expectations and actual services delivered to the customer could be used as a definition for service quality. Many activities can be used as a measure for service quality functions performed by the airlines such as ticket reservation, purchasing, check-in, comfortable and safe travelling and value-added services, such as on-board services, seat comfort, and cleanliness, luggage transportation, promotional incentives, including frequent membership programs and miles rewards, lost baggage handling and services for delayed passengers. Thus, service quality categories can be seen as a combination of various subjective and objective factors, which are difficult to evaluate appropriately.

For the purpose of assessing the Libyan airlines, sixteen indicators were used, as shown in Fig. 1. In this paper we follow the indicators suggested by (Perçin, 2018), which categorized the indicators into five groups as follows:

- Reliability: This category typically includes flight schedule and frequency, on-time performance and flight safety and security.
- Employees: The attitude among the employees towards the customers affects customers' expectations of airline service quality. Therefore, employee courtesy, responsiveness and neat appearance will probably positively influence passengers' perceptions of the airline.
- Management: A good management system is necessary for providing high-quality services to the customers. Therefore, service efficiency, service diversification and flight crew competence help airlines to satisfy customer needs.
- Satisfaction: This category includes the ability of the employees for handling customer complaints and solving problems regarding reservations, check-in, ticketing, baggage, flight delays, cancellations, and boarding situations. Nevertheless, the airline's competitive strengths can affect by the employee inability or unwillingness to handle customer complaints.
- Tangibles: Some other indicators like in-flight services such as airplane comfort and cleanliness, on-board entertainment (movies, magazines, etc.) and on-board services (meals and drinks) are of an important role on passenger satisfaction and perception of an airline's service quality.

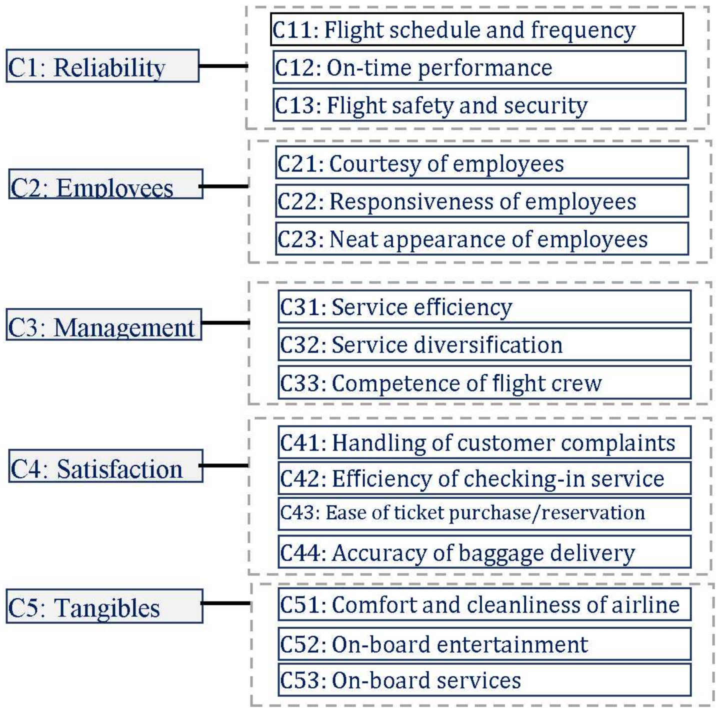

Figure 1. Performance indicators for airlines service quality measurement

There are 13 airlines operates in Libya. The four major airlines are:

Libyan airlines: It operates scheduled passenger and cargo services within Libya and to Europe, Middle east and North Africa. It founded on 1964. The company is100% owned by the government.

Afriqyiah Airways: It is a state-owned airline. It founded on 2001. It is operated domestically and to Europe, Africa, Asia, and middle east.

Libyan wings: It started operations in 2015. It is operated domestically and to two destinations (Turkey and Tunisia).

Buraq air: Founded in 2001. It operates scheduled domestic and international services to Europe, North Africa, and the Middle East.

5. Results and analysis

5.1. Results by AHP method

Table 1 shows the pairwise comparison of the main indicators, with consistency ratio (CR) equal to 10% (Saaty, 1990).

Table 1: Pairwise comparison of the main categories

	C1	C2	C3	C4	C5	ωj
C1	1	5	4	3	7	0.503
C2	1/5	1	½	1/3	1	0.077
C3	1/4	2	1	1/2	2	0.132
C4	1/3	3	2	1	3	0.216
C5	1/7	1	½	1/3	1	0.071
			CR=0.010			

5. 2. Determining the weight of the main criteria using the FUCOM method

Step 1. In the first step, the decision-makers performed the ranking of the criteria: C1> C4> C3> C2 >C5.

Step 2. In the second step (Step 2b), the decision-maker performed the pairwise comparison of the ranked criteria from Step 1. The comparison was made with respect to the first-ranked C2 criterion. The comparison was based on the scale $[1,9]$. Thus, the priorities of the criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 were obtained (Table 2).

Table 2. Priorities of criteria

Criteria	C_1	C_4	C_3	C_2	C_5
$\varpi_{C_{j(k)}}$	1	2.7	5	5.5	5.8

Based on the obtained priorities of the criteria, the comparative priorities of the criteria are calculated: $\varphi_{C_1/C_4} = 2.7/1 = 2.7$, $\varphi_{C_4/C_3} = 5/2.7 = 1.852$, $\varphi_{C_3/C_2} = 5.5/5 = 1.1$, $\varphi_{C_2/C_5} = 5.8/5.5 = 1.055$.

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

a) The final values of the weight coefficients should meet the condition (3), i.e. that $\frac{w_1}{w_4} = 2.7$, $\frac{w_4}{w_3} = 1.852$, $\frac{w_3}{w_2} = 1.1$, $\frac{w_2}{w_5} = 1.055$.

b) In addition to the condition (3), the final values of the weight coefficients should meet the condition of mathematical transitivity, i.e. that $\frac{w_1}{w_3} = 2.7 \times 1.852 = 5$, $\frac{w_4}{w_2} = 1.852 \times 1.1 = 2.037$, $\frac{w_3}{w_5} = 1.1 \times 1.055 = 1.16$. By applying the expression (5), the final model for determining the weight coefficients can be defined as:

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_1}{w_4} - 2.70\right| \le \chi,\ \left|\frac{w_4}{w_3} - 1.852\right| \le \chi,\ \left|\frac{w_3}{w_2} - 1.1\right| \le \chi,\ \left|\frac{w_2}{w_5} - 1.055\right| \le \chi, \\ \left|\frac{w_1}{w_3} - 5.00\right| \le \chi,\ \left|\frac{w_4}{w_2} - 2.037\right| \le \chi,\ \left|\frac{w_3}{w_5} - 1.16\right| \le \chi, \\ \sum_{j=1}^{5} w_j = 1,\ w_j \ge 0, \forall j \end{cases}$$

By solving this model, the final values of the weight coefficients $(0.520, 0.094, 0.104, 0.192, 0.090)^T$ and DFC of the results $\chi = 0.00016$ are obtained. The value of the criteria according to the marks given at the beginning is shown in Table 4. The model is solved using the Lingo17 software. From obtained results it can be concluded that the most important criterion is C1, followed by the criterion C4.

Table 3 presents the weight of the KPAs and KPIs. In terms of key performance areas, reliability have got the most important weight with a value of 0.506. The satisfaction ranked next with a value of 0.216, followed by the management with value of 0.0.131. Employees perspective (0.091) is ranked the fourth most important area, while the tangibles (0.059) is the least important performance area. In KPIs terms, on-time performance (0.289) is regarded as the most important indicator. Flight safety and security is the second most important key performance indicator with a value of 0.115.

Table 3: Criteria weights

Crieria	Sub-criteria	Weights (AHP)	Weights (FUCOM)
C1: Reliability		0.506	0.520
	C11: Flight schedule and frequency	0.072	0.068
	C12: On-time performance	0.289	0.306
	C13: Flight safety and security	0.145	0.146
C2: Employees		0.076	0.094
	C21: Courtesy of employees	0.016	0.021
	C22: Responsiveness of employees	0.042	0.050
	C23: Neat appearance of employees	0.018	0.023
C3: Management		0.131	0.104
	C31: Service efficiency	0.082	0.063
	C32: Service diversification	0.018	0.016
	C33: Competence of flight crew	0.031	0.025
C4: Satisfaction		0.216	0.192
	C41: Handling of customer complaints	0.053	0.039
	C42: Efficiency of checking-in service	0.047	0.033
	C43: Ease of ticket purchase/reservation	0.021	0.028
	C44: Accuracy of baggage delivery	0.94	0.098
C5: Tangibles		0.071	0.090
	C51: Comfort and cleanliness of airline	0.024	0.029
	C52: On-board entertainment	0.007	0.009
	C53: On-board services	0.040	0.052

The results obtained during this work can help the Libyan airlines to compare their performance against others in the future based on the values of the evaluated KPIs. Furthermore, the results can be used as a bases for the airlines to perform internal benchmarking by comparing the performance of different areas with itself during a period of time. The hybrid method which combined the FUCOM method and AHP analysis has been used to select the best practices for the Libyan airlines as follows: Libyan Wings ranked first with the highest importance weight of 0.392. Afriqiyah airlines ranked second with a value of 0.261, followed by Libyan airlines with a value of 0.202, and at last Buraq airlines with score of 0.145, respectively. These scores illustrated that Libyan Wings is the most efficient airlines in Libya according to the experts' opinions. Fig. 2 illustrates the performance of the four airlines in the five key performance areas. In this regards, Libyan Wings airline has the best performance in every area in comparison to the other airlines. On the other hand, Buraq airline has a low performance in management area. Buraq airline has the lowest individual score in three dimensions.

Pairwise comparisons judgements in the AHP (see Table 2) assume that the decision-maker can compare any two elements at the same level within the hierarchy and provide a numerical value for the ratio to their importance. However, a major disadvantage is that the number of the required comparisons increases quadratically with the number of the elements to be compared. Thus, in the proposed method, the assessment of the priorities from the pairwise comparison intervals will be formulated as integer, decimal values or the values from the predefined scale for the pairwise comparison with the criteria, in this regard the proposed method will maximize the decision-maker's satisfaction with a specific crisp priority vector.

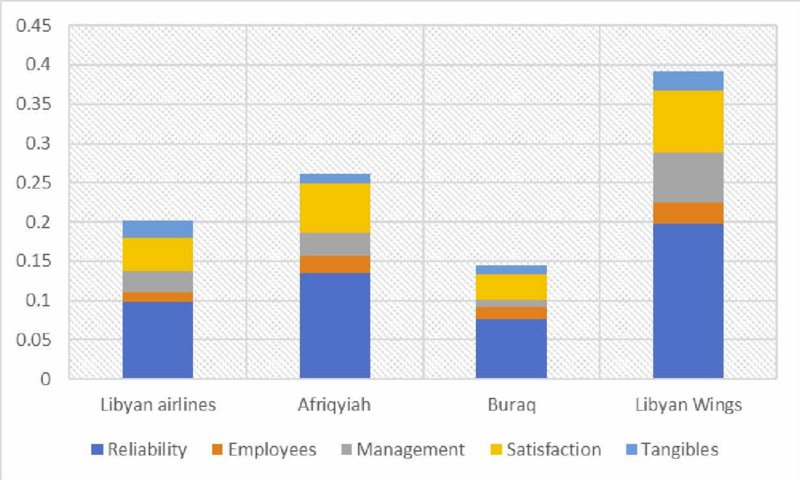

Figure 2: performance of the Libyan airlines

6. Conclusion

This paper used a set of key performance indicators to measure the performance of Libyan airlines. The value obtained in this research can be used by the Libyan airlines to benchmark their performance with other airlines which operates in similar environments. Full Consistency Method (FUCOM) and Analytical Hierarchy Process (AHP) method has been combined in one system in order rank the performance measures. The advantages of FUCOM model is that allows the pairwise comparison of the criteria by means of using integer, decimal values or the values from the predefined scale for the pairwise comparison of the criteria. The results showed that the reliability of the airline and the satisfaction areas are the most important area measures. Considering airlines ranking, Libyan Wings airline is the highest ranked airline followed by Afriqiah airline, Libyan airline, and at last Buraq airline. The model can be used as a decision support tool to improve the airlines performance. Through this paper are demonstrated advantages of FUCOM method in comparison with AHP.

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EVALUATION OF THE ECO-DRIVING TRAINING OF PROFESSIONAL TRUCK DRIVERS

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Abstract. *The paper presents the evaluation of the Eco-driving program impact (classroom with on-road instructions) on truck drivers' operation parameters. A total of 8 professional truck drivers were tested in the real driving conditions. Evaluation of the training impact on the drivers' behavior was done in three periods: intervention period (P1), one month after training (P2) and four months after training (P3). Data was collected with the assistance of the Scania Fleet Management System™. Fuel economy and CO_2 emission, idling time and coasting were significantly improved in the periods P2 and P3 compared to period P1 while speeding significantly increased. Statistically, the use of the brake did not significantly change in the first and fourth month after the completed training in comparison to the intervention period. The drivers' adoption of the eco-driving tips showed that statistically significant differences in fuel consumption and brake usage were obtained. This study shows that the use of the eco-driving techniques has got a potential for significant short-term reduction of fuel consumption and CO_2 emission in road transport; hence in the future the research studies will deal with the effects of training and potential downtrend in the long run (> 6 months). Also, future research projects should analyze the impact of the drivers' socio-economic characteristics on the application of the eco-driving instructions.*

Key Words*: Eco-driving, Truck Drivers, Effect Evaluation, Operation Parameters*

1. Introduction

Road transport produces over 80% of emissions of harmful substances within the European Union transport sector. The road transport (passenger and freight) will especially continue to dominate in the total fuel consumption, with the demand for energy in the road transport considered to be reaching 80% of total demand in the transport sector by the year of 2050 (Kojima & Ryan, 2010). Given these facts, the

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fuel economy and, subsequently, greenhouse gas emissions in this section are of the highest priorities of all the countries. The manner in which the vehicle is operated has an important impact on fuel consumption so that the driver training leads to reduction of fuel consumption (Barkenbus, 2010; ECMT, 2005) and, subsequently, emission reduction.

Eco-driving involves a series of simple rules for maximizing fuel economy of the existing cars while minimizing CO_2 emission. It is a modified way of driving that is the most suitable for modern engine technology.

Studies (Decicco & Ross, 1996; El-Shawarby, Kyoungho, & Hesham, 2005) confirm a technical aspect of the eco-driving program, namely, its operations affecting fuel consumption upmost in driving (for example, in acceleration, deceleration, maintaining constant speed and idle vehicle operation). Eco-driving in Europe, in accordance with the programs and studies (CIECA, 2007; Zarkadoula, 2007) includes the following technical regulations which are of relevance for inducing changes in the driving behavior: maintaining a steady driving speed, turning off engine at the traffic lights (while parked, when loading and unloading, etc.), an appropriate level of transmission in comparison to the type of transmission and an efficient use of brakes.

Apart from the technical recommendations, eco-driving tips also require practical advices that refer more to the restraining of driving habits and drivers' behaviors which are in accordance with the driving patterns. Studies (Wilbers, 1999; Fujikawa & Taniguchi, 2002; Ukita & Shirota, 2003; Matsuki, 2006; Barth & Boriboonsomsin, 2009; IEE, 2008) have prompted eco-driving tips which included: improvement of vehicle maintenance and that of aerodynamics, prediction of traffic conditions, avoidance of excessive vehicle weight, choice of appropriate fuel or motor oil, control of unnecessary use of equipment in the vehicle and the use of on-board computer and navigation systems (for example, simulators, driving systems, cruise control, GPS, engine speedometer, etc.)

Numerous studies have proved a feasible fuel economy of between 5% and 10%, and even in some cases, over 20% (FIAT, 2010; Wilbers, 1999; Onoda, 2009). Reduced fuel consumption also affects reduction of CO_2 emission ranging from 5-25% (Barkenbus, 2010; Mensing, Bideaux, Trigui, & Tattegrain, 2013; Onoda, 2009). The eco-driving benefits are not only limited to the reduction of CO_2 emission, and to fuel economy but are far more extensive as indicated in the given studies (CIECA, 2007; Intelligent Energy Europe, n.d.; Lauper, Moser, Fisher, Matthies, & Kaufmann-Hayoz, 2015):

- Noise reduction,
- Advancement of traffic safety,
- Minimizing of drivers' stress (that occurs when overtaking and speeding),
- Improvement of driving comfort,
- Positive influence on vehicle parts wear and tear or maintenance (for example, brakes, pneumatics), and,
- Improvement of travel time.

In this study, the evaluation of the eco-driving training efficiency was done (classroom with on-road instruction training) through operation parameters (Fuel consumption, CO_2 emission, idling time, braking events, speeding, coasting) of 8 professional truck drivers over a short-term period, and in the first month after the P2 training and the fourth month after the P3 training in comparison to the P1 training period. Besides, there is an approach which analyzes the differences in the adopted instructions among the drivers trained for eco-driving.

2. Methodology

2.1 Participants

The drivers received in-vehicle feedback (advices) and classroom training. They all volunteered to participate in the research and they did not have previous experience with the eco-driving. The drivers' average age was 32 years with SD=3.46 and their average driving experience was 7 years (SD=2.42).

2.2 Testing vehicle

When testing the drivers and measuring the operation parameters, the SCANIA model S500A4*2LA™ tractor truck composition was used, with the semitrailer Schmitz™ that was fully loaded in order to create more realistic driving conditions.

2.3 Testing route

The length of the tested route is 26,2 km in the urban and rural area of Derventa (Fig. 1). Both driving tests (before and after the training) were completed on the same route in order to avoid deviations in fuel consumption because of different distances whereas the parameters that affect fuel consumption remained identical (pressure in the pneumatics, load, etc.). In relation to the decline characteristics of the observed route, 8 sections with different lengths were formed. The biggest incline of 4.38% along the testing route was recorded in the section 4, 2.1 km long, whereas the biggest decline of 2.80% was recorded in the section 5 which is 0.5 km long (Fig. 2). These characteristics of the slope provide an opportunity for the drivers to apply the advices they received during the training on uphill-downhill driving and thus reduce fuel consumption.

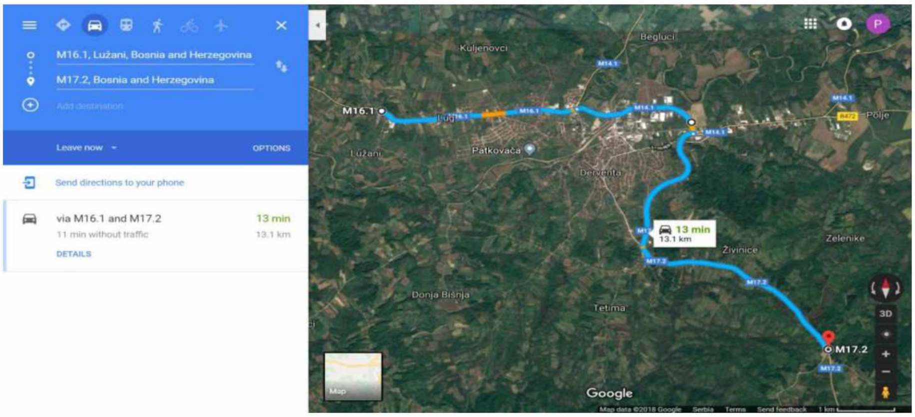

Figure 1 Testing route

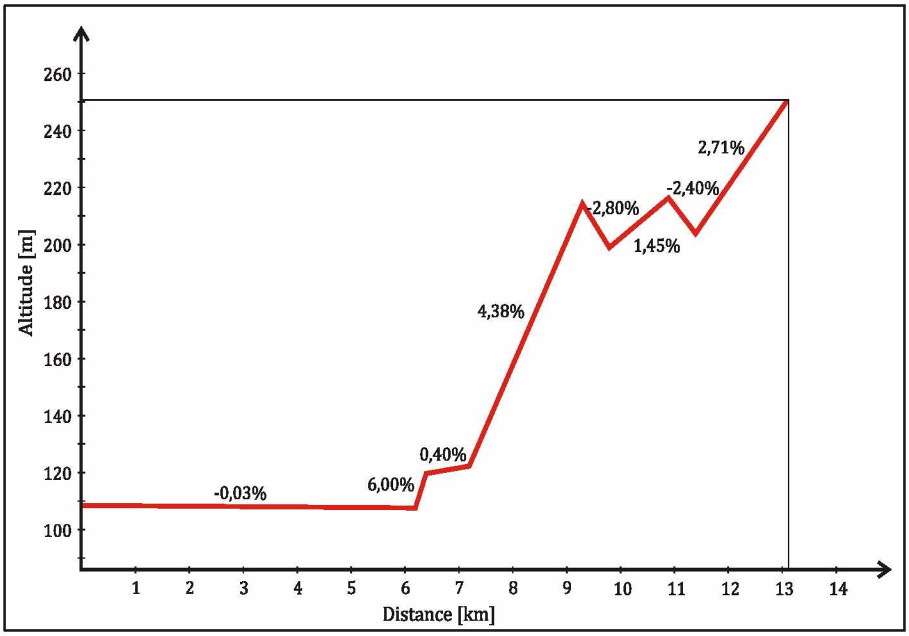

Figure 2 Slope characteristics on testing route

2.4 Measurement results

Results of the measured parameters show their monthly average values. Results comparison of the tested driving parameters (fuel consumption and other parameters) intervention period (P1), one month after training (P2) and four months after training (P3) are presented in Table 1.

2.5 Chronological phases

Phase 1: Intervention Period: March 1 to 31 March, 2018: eco-driving training was conducted for all the drivers and in-vehicle advices were given to the drivers.

Phase 2: Off Period: April 1 to 31 July, 2018: no in-vehicle advices, no eco-driving training – the driving after eco-driving interventions.

Table 1 Training diagnostic data (intervention period, one month after training and four months after training)

Training data	Periods	Driver								
		D1	D2	D3	D4	D5	D6	D7	D8	Avg.
Distance (km*10^3)	P1	22.97	24.61	21.68	22.55	22.49	23.28	22.21	26.26	23.26
	P2	35.13	37.96	31.09	33.72	30.89	35.99	32.77	38.42	34.50
	P3	72.92	82.25	72.20	75.27	63.04	77.15	73.89	81.86	74.82
	Avg.P2/P1 (%)	52.95	54.25	43.46	49.52	56.49	54.57	47.51	46.31	50.63
	Avg.P3/P1 (%)	>100	>100	>100	>100	>100	>100	>100	>100	>100
Fuel consumption (l/100km)	P1	26.3	29	26.1	26.1	26.5	26.2	24.6	27.2	26.50
	P2	23.9	26.6	25.8	25.0	24.8	24.7	22.8	26.6	25.03
	P3	24.2	26.5	25.4	23.2	24.2	25.1	23.7	26.1	24.80
	Avg.P2/P1 (%)	9.12	-8.27	-1.15	-4.21	-6.41	-5.72	-7.32	-2.21	-3.27
	Avg.P3/P1 (%)	-7.98	-8.62	-2.68	-11.11	-8.68	-4.19	-3.66	-4.04	-6.37
CO_2 emission (kg/km)	P1	0.28	0.44	0.32	0.33	0.31	0.32	0.33	0.41	0.34
	P2	0.22	0.25	0.21	0.22	0.18	0.23	0.19	0.22	0.22
	P3	0.11	0.13	0.13	0.12	0.11	0.13	0.12	0.13	0.12
	Avg.P2/P1 (%)	-21.42	-43.18	-34.38	-33.33	-41.94	-28.13	-42.42	-46.34	-36.39
	Avg.P3/P1 (%)	-60.71	-70.45	-59.38	-63.63	-64.51	-59.38	-63.63	-68.29	-63.75
Idling time (min/10^3 km)	P1	41.40	41.89	41.71	46.70	45.54	38.48	34.80	46.91	42.27
	P2	21.95	25.08	42.88	26.90	20.49	18.71	22.03	27.10	25.48
	P3	14.84	12.86	11.74	21.18	13.75	19.27	12.20	18.53	15.63
	Avg.P2/P1 (%)	-46.99	-40.11	2.82	-42.39	-55.00	-51.39	-36.70	-42.24	-39.71
	Avg.P3/P1 (%)	-64.17	-69.30	-71.85	-54.64	-69.80	-49.92	-64.92	-60.50	-63.03
Brake applications (#/100km)	P1	25.8	24.4	32.9	23.9	30.9	25.2	24.9	20.4	26.05
	P2	23.1	24.9	41.1	25.8	26.7	27.0	20.3	21.8	26.34
	P3	23.1	31.3	42.8	27.3	29.9	30.6	19.8	19.5	28.04
	Avg.P2/P1 (%)	-10.46	2.05	24.92	7.95	-13.59	7.14	-18.47	6.86	0.80
	Avg.P3/P1 (%)	-10.46	28.27	30.09	14.22	-3.24	21.43	-20.48	-4.41	6.93
Speeding (% of engine running time)	P1	11.5	1.4	2.1	20.6	0.4	11.5	0.8	0.8	6.14
	P2	40.9	1.5	27.1	35.3	9.9	31.1	23.9	38.5	26.03
	P3	38.7	5.4	14.6	40.0	8.7	37.1	28.6	40.1	26.65
	Avg.P2/P1 (%)	>100	7.14	>100	71.35	>100	>100	>100	>100	>100
	Avg.P3/P1 (%)	>100	>100	>100	>100	>100	>100	>100	>100	>100
Coasting (% of distance driven)	P1	15	16	11	19	13	17	16	17	15.50
	P2	17	18	12	20	14	19	17	18	16.88
	P3	18	18	19	18	16	19	18	19	18.13
	Avg.P2/P1 (%)	13.33	12.5	9.09	5.26	7.69	11.76	6.25	5.88	8.97
	Avg.P3/P1 (%)	20.00	12.5	72.72	-5.26	23.07	11.71	12.5	11.76	19.88

2.6 Training

This study combined classroom training with on-road instructions by the instructor. The typical eco-driving training course consists of a test drive before the classroom training where the drivers learn the eco-driving principles. After the classroom training, the second test drive is conducted during which the instructor is advising the drivers. After the second test, the results are analyzed and compared. Characteristics of the training are as follows: they are relatively expensive; a small number of people can be trained simultaneously because of the limited capacity, and the training has a great impact on the change of the driving behavior over a short period of time (Basarić, et al., 2017; Barać, Zovak, & Periša, 2013; Husnjak, Forenbacher, & Bucak, 2015). A short resume of the training can be found below.

All the participants completed the test drive held by the instructor in Derventa, before completing the classroom training on 13th March 2018 (driver 1 – driver 4) and 14th March 2018 (driver 5 – driver 8) between 9 a.m. and 11:30 a.m. which served as the base point in comparison to the test drive after the training. After that, a 90-minute-long classroom training session (from 12 a.m. to 13:30 p.m.), was held for the same group of drivers during the above periods of time. The purpose of this classroom training is to encourage the drivers to apply techniques of eco-driving after their training (for example, smooth acceleration and deceleration, turning off the engine when the vehicle is idle, predicting traffic conditions, maintaining constant speed, using engine braking, etc.). After the classroom training, the second test drive was conducted from 14 p.m. to 16:30 p.m. combining the techniques learnt from the classroom training with instructions from the instructor during the same drive. In order to assess the effects of the training, the results obtained after the second drive were discussed with the drivers.

2.7 Data collection

Data were collected with the assistance of the Scania Fleet Management System™. The Scania Communicator C300™ is connected to the vehicle *via* CAN bus, and *via* GSM network on the Scania server. All the data related to the work of vehicles and drivers can be found by logging on to the portal.

3. Results and discussion

The focus of this research study was to determine the impact of eco-driving training on drivers' behavior. A special attention was given to the analyses of the vehicle operation indicators, i.e. how the driver operates the vehicle during the training period (P1), in the first month after the training (P2) and in the fourth month after the training (P3).

Table 1 and Figs. 3-4 compare the average measuring driving quality indicators (fuel consumption, CO_2 emission, idling time, brake usage, coasting, and speeding) between the intervention period (P1), one month after training (P2) and four months after training (P3).

The values are calculated as averages for all eight drivers. Although there was a significant increase in speeding (>100%) in the first month after the training (P2) in comparison to the intervention period (P1), until an increase in braking (1,1%), there was still a small reduction in fuel consumption by 3.27% and CO_2 emission by significant 36.39%. There was also an increase in coasting by 8,97% in P2 period, i.e. the drivers used more the vehicle's motion without pressing the accelerator, and a reduction of idling by 39.71%, i.e. the drivers were often turning off the idle vehicle. This shows how idling has a significant impact on fuel consumption and, consequently, CO_2 emission. Accordingly, Beusen et al., (2009) established that 1.5% reduction of engine idling reduces an average fuel consumption by 5%, four months after completing the eco-driving course. The findings show that idling fuel cost per truck per year with six hours of idling per day is $4,134 (Omnitracks, n.d.). In addition, the literature indicates a significant impact of coasting on fuel consumption which was also established in this study. If the vehicle is moving on the straight road, coasting could reduce fuel consumption by 7,9% (Shakouri, Ordys, Darnell, & Kavanagh, 2013) whereas the coasting downhill could reduce fuel consumption by 5% (Koch-Groeber, n.d.).

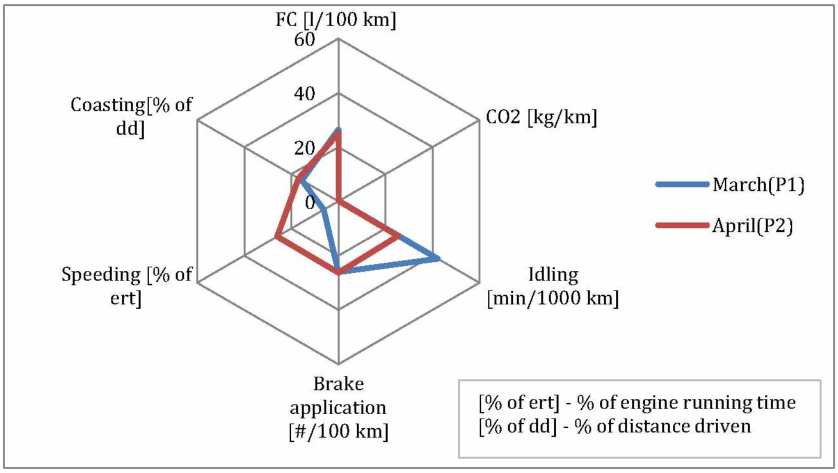

Figure 3 Radar chart with average results of eco-driving training - period P1 and period P2

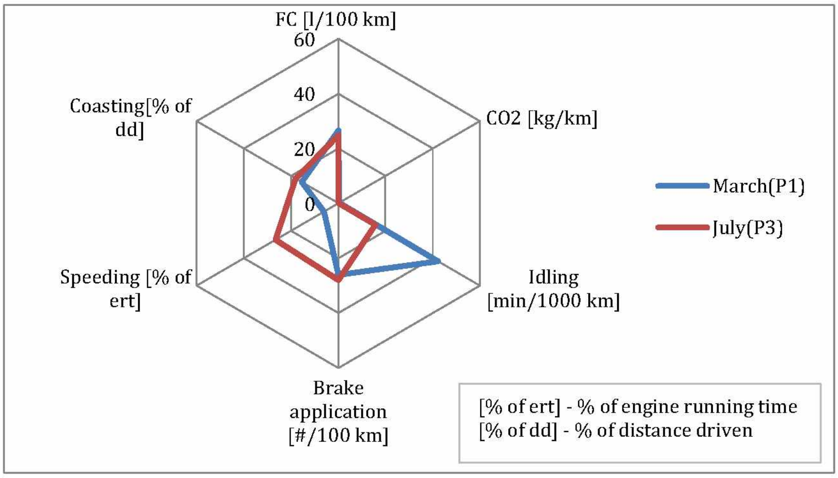

Figure 4 Radar chart with average results of eco-driving training - period P1 and period P3

There was a reduction in fuel consumption and CO_2 emission in period (P3) compared to intervention period (P1) by 6.37% and 63.75%, respectively, whereas the other observed parameters had the same tendency as in comparison to period P2 but significantly distinctive in P3 period. Accordingly, there was an increase in speeding by >100%, braking increased by 6.93% vehicle's engine running when the vehicle is not in motion decreased by 63.03%, and coasting increased by 19.88%. This case also shows that the increased vehicle motion without braking and when coasting, turning off the vehicle while idle, have a positive impact on fuel consumption and CO_2 emission.

The collected data were statistically analyzed in order to assess the effectiveness of the eco-driving training program in a short term period. The statistical evaluation of the driving parameters was conducted in the statistical program MINITAB 17 using ANOVA one-way (at 5% significance level) and Kruskal-Wallis test if there was no data correspondence with normal distribution. These tests were used to determine whether there was a statistically significant difference in the mentioned parameters by periods. Congruency with the Normal distribution was tested using Anderson-Darling Test, which showed that the fuel consumption and CO_2 emission values were susceptible to normal distribution unlike the values of idling time, brake applications, speeding and coasting. In 5 parameters (fuel consumption, CO_2 emission, idling, speeding and coasting) there is a statistically significant difference in values depending on the observation period (Table 2). In fuel consumption, CO_2 emission, idling time and coasting there was a significant improvement after the intervention period, while the speeding significantly increased in the periods after the training, which is negative.

Table 2 Summary statistics of variables by periods

Variable	Fuel consumption	CO_2 emission	Idling time	Brake application	Speeding	Coasting
AD test	0.481	0.071	0.011	0.023	0.010	0.007
P-value	0.025	0.000	0.000	0.851	0.009	0.050

Note: AD test - Anderson-Darling test

The Tukey comparison results are also used to formally test whether the difference between a pair of groups (P1-P2; P1-P3; P2-P3) is statistically significant in fuel consumption (FC) and CO_2 emission. The figures that include the Tukey simultaneous confidence intervals (Fig. 5, 6) show that the confidence interval for the difference between the means of four pairs these two parameters (P1 FC - P3 FC; P1 CO_2 – P2 CO_2; P1 CO_2 – P3 CO_2; P2 CO_2 – P3 CO_2) does not include zero which indicates that the difference is significant, i.e. the values of CO_2 emission were significantly improved in P2 and P3 periods compared to P1 period as well as period P3 compared to P1 period in terms of fuel consumption. The pairs P1 - P2 and P3 - P2 in fuel consumption have zero in the confidence interval which means that there is no statistically significant difference in fuel consumption between the periods P1 and P2 as well as P2 and P3.

To determine the difference between the pairs (levels), for parameters: idling time, speeding and coasting, the Mann-Whitney test was used. It helped establish the differences between all the pairs of the idling time parameter (P1-P2; P1-P3; P2-P3) with their p-values<0.05 as: 0.00009; 0.0009 and 0.0028, respectively. This indicates that the values of the vehicle's engine running, when the vehicle is not in motion, significantly improved in the first and the fourth month after the completed training. In addition, a significant improvement of the motion of the vehicle that is speeding without accelerating was confirmed in the period P3 compared to period P1 (p=0.0209). The differences were not detected in the pairs: P2-speeding and P3-speeding (p=0.7929); P1-coasting and P2-coasting (p=0.2076); P2-coasting and P3-coasting (p=0.3446), which indicates that there is no statistically significant difference in their medians (Table 3).

Table 3 Mann-Whitney test and Tukey comparison results

Variable Test	Fuel consumption	CO_2 emission	Idling time	Speeding	Coasting
	Tukey comparison - (interval)		Mann-Whitney test - (p-value)		
P1-P2	(-3.03489, 0.0848897)	(-0.170315, -0.0846847)	0.00009	0.0101	0.2076
P1-P3	(-3.25989, -0.140110)	(-0.262815, -0.177185)	0.0009	0.0101	0.0209
P2-P3	(-1.78489, 1.33489)	(-0.135315, -0.0496847)	0.0028	0.7929	0.3446

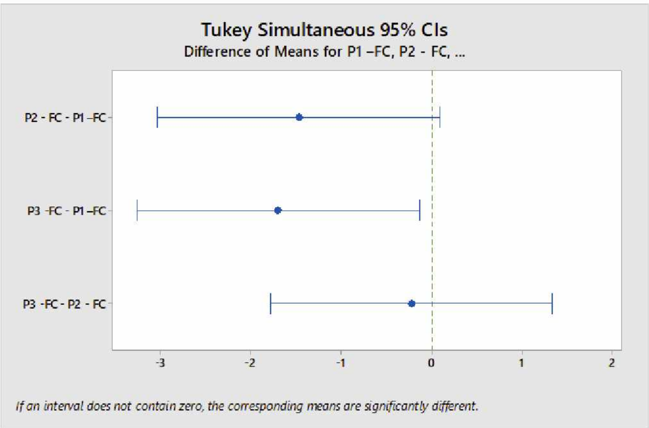

Figure 5 Tukey pairwise comparison of fuel consumption

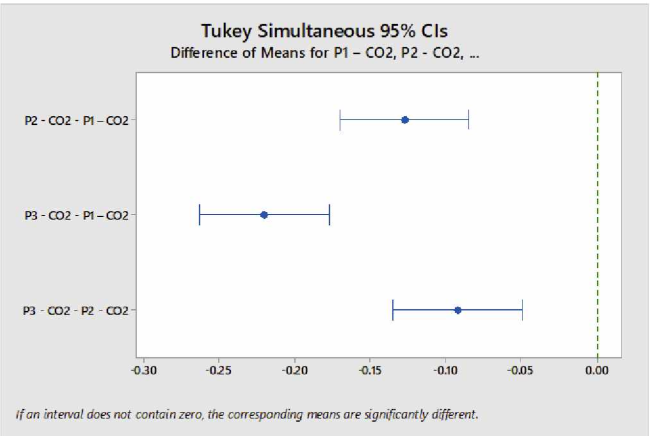

Figure 6 Tukey pairwise comparison of CO_2 emission

There is also an approach to the statistical analysis which serves to determine whether there is a difference in the adopted eco-driving instructions among the drivers. When analyzing the normality of the data set, the same p-values for the Anderson-Darling test and the eco-driving training analysis by periods, have been obtained. Accordingly, to check on whether there was a statistically significant difference in the mentioned parameters among the drivers, appropriate statistical tests have been applied in the analyses, namely, ANOVA one-way (at 5% significance level) and Kruskal-Wallis test subject to data compatibility with Normal distribution. In fuel consumption and brake usage there is a statistically significant difference in values among the drivers with $p<0.05$ (Table 4). In the other analyzed parameters no statistically significant difference has been found. Even though the drivers are of the same age and driving experience without major deviations, this points to the fact that the socio-economic characteristics of the drivers can be a significant factor for the way the eco-driving instructions are adopted and applied.

Table 4 Summary statistics of variables by drivers

Variable	Fuel consumption	CO_2 emission	Idling time	Brake application	Speeding	Coasting
AD test	0.481	0.071	0.011	0.023	0.010	0.007
P-value	0.019	0.992	0.971	0.012	0.155	0.127

Note: AD test - Anderson-Darling test

Economic benefit of eco-driving

Fuel consumption economy estimate enables calculation of the eco-driving economic benefits. If each truck spent around 32,000 liters of fuel annually, with the average fuel consumption savings of 3.27%, it could save 1,046.4 liters of fuel per truck per year. If an average cost of one liter of fuel was 1.18EUR, the annual savings per truck would be 1,235EUR. Economic gains could be even greater if we took into account a higher fuel consumption economy of 6.37% the drivers achieved 4 months after the training, on average. These savings are in accordance with the previous research results (Barać, Zovak, & Periša, 2013). They determined that the implementation of the eco-driving training could save around 1,505EUR per one commercial vehicle per year.

4. Conclusion

In this paper, the effects of the eco-driving program on the drivers' vehicle operation have been shown in a short-term period. Moreover, the effects of the driver eco-driving training were analyzed in the training period (P1) and in the first month (P2) and the fourth month (P3) after completing the training in relation to fuel consumption, CO_2 emission, idling time, brake usage, speeding and coasting. The obtained results are in accordance with the literature by showing how, with the implementation of the eco-driving, a reduction in fuel consumption and CO_2 emission in a short term period is attained. The results of the present study point to a statistically significant reduction in fuel consumption and CO_2 emission in the periods P2 and P3 compared to P1 period mostly due to a decrease of idling time parameter and increase of coasting parameter although there has been a significant increase of speeding, as proven statistically. This indicates that the targeted education about the change of drivers' behavior can be effective. Future research studies will focus on the effects of eco-driving in a long term period (> 6 months) and determine if the effects will downtrend over time. The facts obtained in this research show that the drivers' socio-economic characteristics had an impact on the eco-driving instructions adoption. Statistically significant differences in fuel consumption and brake usage among drivers were obtained. Because of these facts, future research projects should analyze this matter further.

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EVALUATION OF THE TCIS INFLUENCE ON THE CAPACITY UTILIZATION USING THE TOPSIS METHOD: CASE STUDIES OF SERBIAN AND AUSTRIAN RAILWAYS

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Abstract: *Increasing train traffic on the railway infrastructure implies the use of enlarged railway network capacity and the corresponding increase in intelligence - i.e. "intelligentization" - of the railway industries. The Train Control Information System (TCIS) as one of the most important railway systems with a significant impact on the overall railway performance in terms of its efficiency and influence upon the railway infrastructure capacity (RIC). In this paper, the model for evaluation of the TCIS influence upon the capacity utilization, based on the TOPSIS method, is proposed as an alternative to the DEA-based models. Indeed, the main drawback of the DEA-based models is that the DEA evaluates alternatives from only one point of view and classifies them as efficient or inefficient while the TOPSIS allows the benchmarking of the alternatives by detecting the best practices based on the ranking of the alternatives. For the purposes of this paper, the TOPSIS based evaluation where years represent alternatives were tested through case studies of Serbian and Austrian railways for the period from 2006 to 2015. Based on the obtained results it can be pointed out that the TOPSIS method can be applied to evaluation and comparison of the influence of different TCIS on the railway capacity (RC) utilization.*

Key Words: *Evaluation, Train Control Information System, Railway, Capacity, Multicriteria Decision-Making*

1. Introduction

According to the European Commission (2016) the railway is a "backbone of the EU transport system" and it is crucial when a rising demand for transport, traffic jams, fuel security, and decarbonisation are considered. Nevertheless, many European rail markets are still facing stagnation and downturns (European Commission, 2016), which suggests the possibility of an increase in the future rail traffic. Many of the railways are already exploiting their maximum capacity, so they will have to implement certain solutions to meet the new demand. As stated in

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(Djordjević and Krmac, 2018), the main challenge of many railways around the world is limited availability of capacity for all trains of their infrastructure related to topological configuration; although in some cases the capacity of infrastructure did not change despite doubling, tripling or quadrupling tracks.

There are many different factors influencing the railway capacity (RC) utilization. Some of the most important are timetable, signaling, nodal capacity constraints, rolling stock, infrastructure, external factors and governance. Signaling, for example, is a kind of the traffic management system (TMS), which is an important class of the Train Control Information Systems (TCIS) that provides for safe running of trains on a given infrastructure. Advanced signaling system such as the European Railway Traffic Management System (ERTMS) can provide for not only a higher level of safety but also for reduction of headways and blocking time of infrastructure (Melody, 2012) (Krmac and Djordjevic, 2017).

Regarding that the factors influencing efficiency of the railway capacity (RC) utilization are many and different as well as that signaling is one of the most important of them, in this paper the focus is on evaluation of the TCIS influence using the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method as an example of the MCDM (Multi-Criteria Decision-Making) techniques. The TCISs were already considered in (Djordjević and Krmac, 2018), where the evaluation of the TCIS impact on the railway utilization was performed using the DEA method. In this paper, the TOPSIS method is introduced as a new approach to evaluation and comparison of the TCIS influence on the RC utilization. The application of the TOPSIS method was performed on real data for Serbian and on partially assumed data for Austrian railways.

The following section presents a survey of the previous papers considering analysis, measurement, evaluation and improvement of the railway capacity (RC) utilization, as well as the MCDM methods application in this field. In Section 3 description of the TOPSIS method with selection of criteria and alternatives is presented. Results of the TOPSIS method are presented in Section 4. Finally, in Section 5 conclusions and proposals for future work are summed up.

2. Literature review

So far, the topic of railway capacity has been frequently discussed by researchers (Bevrani, 2005). Different methods for estimating the railway capacity utilization and different categorizations or classifications of these methods can be found in the referential literature (Melody, 2012).

Recently, detailed classification of methods and approaches related to the estimation of the railway capacity utilization was presented in the referential literature by (Djordjević and Krmac, 2018). In their paper, methods and approaches are grouped as analytical, optimization, and simulation methods, as well as parametric ones. The factors and parameters which affect the railway capacity utilization are identified and reviewed. Further, the literature review regarding the consideration of the TCIS influence on the capacity consumption is also presented. Moreover, (Djordjević and Krmac, 2018) also introduced a "new approach based on the DEA method for evaluation of the TCIS efficiency in improvement of the railway capacity utilization."

Considering that the RC utilization is a multidisciplinary area, other MCDM methods for evaluation of the TCIS impact on the railway capacity utilization, besides the DEA method, can be applied. Therefore, in this paper the introduction of the TOPSIS method for that purpose is considered. In order to confirm the novelty of introduction of the TOPSIS for evaluating the TCIS efficiency influence on the RC utilization, the literature is reviewed regarding the application of the TOPSIS in railway engineering.

In the evaluation of high speed transport systems where High-Speed Rail and Transrapid Maglev are presented as alternatives, after determination of the importance of particular criteria using the entropy method, Janic (2003) applied the TOPSIS to the "selection of the preferable alternative (high-speed systems) under given circumstances."

The TOPSIS method with the Multilevel grey evaluation (MGE) was employed by Chen et al. (2014) to evaluate the overall performance of passenger transfer at large transport terminals in different alternatives through a case study on the Beijing South Railway Station in China.

Zhao et al. (2018) used the TOPSIS for the evaluation of China transportation networks. In combination with cargo rates, the TOPSIS was used for three models of transportations - i.e., railway, highway, and national road – to "synthesize the evaluation of indices and three networks" with the aim of ranking the city nodes according to their importance.

The entropy-TOPSIS method was formulated and used by Huang et al. (2018) for the evaluation of operation performance of the urban rail transit system from different perspectives: operator's, passenger's, and government's.

The TOPSIS method was also used for analysis of the Swedish railway's network vulnerability of multi-commodity networks with the aim to identify critical links in the network (Whitman et al., 2017).

Bababeik et al. (2018) utilized the TOPSIS for determination of links priorities or calculation of the links while resolving the problem of "optimal location and allocation of relief trains."

The fuzzy TOPSIS with failure mode and effect analysis was proposed by Jinbao and Xing (2014) "for determination of the closeness coefficient of each failure mode of metro door fault criticality."

For measurement of a service quality of rail transit lines the Fuzzy-TOPSIS in combination with statistical analysis and trapezoidal fuzzy numbers has been adopted by (Aydin, 2017).

3. Methodology

Railway capacity and railway performance analyses often deal with multiple conflicting key indicators, what creates a high degree of complexity. The use of the MCDM can be a potential tool for solving such complexities. As an example of the MCDM methods a special DEA model – i.e., a non-radial DEA model - has been applied in (Djordjević and Krmac, 2018) as a tool for consideration of influence of the TCIS efficiency on the railway capacity utilization. However, the authors pointed out that the DEA evaluates alternatives from only one point of view and classifies them as efficient or inefficient. In order to overcome these disadvantages of the DEA method, in this paper the TOPSIS method, which enables minimization and maximization criteria simultaneously, as well as ranking of the evaluated alternatives, is proposed.

Based on the fact that the non-radial DEA model implies some weaknesses and considers decision-making units (DMUs) only from one point of view, in this paper the TOPSIS method is introduced in order to improve the disadvantage of the DEA method and consider the results of the DEA method obtained in (Djordjević and Krmac, 2018). Regarding their results of the sensitivity analysis, it can be said that the DEA is not the most suitable benchmarking tool in the field of the evaluation of the TCIS efficiency influence on the RC utilization. To overcome this weakness, a TOPSIS could be applied as a MCDM method for benchmarking the alternatives by detecting the best practices based on the ranking of alternatives and on the evaluation of the TCIS influence on improvement of the railway infrastructure capacity (RIC).

The introduction of the TOPSIS method for evaluation of the TCIS influence on the RIC and ranking of alternatives was based on its benefit in terms of the simultaneous consideration of alternatives from different viewpoints - i.e., both pessimistic and optimistic aspects - while the DEA ranking methods utilized input or output oriented aspects.

3.1 A description of the TOPSIS method

In this part of the paper, the TOPSIS method proposed by Hwang and Yoon (1981) was employed as a decision-making tool to aid decision-makers (DMs) in "trade-offing" all the alternatives. In the literature, this method has received much interest from researchers and practitioners that confirms a wide range of real-world applications across different fields and specific sub-areas (Behzadian et al., 2012). This method is based on the assumption that the selected alternative is at the shortest possible distance from the ideal positive solution and ideal negative solution. As one of the best and most frequently used MCDM methods, it implies the overall assessment, comparison and ranking of alternatives.

Since the DEA divides alternatives into efficient and inefficient with low total discrimination (Djordjević and Krmac, 2018), in this paper the aim of the TOPSIS method is to find the best alternative - i.e., to rank and solve the drawbacks of the DEA method. Consequently, the additional reason for selecting the TOPSIS for evaluation of the TCIS influence on improvement of the RC utilization and for ranking alternatives, is based on the content of the TOPSIS - i.e., decision-makers' (DM) intention to rank alternatives with the best ranking score closer to the positive ideal and to have the greatest distance from the negative ideal solution, as well as the ability to consider alternatives from both pessimistic and optimistic viewpoints - i.e., inputs and outputs like a cost and benefit criterion (Jahantigh et al., 2013), (Lotfi et al., 2011).

The following steps of the TOPSIS method, proposed by Wang et al. (2014) and Delgarm et al. (2016) were performed:

Step 1: Forming decision matrix $X = [x_{ij}]_{n\times m}$ $i = 1,2,\dots,n; j = 1,2,\dots\dots,m$. Within the decision matrix, the alternatives represent years for each case study (see Tables 1 and 2).

Step 2: Performing the normalization of decision matrix X in order to get normalized decision matrix $R = [r_{ij}]_{n\times m}$ by vector normalization method that is presented as

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \qquad (1)$$

Step 3: Calculation of the weight normalized decision matrix as

$$V = [v_{ij}]_{n\times m} = [w_i r_{ij}]_{n\times m}, \qquad (2)$$

Where w_i is a weight given to criteria from DM and sum of weights $\sum_{i=1}^{n} w_i = 1$. This method is appropriate for decision-making which is based on criteria of different importance.

Different weights were delegated to each criterion only for evaluation of the TCIS influence in terms of the obtained RIC. For each criterion weights were assigned for each case study - i.e., length of *railway network (C1)* (w_1= 0.15), *number of trains (per day) (C2)* (w_2= 0.2), *freight kilometers (C3)* (w_3= 0.2), *passenger kilometers (C4)* (w_4=0.2), *number of failures of whole system* or *its subsystem (C5)* (w_5=0.1), *punctuality of the trains (C6)* (w_6=0.15).

Step 4: Determination of positive ideal and negative ideal solutions is denoted as $A^+$and A^-, respectively. In case of the paper, $A^+$and A^- represent the best and the worst alternative, respectively, demonstrated as

$$A^+ = \left\{ \left(\max_i v_{ij} \,\middle|\, j \epsilon J_+ \right), \left(\min_i v_{ij} \,\middle|\, j \epsilon J_- \right) \middle| i = 1,2,\dots,n \right\} = \{v_1^+,\dots,v_m^+\} \qquad (3)$$

$$A^- = \left\{ \left(\min_i v_{ij} \,\middle|\, j \epsilon J_+ \right), \left(\max_i v_{ij} \,\middle|\, j \epsilon J_- \right) \middle| i = 1,2,\dots,n \right\} = \{v_1^-,\dots,v_m^-\}, \qquad (4)$$

where$J_+ = \{j_1, j_2, \dots, j_{m_1}\}$, $J_- = \{j_{m_1+1}, j_{m_1+2}, \dots, j_m\}$ and $J_+ \cup J_- = \{1,2,\dots,m\}$ are benefit and cost criteria, respectively. In this case of the TOPSIS method application, the benefit criteria are represented by *length of railway network (C1), number of trains (per day) (C2), freight kilometers (C3), passenger kilometers (C4),* while the cost criteria include *number of failures of whole system* or *its subsystem (C5),* and *punctuality of the trains (C6).*

Step 5: Calculation of the separation measure between each alternative by Euclidean distance. The separation of each alternative from the positive ideal is given as

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^+\right)^2} \;, i = 1,2,\dots\dots,n., \qquad (5)$$

while the separation from the negative ideal is given as

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2} \,, i = 1,2,\dots\dots,n. \qquad (6)$$

Step 6: Calculation of relative closeness A_i to positive ideal solution A^+ defined as

$$A_i = S_i^+/(S_i^+ + S_i^-)\,,\ 0 \leq A_i \leq 1,\ i = 1, 2, \dots, n. \quad (7)$$

If $A_i = 1$ is clear that alternative is the best, and $A_i = 0$ than alternative is the worst. Alternative is closer to the best as A_i approaches 1.

Step 7: Ranking the alternatives according to A_i, where a higher value of A_i denotes a better solution in terms of the TCIS influence on improvement of the RIC.

3.2 Application of the TOPSIS method to evaluation of the TCIS efficiency on the obtained RIC

3.2.1 Selection of criteria

Based on the factors that affect RC, reviewed by (Djordjević and Krmac, 2018), available data, and the fact that other indicators can also be used for RC description, adequate criteria for the evaluation of the TCIS influence on the obtained RIC were selected. The obtained railway capacity is presented based on the required capacity and spare capacity. Spare capacity might absorb variations from day to day or a future traffic increase (Nystrom, 2009).

Regarding that railway transportation can be viewed as a production process, the *length of railway network (C1)* and *number of trains per day (C2)* were selected as timetable indicators. The *number of trains per day* also represents one of the main indicators of the infrastructure capacity, which is related to the infrastructure availability (Patra et al., 2010). As outputs of railway transportation as production process, the *realized freight (tkm) kilometers (C3)* and *passenger kilometers (C4)* (Boysen, 2012) were included as criteria in the TOPSIS method. On the liberalized railway markets higher values of *C1* and *C2* produce higher capacity. Therefore, "capacity is the maximum amount that can be produced in relation to the limiting constraints from infrastructure, rolling stock or staff" (Boysen, 2012). According to (Djordjević and Krmac, 2018) two more criteria were selected: criteria that is closely related to the functioning of the TCIS – the *number of failures of the whole system or its subsystem (C5)*, and criteria *punctuality of the trains (C6)*, which is the result of system failures and is related to the infrastructure availability (Patra et al., 2010).

3.2.2 Selection of alternatives and case studies

The second important stage of the TOPSIS methodology is the selection of alternatives. At the beginning of the TOPSIS method application and the analysis of the results of the model, the TCIS used at Serbian and Austrian railways were considered as case studies. Because the railways of Serbia and Austria are significantly different in terms of length of the network and volume of the transport, they were not compared. Hence, in the study these case studies were evaluated separately while years as alternatives were jointly considered for each case study. So, the alternatives of the selected case studies represent years. For each Serbian alternative real data were used. Data for criteria such as *number of trains (per day)* and *punctuality of the trains* were collected from planned and realized timetables, data of the *number of failures* were collected from the Serbian railways evidence, while *realized freight and passenger kilometers* and *length of railway network* data were extracted from Serbian statistics (Djordjević and Krmac, 2018).

Real data for the Austrian case, published by (OBB, 2016), were used only for 2015 and were collected for *length of railway network* and *number of trains (per day)* while Eurostat data for *freight and passenger kilometers* was used. However, because of missing data for *number of failures* and unavailability of data for other years, these data were assumed. The data for Serbian case study are presented in Table 1 while those for Austrian case study in Table 2. Since the data for each case study were not collected from the same source, there is a doubt in terms of the data and results accuracy.

Table 1. Data used for the TOPSIS method – Serbian case study

Alternatives/DMUs	Serbian case					
	C1	C2	C3	C4	C5	C6
2006	3819	1.510	684110	4232	55	40%
2007	3819	1.515	687002	4551	43	55%
2008	3819	1.502	583071	4339	38	60%
2009	3819	1.430	522033	2967	35	65%
2010	3819	1.431	521933	3522	39	60%
2011	3819	1.431	540911	3611	34	70%
2012	3819	1.430	539727	2769	23	80%
2013	3819	1.433	612495	3022	34	70%
2014	3819	1.420	452963	2988	27	80%
2015	3739	1.436	508678	3249	30	80%

Table 2. Data used for the TOPSIS method – Austrian case study

Alternatives/DMUs	Austrian case					
	C1	C2	C3	C4	C5	C6
2006	9646*	6.327*	110778	8907	8	90%*
2007	9646*	6.329*	115526	9167	7	95%*
2008	9646*	6.345*	121579	10365	7	95%*
2009	9646*	6.332*	98887	10184	9	80%*
2010	9646*	6.340*	107670	10263	10	85%*
2011	9646*	6.340*	107587	10778	7	95%*
2012	9646*	6.339*	100452	11211	6	96%*
2013	9646*	6.330*	95449	11804	8	90%*
2014	9646*	6.335*	98281	11981	7	95%*
2015	9646	6.340	97642	12104	5	96.3%

*- denotes assumed data

4. Results of the TOPSIS method

Both the railway capacity (RC) analysis and the railway performance analysis often deal with multiple conflicting key performance indicators (KPIs) (Bevrani, 2015). These complexities can be a subject of the MCDM. As the main MCDM method in our case, the TOPSIS method, which enables minimization and maximization criteria simultaneously as well as ranking of evaluated alternatives, is proposed.

Therefore, the TOPSIS method with both viewpoints - i.e., pessimistic and optimistic - is used in order to evaluate and rank alternatives. Moreover, in this paper, the TOPSIS is employed with the aim of checking the results of the non-radial DEA model applied in (Djordjević and Krmac, 2018). The results of the TOPSIS method are calculated using Excel environment and are summarized in Table 3.

In terms of Serbia, the best influence of the TCIS on the obtained RIC was in 2007, while in Austria the best impact of the TCIS on capacity was in 2008 (see Table 3).

From Table 3 the rank for other alternatives/years in terms of the TCIS influence on the obtained RIC may be seen.

Table 3. Results of the TOPSIS method

Alternatives/DMUs	Serbian case		Austrian case	
	Ci	Rank	Ci	Rank
2006	0.6223	3	0.4588	6
2007	0.6942	1	0.5981	2
2008	0.6233	2	0.6158	1
2009	0.3574	9	0.3441	10
2010	0.4335	5	0.3758	9
2011	0.4436	4	0.4892	4
2012	0.3904	7	0.4737	5
2013	0.4203	6	0.4401	7
2014	0.3388	10	0.4350	8
2015	0.3625	8	0.5215	3

However, considering the characteristics and the process, the results of the TOPSIS method were different from expected in comparison with the results obtained by the non-radial DEA model in (Djordjević and Krmac, 2018). For instance, for the Serbian case study, Alternative 2007 was ranked as 1 by the TOPSIS and also had the best value of efficiency obtained by the non-radial DEA model, while for 2012 with efficiency 1 the rank was 7. Also for the Austrian case study, the results of the TOPSIS method were different from the results of the non-radial DEA model. For example, Alternative 2008 had a rank of 1 and had also obtained the best efficiency by the non-radial DEA model. However, the year 2015 with a rank of 3 by the TOPSIS had an efficiency score of 1 by the non-radial DEA method. The reason for differences in the results should be found in the fact that the DEA considered inputs for a given level of outputs while the TOPSIS method differed thusly; seeking the best alternatives, closest to the ideal positive solution and furthest from the negative. Another reason for differences in the results is the involvement of weights for each criterion, not only for variables in the goal function in the non-radial DEA model.

5. Conclusion

Increasing train traffic on the railway infrastructure, such as the state of railways in EU, implies the use of enlarged railway network capacity. To realize all necessary changes and increase speed, capacity and higher overall performance, the railway industries have to move towards so-called “intelligentization” creating “modern railway transport” (Li et al., 2003). In terms of railway, according to Fantechi et al. (2014), “one such example of complex systems refers to the TCIS which is characterized by a large number of components of various kinds (mechanical, electrical, computer, etc.) that have different types of interactions (local, simultaneous, etc.) which are interconnected and operate in synergy with each other.” In order to evaluate the TCIS efficiency influence on the RIC, the non-radial DEA model was introduced in (Djordjević and Krmac, 2018). However, based on the disadvantages of the DEA method described above, in this paper the TOPSIS method, which allows ranking of considered alternatives and enables their evaluation from pessimistic and optimistic point of view, was introduced. The evaluation where years represent alternatives was tested through case studies of Serbian and Austrian railways for the period from 2006 to 2015. While data for Serbian railways were real, those for Austrian railways were mainly assumed. Based on the obtained results it can be pointed out that the TOPSIS method can be applied to evaluation and comparison of the influence of different TCISs on the RC utilization.

As future work, the proposed method can be applied to a comprehensive and accurate set of real data, using different variables or criteria, along with the performance of validity check. The proposed method could also be applied on the micro level, - i.e., the evaluation of the TCIS influence on the capacity utilization for a particular line. Likewise, it could also be applied to other concepts of capacity.

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INTEGRATED MCDM MODEL FOR PROCESSES OPTIMIZATION IN THE SUPPLY CHAIN MANAGEMENT IN THE WOOD COMPANY

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Abstract. *Supply chain management (SCM) is a global strategy in nowadays business environment. It is a useful tool for managing a number of processes and activities on a daily basis in order to achieve a competitive advantage. Also, in order to achieve adequate bases for successful functioning, it is necessary to know their abilities and weaknesses; this knowledge, yet, requires decomposition of the overall system. In this paper the decomposition in a wood company and its supplier selection in the subsystem of procurement is performed. For determining criteria weights the Full Consistency Method (FUCOM) is applied while the ranking of suppliers is performed using the Weighted Aggregated Sum Product Assessment (WASPAS) method. The obtained results are checked through the sensitivity analysis that is formed with modeling of criteria weights. In the sensitivity analysis it was found that the changes in the significance of the criteria could influence the decision-making and ranking of suppliers.*

Key Words: *FUCOM, WASPAS, SCM, Evaluation of Suppliers, Decomposition*

1. Introduction

A system approach to management is the base of every company's success because optimization is directly related to cost reduction across the supply chain. The supply chain management, as a new field of research for economists, provides a lot of examples where it is almost impossible to reach precise evaluation of the variables affecting the decision-making (Kozarević and Puška, 2018). Modern production is increasingly complex with regard to the participation of technology or production processes or operations. In complex process manufacturing, logistics is particularly important because it combines all the processes from the procurement of materials to the distribution of finished or semi-finished products. For the production process to be efficient, it is necessary to optimize the procurement

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subsystem. In doing so, great coordination is needed of the preparation, storage, and, especially, production system.

In this paper, the decomposition of logistics systems was first performed, i.e. the division of the same into procurement of materials, drying of boards, production, packaging, and distribution. In the part of the materials' procurement, the supplier was evaluated according to the seven criteria, ranking from the best to the worst. The FUCOM methods for determining weight coefficients and the WASPAS methods for ranking suppliers were used. The selection of suppliers is the first step in the process of product realization, starting from the procurement of materials to the delivery of the product (Stević et al. 2017b; Puška et al. 2017). The aim of the paper is to integrate all the processes of the logistics system, starting from the procurement. i.e. selection of the best supplier, *via* the production processes to the distribution. In addition, the goal of the paper is to create an adequate basis for future actions that involve the segmentation of the key performance indicators based on the performed logistic system decomposition, and their measurement and monitoring. The research was carried out in the wood design company "Wood Design" Ltd. in Bosnia and Herzegovina. By using the FUCOM method for determining criteria weights and the WASPAS method for ranking alternatives we obtain that Supplier 1 represents the best solution.

After the introductory considerations, the second part presents the algorithm of the used methods. In the third part of the paper, a case study was presented with a detailed explanation of the calculation. The fourth part presents the sensitivity analysis and the discussion of the obtained results, while in the fifth section the final considerations are presented.

2. Methods

By applying multi-criteria decision-making methods, it is possible to make valid decisions in different areas. Some of these decisions are: selection of adequate strategies, rationalization of logistics processes, and the decision-making that has an impact on the operations of companies or their subsystems, as evidenced by the next research (Stević et al. 2015; Stević et al. 2016; Ranjan et al. 2016; Jusoh et al. 2018)

2.1 Full Consistency Method (FUCOM)

The FUCOM method represents a new method for determining criteria weights developed by Pamučar et al. (2018). So far it is applied in few studies: (Prentkovskis et al. 2018; Nunić, 2018; Pamučar et al. 2018; Zavadskas et al. 2018; Fazlolahtabar et al. 2019). It consists of the following three steps:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.2 WASPAS method

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

WASPAS methods consist of the following steps:

Step 1 Formatting of initial decision matrix (X). The first step is to evaluate *m* alternatives by *n* criteria. Alternatives are shown to the vectors: $A_i = \left(x_{i1}, x_{i2}, \ldots, x_{in}\right)$ where x_{ij} is value of i-th alternatives according to j-th criterion $\left(i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n\right)$.

$$X = \begin{matrix} \\ A_1 \\ \ldots \\ A_m \end{matrix} \begin{matrix} C_1 & \ldots & C_n \\ \left(\begin{matrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{matrix}\right) \end{matrix} \tag{6}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Step 6 Determination of the relative values of alternative A_i:

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

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

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

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

3. Case study

3.1 Decomposition of the logistic systems

The decomposition of the logistics of the system implies the division of the system into several smaller subsystems. Concretely, in this case, the decomposition was performed on the following subsystems: procurement, boards' drying, production, packaging and, finally, distribution of finished or semi-finished products.

The process of the boards drying and its length depend on the type of wood, its moisture and dimensions. This process lasts from 15 to 100 days. When the drying process is completed, the acclimatization process of the board is performed where the board equals the outside temperature with the temperature in the chamber as well as moisture. This process takes 48 hours. When it is all over, the board is fully ready for use and technical processing. After that, the boards must be properly stored.

The production at the company "Wood Design" Ltd. Usora is performed in 6 stages in order to reach the desired product. The phases are:

1. Cutting the boards,
2. Machining of the board on a four-sided machine,
3. Pairing the board,
4. Pressing and gluing,
5. Cutting to a certain length, and,

6. Sanding the boards on both sides.

After finishing the sanding of the boards, the next and final operation before delivery is the packaging of the boards. In this company, the finished packages are wrapped with stretch foil. The boards are packed in the pallets which are 66 cm wide while their length depends on the required package of the customer. 25 panels are placed in one pallet. When packing furniture boards, 10 boards are placed in one pallet, and each plate is wrapped in nylon, unlike the plates. The other principle of packaging is the same.

As for the deadline for delivering of ready-made boards, it is usually two weeks after the date of the received order, or one week if the order is urgent. Of course, the semi-finished products can be ordered earlier if the customer is not a priority.

3.2 Supplier selection in the wood company

The criteria for the evaluation of the supplier are shown below: C1 - quality of material, C2 - price of materials, C3 - product certification, C4 - delivery time, C5 - reputation, C6 - additional discount on quantity, C7 - warranty period, C8 - reliability, C9 - payment method. These criteria have been used in the following studies (Puška et al. 2018; Stević et al. 2017b; Stojić et al. 2018). The research was carried out at the company "Wood Design" Ltd., and accordingly, a supplier evaluation table was given with six suppliers taken into consideration. It should be noted that the criteria C1, C3, C5, C6, and C8 qualitative indicators are evaluated according to the linguistic scale in (Stević et al. 2017): 1 – excellent, 3 – very good, 5 – good, 7 – medium, 9 – poor, in the case that the criterion should be minimized. In the case where the criteria should be maximized, the evaluation is entered in reverse order. The C2, C4, C7 and C9 quantitative indicators are shown as the cash units for the price of the material, that is, during the delivery days, the warranty period and the method of payment.

Table 1. Initial MCDM matrix

	C1	C2	C3	C4	C5	C6	C7
D1	9	1200	9	5	7	5	7
D2	7	1000	7	3	5	7	3
D3	9	1250	9	7	15	3	9
D4	9	1150	7	5	7	5	5
D5	5	750	9	5	3	9	3
D6	9	1200	9	5	15	7	1

According to criteria C5 and C6, all suppliers have an equal estimate of 5 of 9. In the next step, these criteria are eliminated because they have no influence on making the final decision. Also, it is important to note that the suppliers are evaluated according to the criterion "payment method" on the basis of the following facts:

1 - Advance 30% before delivery; 3 - Cash (payment upon download); 5 - delay up to 7 days after delivery; 7 - delay up to 15 days after delivery; 9 - delay up to 30 days after delivery.

3.2.1 Determining criteria weights using the FUCOM method

Step 1 Ranking the criteria:

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

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

Table 2. Ranking and assessment of the criteria

Criteria	C1	C2	C4	C7	C6	C5	C3
$\omega_{j(k)}$	1	2	2.3	2.7	3	3.8	4

On the basis of the obtained significance of the criteria (Table 2) it is necessary to calculate comparative priority of the criteria:

$$\varphi_{C_1/C_2} = 2/1 = 2,\ \varphi_{C_2/C_4} = 2.3/2 = 1.15,\ \varphi_{C_4/C_7} = 2.7/2.3 = 1.17$$
$$\varphi_{C_7/C_6} = 3/2.7 = 1.11,\ \varphi_{C_6/C_5} = 3.8/3 = 1.27,\ \varphi_{C_5/C_3} = 4/3.8 = 1.05$$

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

a) The final values of the weight coefficients should meet condition (3), i.e. that $\frac{w_1}{w_2} = 2$, $\frac{w_2}{w_4} = 1.15$, $\frac{w_4}{w_7} = 1.17$, $\frac{w_7}{w_6} = 1.11$, $\frac{w_6}{w_5} = 1.27$ and $\frac{w_5}{w_3} = 1.05$.

b) In addition to condition (3), the final values of the weight coefficients should meet the condition of mathematical transitivity, i.e. that $\frac{w_1}{w_4} = 2\times 1.15 = 2.3$, $\frac{w_2}{w_7} = 1.15\times 1.17 = 1.35$, $\frac{w_4}{w_6} = 1.17\times 1.11 = 1.30$, $\frac{w_7}{w_5} = 1.11\times 1.27 = 1.41$ and $\frac{w_6}{w_3} = 1.27\times 1.05 = 1.33$.

By applying expression (5), the final model for determining the weight coefficients can be defined as:

$$\min \chi$$
$$s.t.\begin{cases} \left|\frac{w_1}{w_2}-2\right| \le \chi,\ \left|\frac{w_2}{w_4}-1.15\right| \le \chi,\ \left|\frac{w_4}{w_7}-1.17\right| \le \chi,\ \left|\frac{w_7}{w_6}-1.11\right| \le \chi,\ \left|\frac{w_6}{w_5}-1.27\right| \le \chi,\ \left|\frac{w_5}{w_3}-1.05\right| \le \chi, \\ \left|\frac{w_1}{w_4}-2.3\right| \le \chi,\ \left|\frac{w_2}{w_7}-1.35\right| \le \chi,\ \left|\frac{w_4}{w_6}-1.3\right| \le \chi,\ \left|\frac{w_7}{w_5}-1.41\right| \le \chi,\ \left|\frac{w_6}{w_3}-1.33\right| \le \chi, \\ \sum_{j=1}^{7} w_j = 1,\ w_j \ge 0, \forall j \end{cases}$$

By solving this model, the final values of the weight coefficients are:

Quality of material $w_1 = 0.317$, price of material $w_2 = 0.159$, product certification $w_3 = 0.080$, delivery time $w_4 = 0.138$, warranty period $w_5 = 0.083$, reliability $w_6 = 0.106$, payment method $w_7 = 0.118$ and DFC of results $\chi = 0.001$ are obtained.

After obtaining the results we can conclude that the first criterion quality of material is the most important one with value 0.317.

3.2.2 Supplier evaluation and selection using the WASPAS method

In Table 3 the multi-criteria decision-making model is shown as consisting of seven criteria and six alternatives, i.e. suppliers. This represents the first step of the WASPAS method.

Table 3. Initial decision-making matrix extended with criteria orientation

	C1	C2	C3	C4	C5	C6	C7
S1	9	1200	9	5	7	5	7
S2	7	1000	7	3	5	7	3
S3	9	1250	9	7	15	3	9
S4	9	1150	7	5	7	5	5
S5	5	750	9	5	3	9	3
S6	9	1200	9	5	15	7	1
	MAX	MIN	MAX	MIN	MAX	MAX	MAX
	9	750	9	3	15	9	9

Step 2 Normalization of initial matrix (Table 4) using the following equations:

$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}}$ for criteria C1, C3, C5, C6 and C7,

i.e. $n_{ij} = \frac{\min_i x_{ij}}{x_{ij}}$ for criteria C2 andC4.

Table 4. Process of calculation for normalization of initial matrix

	C1	C2	C3	C4	C5	C6	C7
S1	9/9	750/1200	9/9	3/5	7/15	5/9	7/9
S2	7/9	750/1000	7/9	3/3	5/15	7/9	3/9
S3	9/9	750/1250	9/9	3/7	15/15	3/9	9/9
S4	9/9	750/1150	7/9	3/5	7/15	5/9	5/9
S5	5/9	750/750	9/9	3/5	3/15	9/9	3/9
S6	9/9	750/1200	9/9	3/5	15/15	7/9	1/9

Results obtained using normalization process are shown in Table 5.

Table 5. Normalized matrix

	C1	C2	C3	C4	C5	C6	C7
S1	1	0.625	1	0.6	0.467	0.556	0.778
S2	0.778	0.75	0.778	1	0.333	0.778	0.333
S3	1	0.6	1	0.429	1	0.333	1
S4	1	0.652	0.778	0.6	0.467	0.556	0.556
S5	0.556	1	1	0.6	0.2	1	0.333
S6	1	0.625	1	0.6	1	0.778	0.111

Step 3 Multiplication of the previously obtained matrix with criteria weights. Using the following equation:

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

In Table 6 the normalized matrix with criteria weights is shown.

Table 6. Normalized matrix with criteria weights

	C1	C2	C3	C4	C5	C6	C7
S1	1	0.625	1	0.6	0.467	0.556	0.778
S2	0.778	0.75	0.778	1	0.333	0.778	0.333
S3	1	0.6	1	0.429	1	0.333	1
S4	1	0.652	0.778	0.6	0.467	0.556	0.556
S5	0.556	1	1	0.6	0.2	1	0.333
S6	1	0.625	1	0.6	1	0.778	0.111
W	0.317	0.159	0.080	0.138	0.083	0.106	0.118

Example of calculation:

$$v_{11} = 0.317 \times 1.000 = 0.317$$

$$v_{12} = 0.159 \times 0.625 = 0.099$$

Weighted normalized matrix is shown in Table 7.

Table 7. Weighted normalized matrix

	C1	C2	C3	C4	C5	C6	C7
S1	0.317	0.099	0.080	0.083	0.039	0.059	0.092
S2	0.247	0.119	0.062	0.138	0.028	0.082	0.039
S3	0.317	0.095	0.080	0.059	0.083	0.035	0.018
S4	0.317	0.104	0.062	0.083	0.039	0.059	0.066
S5	0.176	0.159	0.080	0.083	0.017	0.106	0.039
S6	0.317	0.099	0.080	0.083	0.083	0.082	0.013

Step 4 Summarizing of all values per alternatives (Summarizing per rows, Table 8)

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

Example:

$$Q_1 = 0.317 + 0.099 + 0.080 + 0.083 + 0.039 + 0.059 + 0.092 = 0.769$$

Table 8. Calculation of Qi

	C1	C2	C3	C4	C5	C6	C7	Qi
S1	0.317	0.099	0.080	0.083	0.039	0.059	0.092	0.769
S2	0.247	0.119	0.062	0.138	0.028	0.082	0.039	0.715
S3	0.317	0.095	0.080	0.059	0.083	0.035	0.018	0.687
S4	0.317	0.104	0.062	0.083	0.039	0.059	0.066	0.730
S5	0.176	0.159	0.080	0.083	0.017	0.106	0.039	0.660
S6	0.317	0.099	0.080	0.083	0.083	0.082	0.013	0.757

Step 5: Determining of the weighted product model using the following equation (Table 9): $p_{ij} = \prod_{j=1}^{n} (v_{ij})^{wj}$, Example:

$$P_1 = (1.000)^{0.317} \times (0.625)^{0.159} \times (1.000)^{0.080} \times (0.600)^{0.138} \times (0.467)^{0.083}$$
$$\times (0.056)^{0.106} \times (0.778)^{0.118} = 0.741$$

Table 9. Weighted product model

	C1	C2	C3	C4	C5	C6	C7	Pi
S1	1	0.625	1	0.6	0.467	0.556	0.778	0.741
S2	0.778	0.75	0.778	1	0.333	0.778	0.333	0.675
S3	1	0.6	1	0.429	1	0.333	1	0.730
S4	1	0.652	0.778	0.6	0.467	0.556	0.556	0.703
S5	0.556	1	1	0.6	0.2	1	0.333	0.594
S6	1	0.625	1	0.6	1	0.778	0.111	0.655
W	0.317	0.159	0.080	0.138	0.083	0.106	0.118	

Step 6 Determining of relative values alternatives *Ai*.

We have taken value λ=0.5.

$$A_1 = 0.5 \times 0.769 + (1 - 0.5) \times 0.741 = 0.755$$

Step 7 Ranking of the alternatives (Table 10). Alternative with the biggest value represents the best ranked while the smallest value denotes the worst alternative.

Table 10. Ranking of alternatives

	Qi	Pi	Ai
Supplier 1	***0.769***	***0.741***	***0.755***
Supplier 2	*0.715*	*0.675*	*0.695*
Supplier 3	*0.687*	*0.730*	*0.709*
Supplier 4	*0.730*	*0.703*	*0.717*
Supplier 5	*0.660*	*0.594*	*0.627*
Supplier 6	*0.757*	*0.655*	*0.706*

$$S_1 > S_4 > S_3 > S_6 > S_2 > S_5$$

Using the FUCOM method for determining criteria weights and the WASPAS method for ranking alternatives we obtain that Supplier 1 represents the best solution.

4. Sensitivity analysis and discussion

Sensitivity analysis is a component part of experimental simulation and can have influence on formulation model. Usually it is used for investigating behavior of the model. In this case, the sensitivity analysis is performed forming scenarios with changes of criteria weights (Fig. 1).

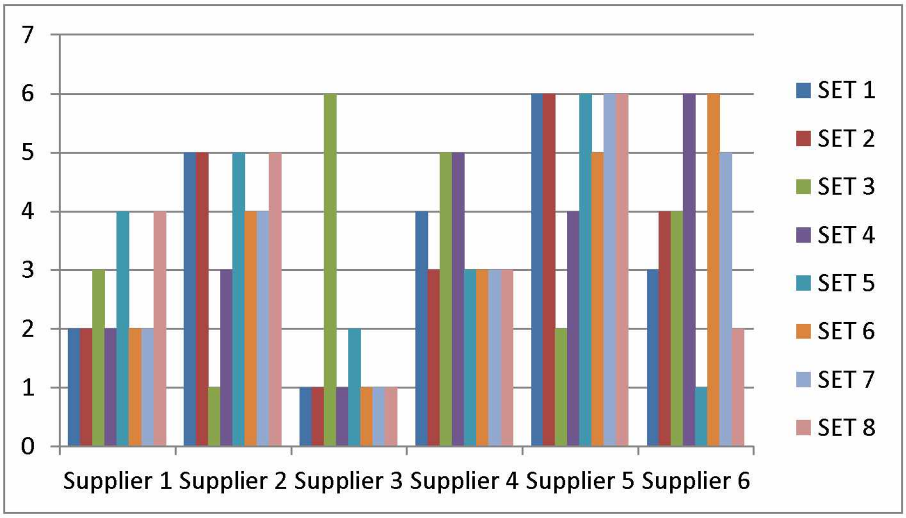

Figure 1. Formed scenarios in sensitivity analysis

In SET 1, weights of first two criteria w_1 and w_2 are decreased by 10%, while w_3, w_4, w_5, w_6 and w_7 are increased for 4%. In this set, with the decreasing significance of criteria quality and price as well as the increasing other criteria, the third supplier is getting higher values and represents the best solution. In the second place is the first supplier, in third Supplier 6, fourth Supplier 4, fifth Supplier 2 and in the last place is Supplier 5. In SET 2, weights of the last three criteria w_5, w_6 and w_7 are increased for 4%, while w_1, w_2, w_3 and w_4 are decreased per 3%. With the increasing significance of the criteria warranty period, reliability and payment method, and with the decreasing significance of the other criteria, Supplier 3 has higher values and represents the best solution. In this set, Supplier 1 is in the second place, Supplier 4 in the third, Supplier 2 in the fifth place and Supplier 5 in the last place. In SET 3, weight coefficients w_1, w_3, w_5 and w_7 are decreased per 6%, while other three w_2, w_4 and w_6 are increased per 8%. In SET 4, the first weight coefficient w_1 is decreased per 24%, while other w_2, w_3, w_4, w_5, w_6 and w_7 are increased per 4%. In this set with the decreasing significance of the criterion quality of material and the increasing of the other criteria, Supplier 3 gets higher values and represents the best alternative. In SET 5, the first five weight coefficients w_1, w_2, w_3, w_4 and w_5 are increased per 4%, while w_6 and w_7 are decreased per 10%. With increasing criteria quality, price, product certification, delivery time and warranty period, Supplier 3 obtains the highest value. In SET 6, only the last weight coefficient w_7 is increased per 30%, while other w_1, w_2, w_3, w_4, w_5 and w_6 are decreased per 5%. With the increasing of significance of the criterion payment method and the other six criteria decreasing, Supplier 3 is the best solution. In SET7, the first and last weight coefficients, i.e. w_1 and w_7 are increased per 15%, while w_2, w_3, w_4, w_5 and w_6 are decreased per 6%. The first ranked alternative in this set is also Supplier 3. In the last SET8, weight coefficients w_3 and w_5 are increased per 20%, while the other five criteria, i.e., w_1, w_2, w_4, w_6 and w_7 are decreased per 8%. Supplier 3 is the first ranked alternative.

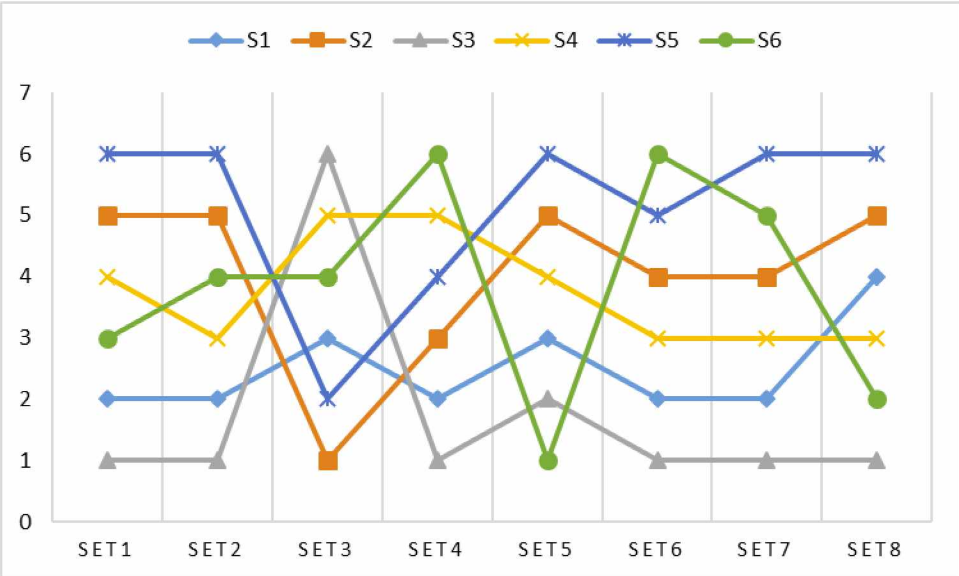

Figure 2. Ranking of suppliers in various scenarios

With decreasing of the significance of criteria quality of material, product certification and warranty period, and, on other hand, with increasing the other criteria, the best solution is Supplier 2. Of the eight SETs made, the best solution for them was Supplier 3 in six sets as can be seen in Fig. 2.

5. Conclusion

For each company, the main goal is to do successful business and achieve a competitive position in a very demanding market. In order to achieve long-term sustainability of the company in the business world, one needs to take into account all the business processes of one company. Each manufacturer should respond to the customers' requests to meet their needs. Yet, in order to meet these requirements, each manufacturer must dispose of his product at the required place, at the required time and in the required quantity. Fulfilling these requirements and achieving a successful business both require the constant disposal of required quantities and types of products.

In this paper, the decomposition of the logistic systems was carried out on the procurement of materials, drying of the boards, production, packaging, and distribution. The aim of the procurement is the quality and timely realization of material goods flows (Stojić et al., 2018, Stević et al., 2017a, Stević et al., 2019), and in this regard, most attention was devoted to the development of a model for evaluating suppliers. In this section, the FUCOM-WASPAS model was used to rank suppliers. We realized that Supplier 1 was the most suitable for further cooperation. After procurement of the material, the drying process of the board lasts from 15 to 100 days depending on the type and characteristics of the wood; in addition, this is very important for the process of production itself because artificial drying under controlled conditions provides material that is suitable for further processing. The production process takes place in six stages. All the phases are interconnected and each phase needs to be thoroughly done if the final product is to be of high quality. After the production process, the process of packaging follows. In the end, the distribution process in which the finished product is placed at the disposal of the customer is completed, that is, it follows the transport to the country from which the order came. Since this company produces boards or semi-finished products, its final product is completed in cooperation with other companies.

In addition, during the analysis and discussion of the solutions achieved, by changing the weight coefficients and by increasing or decreasing the value of certain criteria, the rank of the supplier also changed. It could be concluded that the changing of weight coefficients affected the final result. After setting eight SET with changing of weight coefficients, Supplier 3 had highest ranking results. Through this research, an adequate basis for future actions is created, which implies the separation of key performance indicators based on the executed decomposition of logistics systems, and their measurement and monitoring.

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AN OPTIMAL MANAGEMENT MODEL FOR EMPTY FREIGHT RAILCARS IN TRANSPORT NODES

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Abstract. *The paper presents the actual problem of increasing the efficiency of empty railcars management in rail nodes. The problem lies in need to consider the several constraints. Firstly, railcars' owners are willing to load their rolling stock by specific goods for the given directions (consumers). Secondly, it is necessary to consider schedule and formation of trains between railway stations of the node when we developing the routes for movement of the empty railcars. Final constraint is based on compliance with the schedule of the railcars loading in the transport node. We propose the minimum of total time costs that railcar has spent in the specific transport node as the objective function. This problem is being sophisticated in terms of increased irregularity of railcar traffic flows, and as a result, it increases the loading factor of the individual railway stations in the transport node. Hence, it creates an uneven loading factor of railway stations in the node. In order to optimally manage empty railcars at rail nodes, both the mathematical model and its solving method are presented. One of the distinctive features of the developed model lies in the application of a fuzzy logic method to evaluate online the loading factor of railway stations in the rail node. Moreover, this model takes into account these evaluations by optimizing the distribution of empty railcars at the loading points. The present study puts forward the method and algorithm of the developed mathematical model for empty railcars management. They could additionally take into account the possibility to include empty railcars groups in the composition of trains moving on schedule within large railway nodes or in systems of railway transport at large industrial enterprises. The proposed model significantly reduces the complexity of operational planning of dispatchers for distributing the empty railcar traffic volumes. Furthermore, the developed model minimizes the total handling time of railcars in rail nodes and ensures the timely supply of empty railcars to the loading points.*

Key words: *rail transport, railcar traffic volume, empty railcars, station loading, train schedule, mathematical model, linear programming, fuzzy-logic.*

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1 Introduction

The railways in the countries of the former Soviet Union heritage the complex railway transport systems of large industrial enterprises, whose width of the rail gauge equals 1520 mm. Currently, the transport system is faced with a dramatic increase in railcar handling costs. As a result of the uncoordinated interaction between the mainline and the industrial rail transport, the total annual losses of a single metallurgical enterprise could reach up to 1.5 billion rubles ($45 million US dollars) (Osintsev and Rakhmangulov, 2013; Rakhmangulov et al. 2016).

An increase in these losses mainly occurs due to the increased complexity of the operational planning and management of railcar traffic in the railway transport node. The following factors might be the source of this intricacy:

- the growth and multiplicity of rail freight traffic in Russia and the CIS;
- a plenty of new private railcar owners;
- an increase in uneven railcar traffic;
- frequent and significant workload changes in railway stations and spans (Rakhmangulov, 2014).

According to these conditions, a possible way to solve this issue might be linked to the modernization of the freight traffic flow system in order to reduce the total railcar dead time in the transport nodes. Moreover, a lack of promptness with respect to the delivery of railcars is the main concern the railcar owner is faced with, which significantly raises their overpayment. This issue should, therefore, be considered as well.

The changes caused by the structural reform of the Federal railway transport have a significant impact on the functioning of the transport service systems (Rakhmangulov et al. 2014). The main factor of this reform is the transfer of freight railcars to the operating companies' properties. As a result, by the beginning of 2015, the proportion of private railcars increased up to 100%. At the same time, there is an outstripping growth of the value of the freight traffic flow in relation to the rail transport volume. This correlation indicates the irrational use of railcars.

The disadvantages of such a type of changes are as follows:

- a rise in empty railcar transit;
- a decrease in the reserves of the throughput and the capacity of railway stations and the span because of the enlargement of the effective railcar time usage;
- an increase in the new rolling stock necessity (Borodin and Sotnikov, 2011; Rakhmangulov et al. 2014).

The rail transport analysis of industrial enterprises depicts an increase in the railcar dead time by 20% on average during the last seven years (Kornilov and Varzhina, 2015).

As is shown in the Russian and foreign experience, a reduction in railcar dead time in industrial transport systems (ITSs) is achieved as a result of the variety of the accounting parameters of railcar volumes based on the methods for managing railcar traffic volumes in intelligent transport systems. These methods include linear and nonlinear optimization, dynamic optimization, simulation modelling (Lind, 2000; Berezhnaya and Berezhnoy, 2006; Lesin, 2011).

Based on the operational control methods for railcar exploitation, the problem of the acceleration of the railcar transit time in transport systems has been discussed in North America and in Europe (Clausen and Voll, 2013; Clausen and Rotmann, 2014). European researchers emphasized the mathematical and heuristic approaches to solving the optimization problems of the railcar traffic flow in rail transport nodes.

The discrete mathematical models and algorithms, their implementation and the development strategy of the railcar traffic flow planning within various speeds for a small transport network are proposed in the late 1990s (Carey and Lockwood, 1995; Dorfman and Medanic, 2004). Different ways were proposed at that time:

- the adjustment of the train traffic route on the basis of increasing the accuracy of a reaction to the high dynamics of the train schedule parameters (Pellegrini et al., 2014);
- the heuristic approaches to the railcar traffic flow management while simultaneously optimizing the solving of the problems of their movement in the railway transport node (Fugenschuh et al. 2008);
- an analysis of the empty railcar management methods (Spieckermann and Vosz, 1995).

The previous studies (Jha et al. 2008) are focused on the practical application of the modern heuristic methods based on the solution to the multi-product transportation problem. Later, these techniques were developed (Kauppi et al. 2006; D'Ariano, 2008) and, consequently, the optimization of the transport issue was described. The result of solving this issue implies the minimization of the costs of the private railcar movement in transport systems.

The practical application of the operative management methods for industrial transport reflects in the implementation of the automated systems of the management of the railway transportation process. The researcher (Hailes, 2006; Kozlov, 2007) described how the methods were formed and how computerized systems were developed for the management of the railcar traffic flow in rail transport nodes and the ITS.

However, the mathematical models currently used in intelligent rail transport systems do not sufficiently take into account the complex and variable structure of railcar traffic volumes. Furthermore, these models do not consider the uneven workload of railway stations in the railway transport node. It can be explained that, due to the railcar owners' decisions, restrictions on their use of railcars often change. As a rule, such changes occur once at the beginning of the day (an estimated period). This feature allows us to consider the problem of the optimal empty railcar distribution in transport nodes as a static linear programming problem and also to modify it to the transport problem with additional constraints (Rakhmangulov et al. 2016).

According to the well-known models (Spieckermann and Vosz, 1995; Shenfeld et al. 2012), constraints on the supply of certain empty railcars by certain consignors in the railway transport node were previously implemented. However, delays in the supply of empty railcars for the workload associated with the inclusion of these railcars in the size of the trains moving between railway transport node stations according to the fixed or flexible schedule are not taken into account by these models. Such a flexible schedule can be formed in an operational mode by changing the train routes in the railway transport node and by choosing the stations with a low level of workload (a large amount of the capacity reserve) for the transportation of these types of trains.

The solution to the problem of the optimal control of empty railcars in the railway transport node, together with the abovementioned limitations, requires that operational data should be used by means of modern intelligent transport systems in railway transport (Kozlov et al. 2011; Crainic and Laporte, 1997).

2 A Mathematical Model of the Optimal Distribution of Empty Railcars in the Railway Transport Node

2.1. The Statement of the Operating Problem of Empty Railcar Flows

The effectiveness of the distribution of empty railroad cars in the railway transport node was deeply discussed in a previous study (Rakhmangulov et al. 2014). However, the disadvantage of this paper is the absence of real station workload data. Hence, the current research study presents a promising model combining the operating work level of railway stations and the allocation of empty railcars.

The objective function of the model minimizes the railcar-hours cost during the period of the storage of empty railroad cars in the railway transport node to the loading places.

$$\sum_{k=1}^{L}\sum_{i=1}^{M}\sum_{j=1}^{N} C_{kij} \cdot x_{kij} \rightarrow \min, \quad (1)$$

where C is the amount of the transit time from the railway station i to the railway station j of the empty railcars belonging to the group k (depending on their type and/or their belonging to a certain railcar owner); x is the number of the railcars belonging to the group k and included in the freight railcars flow (a block of railcars) between the stations i and j; L is the number of the empty railcar groups in the railway node at the beginning of the base period; M is the number of the railway stations in the railway node; N is the number of the loading points of the empty railcars in the railway node.

The following constraints should be satisfied during the planning of the distribution of empty railcars in the railway transport node:

- the distribution of all empty railcars situated in the railway node at the beginning of the base period:

$$\sum_{i=1}^{M} A_{ki} = \sum_{j=1}^{N} B_{kj} = A_k, k = 1, 2, \ldots, L, \quad (2)$$

where A_{ki}, B_{kj} are the number of the railcars belonging to the group *k* and, respectively, located at the departure stations (*i*) and at the empty railcar loading points (*j*).

- taking into consideration all of the empty railcars belonging to a certain group with respect to the railcar traffic flows in the railway transport node:

$$\sum_{i=1}^{M}\sum_{j=1}^{N} x_{kij} = A_k, k = 1, 2, \ldots L. \quad (3)$$

- always a positive value of the railcar traffic flows in the railway transport node:

$$x_{kij} \geq 0, k = 1, 2, \ldots L; i = 1, 2, \ldots M; j = 1, 2, \ldots N. \quad (4)$$

- taking into consideration the empty railcar block with respect to their addition to the train size departing from the railway station soon:

$$t_{ir-1} < (p_i + t_i \sigma_i) \leq t_{ir}, \quad (5)$$

where *r* is the sequence train number in the train departure schedule of the railway station *i*. In this case, the index *i* denotes any station of the railway transport node where at the current moment of time the empty railcars included in the train *r* are located; t_{ir} is the departure time of the train *r* from the railway station *i*; p_i is the potential of the i^{th} TOR (Table of an Optimal Route) of the transport network describing the scheme of the railway transport node tracks, or the total time of railcar transit on their route from the starting route station to the i^{th} station; t_{ir} is the dead time of the railcars at the station *i*; σ_i is the station workload factor (the calculation approach is presented in Section 2.2).

- taking into consideration the minimum transit time of the empty railcars inside the railway transport node (according to Formula (5), the dead time of the empty railcars before they can be added to the soonest train and the transit delay due to the operating work level of the railroad station should be taken into account)

$$p_j - p_{i_i} > p_{ij}, i = 1, 2, \ldots M; j = 1, 2, \ldots N, \quad (6)$$

where p_j is the potential of the j^{th} TOR of the transport network, for which the i^{th} peak is the preceding one of the empty railcar route; p_{ij} is the potential of the transport network arc connecting the peaks *i* and *j*, or the amount of the transit time of the empty railcars on the railway track which directly connects the stations *i* and *j*.

- an equilibrium between the potential (estimation) of the TOR peak of the transport network (*j*) and the summation of the potential of the preceding TOR peak (*i*) and the potential of the transport network arc connecting these peaks:

$$p_j = p_{i_i} + p_{ij} \tag{7}$$

- the interconnection of the transport network peaks – this condition is used to implement Formula (6) for the purpose of the verification of all the transport network peaks for which the station *i* is the preceding station. Transport network peaks might be checked via the algorithm presented in the third section of this study.

$$i = \lambda_j, i = 1, 2, \ldots M; j = 1, 2, \ldots N, \tag{8}$$

where λ_j is the index of the TOR peak (the railway station) which precedes the *j*th station on the way of the empty railcars in the railway transport node, i.e.:

$$i \in S_{ij} = \{i, \ldots, \lambda_i, j\}.$$

- a constraint on the number of the railcars in the train *r* to which the empty railcars belonging to the railcar flow x_{kij} and being at the station *i* can be added:

$$x_{kij} \leq Q_{ir}, \tag{9}$$

where Q_{ir} is the maximum train *r* size.

In Chapter 3, both the approach to and the example of solving a transport problem, specifically being the issue of the optimization of the distribution of empty railcars in the railway transport node.

2.2 The Assessment of the Throughput and the Handling Capacity of the Railway Station – A Fuzzy Logic Approach

Basically, the statement of the problem of the evaluation of the effectiveness of the throughput and the handling capacity of a railway station might be described as follows. There are many technological railway stations, each characterized by a reserve of the throughput and the handling capacity $A = \{a_1, a_2, .. a_i, ..., a_m\}$. In turn, each station is characterized by a set of the indicators that on their own part exert an influence on the throughput and the handling capacity reserves $K = \{K_1, K_2, ..., K_j, ..., K_n\}$. Thus, the station with the largest throughput and the handling capacity reserve should be chosen, i.e. the variant a_i from the set A.

Table 1 indicates the four-factor groups (Rakhmangulov et al. 2016) used in order to estimate the work of the railway station K. In the previous study (Rakhmangulov and Osintsev, 2011), each factor was found to have its own functions, qualitatively determining the influence of the ratio on the amount of the throughput and the handling capacity reserve at the railway station.

Table 1. The factors and indicators of the operational assessment of the railway station workload

Factor groups ID	Factor groups feature	Assessment indices of the railway station
Technical factors group	The characterization of the technical equipment of the station – railway tracks development, shunting and cargo facilities	The number of the automatic switches The number of the train locomotives Type of the shunting locomotives The blocking type in the railway spans The incline of the station railway tracks The presence of the technical inspection points of the railcars at the station The number of the railroad spans at the station The number of the loading areas The presence of the weighing facilities at the station The presence of the weighing facilities in the loading areas
Technological factors group	The characterization of the amount and complexity of the technological operations currently being performed at the station; the characterization of the availability of the railway track elements	The presence of shunting work in the railway span The presence of shunting work in the loading areas Exceeding the limit of the dead time during the loading operations Uneven goods arrival from the external network Uneven products loading The reconstruction of the railway station The reconstruction of the workshop The time of the day Visibility Air temperature The number of the railcars The availability of shunting locomotives
Subjective factors group	The characterization of the complexity of the operational management of the railway station under certain conditions: depending on the level of organization, informatization, automatization, the weather and climatic conditions, the time of the day, etc.	The sufficiency of the shunting facilities at the station The sufficiency of the receiving/shipping railway tracks at the station The sufficiency of the receiving/shipping railway tracks capacity at the station A sufficient number of the exits at the station The actual capacity of each railway span The level of the technical development and capacity of the loading areas The professional competence of the operating personnel The presence of unfavorable routes at the station The presence of the corner railway tracks at the station
Employees factors group	The characterization of the professional competence of the railway station management	The years of age of the railway station managers The railway station managers' education The railway station managers' work experience

As is shown in Figure 1 below, in order to estimate the reserve of the throughput and the handling capacity of the station, the methods of the fuzzy set theory can be applied (Andreichikov and Andreichikova, 2000; Harris, 2006; Rakhmangulov and Osintsev, 2011).

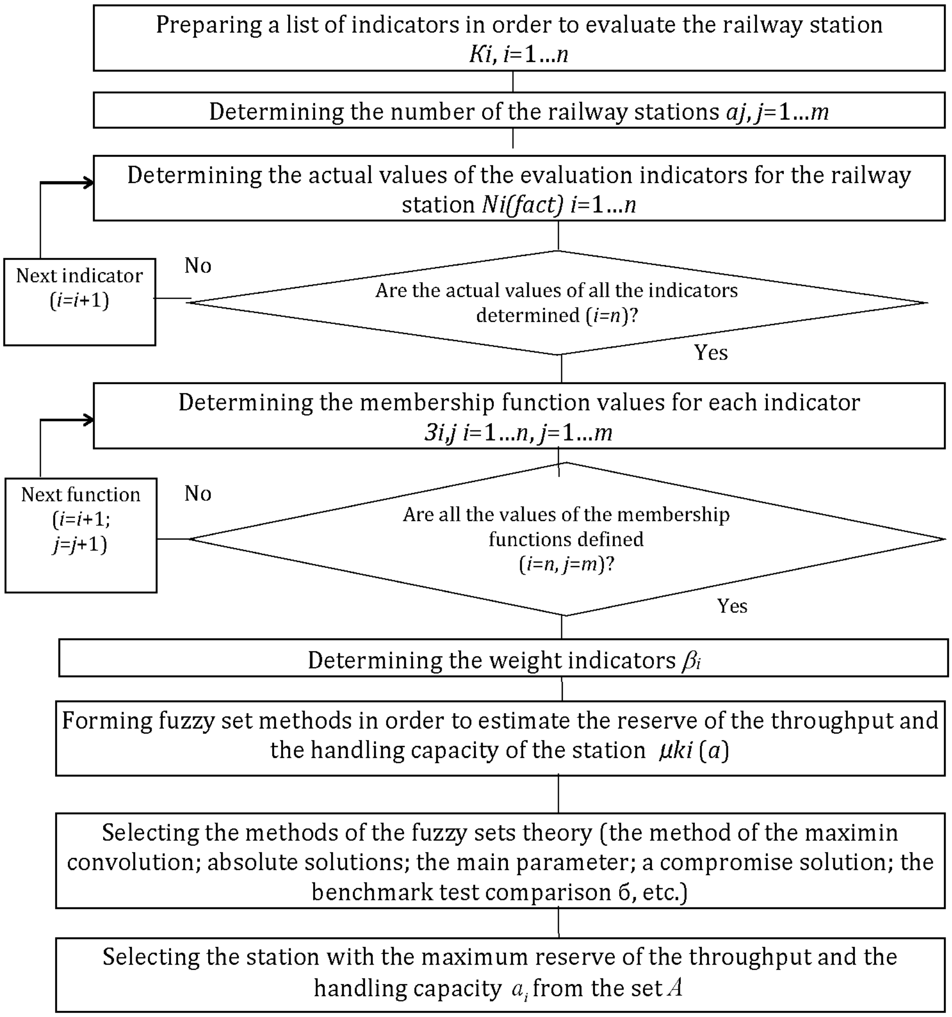


Figure 1. The algorithm for the estimation of the reserve of the throughput and the handling capacity of the station.

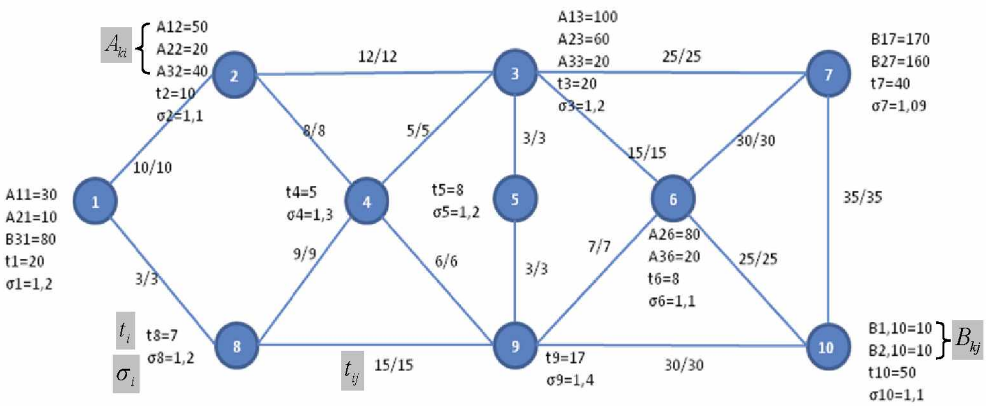
The numerical values of the reserve of the throughput and the handling capacity of stations are evaluated by the load factor of the station (σ_i) (Rakhmangulov and Osintsev, 2011). These values can be used to calculate the cost of the railcar hours during the passing of empty railcar flows on their routes.

3 The Calculation of the Plan for the Optimal Distribution of Empty Railcars in the Railway Transport Node. The Method, the Algorithm and an Example.

In previous studies (Rakhmangulov et al. 2014), several methods for the optimal distribution of empty railcars in the railway transport node were discussed. The practical implementation of the proposed model consists of the seven stages.

Stage 1 is associated with the preparation of the initial data characterizing the technical and technological indicators of the conditions of the transport network, the number of different railcar groups at the stations (Figure 2) and the train timetable inside the railway transport node (Table 2).

The railcar handling time at the stations $t_i \sigma_i$ is calculated based on the reserves of the throughput and the handling capacity of each station and the railcar handling time at a single station.



1 — Peaks of the transport network (stations, loading areas) which are conventionally numbered with prime numbers;

A_{ki} is the number of the railcars of each group k which are located at each railway station i of the railway transport node, railcars;

B_{kj} is the exigency of the empty railcars at each j th station or at the loading point, railcars;

t_i is the average handling time of transit railcars at the j th station, min.;

σ_i is the coefficient of the station workload;

t_{ij} is the train movement time between the neighboring stations of the railway transport node, min.;

t_{ir} is the train timetable inside the railway transport node. The moments of the train departures for each r th train at the railway station, min.;

Q_{ir} is the maximum number of the railcars that can be included in the train size r which is supposed to be sent according to the schedule from the station i at a moment of time t_{ir}, railcars.

Figure 2. An example of a transport network scheme with the initial data in order to calculate the optimal plan for the distribution of empty railcars in the railway transport node

Table 2. The train timetable between the stations inside the railway transport node

	j	t_{i1}	Q_{i1}	t_{i2}	Q_{i2}	t_{i3}	Q_{i3}	t_{i4}	Q_{i4}	t_{i5}	Q_{i5}
1	**2**	60	26	282	17	465	26	696	12	865	6
2	**1**	30	15	203	16	472	23	758	13	1115	10
2	**3**	90	16	223	11	437	17	758	24	1047	23
3	**2**	120	16	417	14	658	29	997	9	1062	8
2	**4**	30	9	146	29	300	20	615	19	865	17
4	**2**	360	28	528	20	762	19	1073	23	1213	5
1	**8**	100	27	191	17	493	11	662	8	940	23
8	**1**	80	24	435	26	578	29	746	13	853	8
8	**4**	70	7	393	24	635	28	834	28	1129	21
4	**8**	60	14	340	10	566	11	816	28	1161	17
4	**3**	40	12	212	7	364	26	469	5	740	15
3	**4**	50	6	131	24	385	5	586	15	912	29
3	**5**	90	14	206	11	531	16	616	30	937	17
5	**3**	80	20	425	25	769	21	1006	24	1360	28
4	**9**	45	10	373	13	452	21	657	22	929	9
9	**4**	60	8	154	11	262	10	493	18	576	16
8	**9**	90	10	400	16	700	15	837	15	1098	21
9	**8**	120	28	227	17	467	18	731	16	1060	17
5	**9**	140	10	492	9	623	7	790	26	1111	5
9	**5**	300	22	508	21	797	11	1030	8	1302	19
3	**6**	200	12	346	7	490	13	718	14	784	9
6	**3**	120	28	474	10	818	10	1096	7	1260	30
3	**7**	300	8	564	15	836	24	1032	27	1145	12
7	**3**	30	27	265	16	381	25	451	9	692	9
9	**6**	15	21	233	5	535	6	711	29	812	6
6	**9**	10	15	340	21	468	15	560	28	896	16
6	**7**	60	13	211	7	549	12	838	20	1024	18
7	**6**	70	25	321	5	525	26	870	29	1065	16
6	**10**	90	10	428	28	572	5	666	16	736	13
10	**6**	80	25	225	5	386	10	635	18	950	26
9	**10**	120	14	471	16	580	21	712	26	999	30
10	**9**	100	7	394	27	685	25	752	28	961	27
7	**10**	30	7	180	8	471	15	626	27	918	15
10	**7**	20	25	253	6	389	21	577	6	654	24

Stage 2 is linked to the construction of an optimal route set for all the stations which have empty railcars A_{ki}. For example, as is shown in Figure 2, the stations №1, №2, №3 and №6 are considered to be these types of stations.

The formation of an optimal route set is made by the constructing method of the Table of an Optimal Route (TOR) in the transport network (Rakhmangulov, 1999). The table of an optimal route consists of three columns (Figure 3). The first column contains the number of the stations i (the transport network peaks). The second column has the numbers of the preceding peaks λ_i. The third consists of the potentials of the peaks p_i. The shortest route to the i th peak is determined by the numbers of the preceding peaks. In the TOR constructing process, it is possible to repeatedly adjust the peak potentials and the numbers of the previous peaks. Thus, it is common to build several tables and transfer the results of the previous constructions to a new table.

The TOR constructing algorithm consists of the following actions:

1. The first and the second columns of TOR are filled in with the peak numbers of the transport network in ascending order. In the second column, the starting peaks are marked as the negative values. The third column is filled in by the starting potentials of the peaks. The initial potentials of the starting peaks are equal to zero. The initial potentials of all other peaks are taken as the number M – the largest possible number.

2. For each arc from the marked peak, the optimal arc condition $p_j - p_{i_i} > p_{ij}$ is checked. It means that a potential difference between the starting and the final arc peaks needs to be greater than the assessment value of the arc in-between these peaks. If this condition is satisfied, the usage of this arc is favorable. Then, as the preceding peak for the final arc peak (the second column is TOR) the peak number i (marked) is specified. The final peak potential is defined as the sum of the starting arc peak potential and the estimation of that arc, i.e. $p_j = p_{i_i} + p_{ij}$.

3. If the optimal arc condition fails, the next arc from the marked peak is checked.

4. If the optimal arc condition is checked for all the arcs from the marked peak, then the label from this peak is removed and the arcs from any next marked peaks are considered. After that, all calculations are repeated, starting with the second. The optimal route constructions are repeated as long as there is at least one marked peak in TOR.

Figure 3 shows the results of the TOR construction for the station №1.

Stage 3 is associated with the determination of the transportation time C_{kij} of the empty railcars delivered from the starting station of each route i to the final stations j, where there is an empty railcar exigency B_{kj}. In this case, the value C_{kij} might be equal to the final peak potential value of the corresponding route, i.e. $C_{kij} = p_j$. For example, since there are empty railcars of the groups №1 and №2 at the station №1, the transportation cost is only determined for those stations where there is the railcar exigency of this group.

	Starting table		The first iteration		The second iteration		The third iteration		The forth iteration		The fifth iteration		The sixth iteration	
i	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**	**λi**	**pi**
1	-1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	2	M	-1	70	1	70	1	70	1	70	1	70	1	70
3	3	M	3	M	-2	102	2	102	2	102	2	102	2	102
4	4	M	4	M	-2	154	-3	136	3	136	3	136	3	136
5	5	M	5	M	5	M	-3	209	-3	209	3	209	3	209
6	6	M	6	M	6	M	-3	215	-3	215	3	215	3	215
7	7	M	7	M	7	M	-3	325	-3	325	-3	325	3	325
8	8	M	-1	100	-1	100	-1	100	-1	100	-1	100	1	100
9	9	M	9	M	9	M	9	M	-4	379	-6	347	6	347
10	10	M	10	M	10	M	10	M	10	M	-6	453	6	453

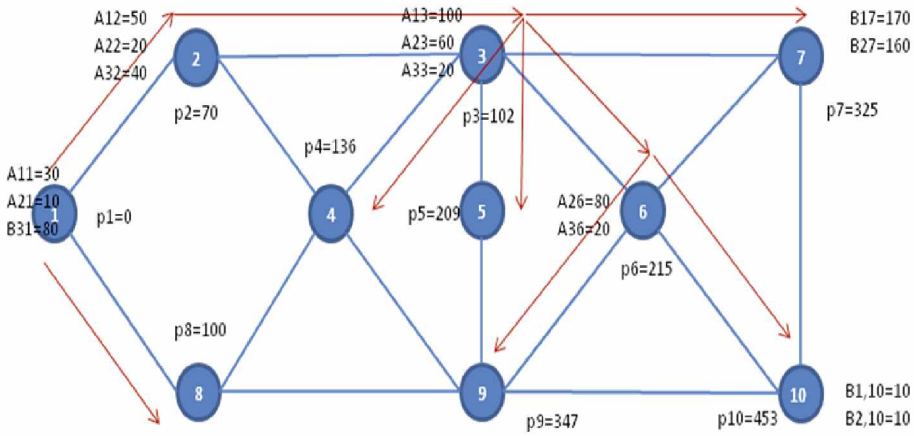


Figure 3. The example of the calculation of the optimal routes for the station i=1

There is demand of the first railcars group at the stations № 7 and №10.
$C_{1,1,7}$ = 325 min.;
$C_{1,1,10}$ = 453 min.;
There is demand of the second railcars group at the stations № 7 and №10.
$C_{2,1,7}$ = 325 min.;
$C_{2,1,10}$ = 453 min.

Similarly, the values C_{kij} are defined for another railway starting station and for another railcar group. As a result, the transportation time matrix for the empty railcars k of each group belonging to the contact schedule (Table 3) is formulated.

Table 3. The transportation time matrix of the empty railcars as a part of the trains inside the railway transport node

The railcar group	The number of the railcars at the station A_{ki}	The number of the railcars at the station C_{kij} and the exigency of the empty railcars B_{kj} at the station	
k =1		B_{17}=170	$B_{1,10}$=10
	A_{11}=30	325	453
	A_{12}=50	288	150
	A_{13}=100	325	453
k =2		B_{27}=160	$B_{2,10}$=10
	A_{21}=10	325	453
	A_{22}=20	288	150
	A_{23}=60	325	453
	A_{26}=80	90	150
k =3		B_{31}=80	
	A_{32}=40	40	
	A_{33}=20	213	
	A_{36}=20	438	

Stage 4 is related to the calculation of the optimal values of the empty railcar flow x_{kij} (Formula 1) and is based on the solution to the static transport problem of linear programming in the matrix formulation (Rakhmangulov, 1999; Rakhmangulov et al., 2014) (Table 4). The standard Excel Macros "Solution search" was used to solve this example. However, in order to implement the developed algorithm as a part of the intelligent transport system of railway transport, it is recommended that specialized programs for solving transport problems or linear programming libraries, e.g. the Linear Programming Library (GIPALS32), should be used.

Table 4. The results of the calculation of the optimal size of the empty railcar flow inside the railway transport node

The railcar group	The number of the railcars at the station A_{ki}	The sizes of the empty railcar traffic flow x_{kij}	
k =1		B_{17}=170	$B_{1,10}$=10
	A_{11}=30	30	0
	A_{12}=50	40	10
	A_{13}=100	100	0
k =2		B_{27}=160	$B_{2,10}$=10
	A_{21}=10	10	0
	A_{22}=20	10	10
	A_{23}=60	60	0
	A_{26}=80	80	0
k =3		B_{31}=80	
	A_{32}=40	40	
	A_{33}=20	213	
	A_{36}=20	438	

Stage 5 is relevant to the preparation of the initial data in order to check the limit (Formula 9) of the number of the empty railcars in the train size (Table 5).

Table 5. Initial data to check the limit of the number of the empty railcars in the train size

The railcar group, k	The starting station, i	The final station, j	The optimal size of the railcar block, x_{kij}, the railcar	The size of the undistributed empty railcar block, $\dot{x}_{kij}$, the railcar	The size of the distributed empty railcar block, x_{kij}, the railcar	Transportation time, C_{kij} min.
3	2	1	40	25	15	40
2	6	7	80	67	13	90
1	2	10	10	1	9	150
2	2	10	10	10	0	150
3	3	1	20	4	16	213
1	2	7	40	40	0	288
2	2	7	10	10	0	288
1	1	7	30	22	8	325
1	3	7	100	100	0	325
2	1	7	10	10	0	325
2	3	7	60	60	0	325
3	6	1	20	5	15	438

If the condition $x_{kij} \le Q_{ir}$ fails for the train r on any of the route peaks, then the railcar block size x_{kij} is taken as the minimum value $x_{kij} = \min Q_{ir} \ for \ \forall i \in S_{ij}$, and the difference $\bar{x}_{kij} = x_{kij} - \min Q_{ir}$ is stored as an undistributed block.

If the condition $x_{kij} \le Q_{ir}$ is satisfied, the values Q_{ir} for all the route peaks are reduced by the block size $Q_{ir} = Q_{ir} - x_{kij}$. Consequently, the block x_{kij} is stored as distributed. If the value Q_{ir} becomes zero for the train r, then the train is excluded from further calculations (Table 6).

Table 6. The check results of the limit of the number of the empty railcars in the train size

No.1	r	Q_{ir}	No. 2	r	Q_{ir}	No. 3	r	Q_{ir}	No.4	r	Q_{ir}	No.5	r	Q_{ir}
2	1	15	1	-	-	-	-	-	-	-	-	-	-	-
6	1	13	7	-	-	-	-	-	-	-	-	-	-	-
2	1	9	4	1	10	9	1	14	10	-	-	-	-	-
2	1	0	4	1	1	9	1	5	10	-	-	-	-	-
3	1	16	2	2	16	1	-	-	-	-	-	-	-	-
2	1	0	4	1	1	9	1	5	10	2	6	7	-	-
2	1	0	4	1	1	9	1	5	10	2	6	7	-	-
1	1	26	2	1	16	3	1	8	7	-	-	-	-	-
3	1	0	7	-	-	-	-	-	-	-	-	-	-	-
1	1	18	2	1	8	3	1	0	7	-	-	-	-	-
3	1	0	7	-	-	-	-	-	-	-	-	-	-	-
6	1	15	9	1	28	8	2	26	1	-	-	-	-	-

As a result of the distribution of the railcar block x_{321} for the stations No. 2 and No. 1, the following consequences occur:

- the size of the block x_{321} decreases by 15 cars;
- the size of the block x_{267} decreases by 13 cars, and so on.

Tables 7, 8 present the maximum possible number of empty railcars as a part of train size (initial data). Also, these tables include the distribution result of the railcar blocks x_{321}, x_{267}, $x_{12,10}$, $x_{22,10}$, x_{331}, x_{127}, x_{227}, x_{117}, x_{137}, x_{217}, x_{237}, x_{361}.

Table 7. The maximum possible number of the empty railcars in the train size (the initial data)

i	j	Q_{i1}	Q_{i2}	Q_{i3}	Q_{i4}	Q_{i5}
1	2	26	17	26	12	6
2	1	15	16	23	13	10
2	3	16	11	17	24	23
3	2	16	14	29	9	8
2	4	9	29	20	19	17
4	2	28	20	19	23	5
1	8	27	17	11	8	23
8	1	24	26	29	13	8
8	4	7	24	28	28	21
4	8	14	10	11	28	17
4	3	12	7	26	5	15
3	4	6	24	5	15	29
3	5	14	11	16	30	17
5	3	20	25	21	24	28
4	9	10	13	21	22	9
9	4	8	11	10	18	16
8	9	10	16	15	15	21
9	8	28	17	18	16	17
5	9	10	9	7	26	5
9	5	22	21	11	8	19

3	6	12	7	13	14	9
6	3	28	10	10	7	30
3	7	8	15	24	27	12
7	3	27	16	25	9	9
9	6	21	5	6	29	6
6	9	15	21	15	28	16
6	7	13	7	12	20	18
7	6	25	5	26	29	16
6	10	10	28	5	16	13
10	6	25	5	10	18	26
9	10	14	16	21	26	30
10	9	7	27	25	28	27
7	10	7	8	15	27	15
10	7	25	6	21	6	24

Table 8. The number of the empty railcars in the train size (after the distribution of the railcar blocks)

i	j	Q_{i1}	Q_{i2}	Q_{i3}	Q_{i4}	Q_{i5}
1	2	18	17	26	12	6
2	1	0	0	23	13	10
2	3	8	11	17	24	23
3	2	0	14	29	9	8
2	4	0	29	20	19	17
4	2	28	20	19	23	5
1	8	27	17	11	8	23
8	1	24	11	29	13	8
8	4	7	24	28	28	21
4	8	14	10	11	28	17
4	3	12	7	26	5	15
3	4	6	24	5	15	29
3	5	14	11	16	30	17
5	3	20	25	21	24	28
4	9	1	13	21	22	9
9	4	8	11	10	18	16
8	9	10	16	15	15	21
9	8	13	17	18	16	17
5	9	10	9	7	26	5
9	5	22	21	11	8	19
3	6	12	7	13	14	9
6	3	28	10	10	7	30
3	7	0	15	24	27	12
7	3	27	16	25	9	9
9	6	21	5	6	29	6
6	9	0	21	15	28	16
6	7	0	7	12	20	18
7	6	25	5	26	29	16
6	10	10	28	5	16	13
10	6	25	5	10	18	26
9	10	5	16	21	26	30
10	9	7	27	25	28	27
7	10	7	8	15	27	15
10	7	25	6	21	6	24

Stage 6 is related to the correction of leftover empty railcars at the stations (Table 9).

Table 9. The effect of the adjustment of the leftover empty railcars.

Undistributed railcar blocks			**Distributed railcar blocks**		
k	i	$\dot{x}_{kij}$	k	j	x_{kij}
1	1	22	1	7	0
1	2	1	1	7	8
1	2	40	1	7	0
1	3	100	1	10	9
2	1	10	2	7	13
2	2	10	2	7	0
2	2	10	2	7	0
2	3	60	2	7	0
2	6	67	2	10	0
3	2	25	3	1	15
3	3	4	3	1	16
3	6	5	3	1	15

$A_{11}=22$; $A_{12}=41$; $A_{13}=100$; $A_{21}=10$; $A_{22}=20$; $A_{23}=60$; $A_{26}=67$; $A_{32}=25$; $A_{33}=4$; $A_{36}=5$;

Total: 354 railcars

$B_{17}=162$; $B_{1,10}=1$; $B_{27}=147$; $B_{2,10}=10$; $B_{31}=34$

Total: 354 railcars

Thus, according to the adjustment, the following intermediate results are formed:

- a set of the distributed railcar blocks x_{kij};
- the routes of their transit S_{ij};
- the train numbers r which have distributed railcar groups in their train size (Table 10).

Table 10. The intermediate results of the optimal distribution of the empty railcars

k	i	j	x_{kij}	C_{kij}	No.1	r	No.2	r	No.3	r	No.4	r	No.5	r
1	1	7	8	325	1	1	2	1	3	1	7	-	-	-
1	2	10	9	150	2	1	4	1	9	1	10	-	-	-
2	6	7	13	90	6	1	7	-	-	-	-	-	-	-
3	2	1	15	40	2	1	1	-	-	-	-	-	-	-
3	3	1	16	213	3	1	2	2	1	-	-	-	-	-
3	6	1	15	438	6	1	9	1	8	2	1	-	-	-

Stage 7 is related to the correction of the initial data for the next iteration, and it includes:

1. the adjustment of the number of the empty railcars at the stations (Figure 4, the new values are marked in red).

2. the adjustment of the train schedule according to the contact itinerary. As a result of this adjustment, the trains that can no longer include empty railcars are removed from the train schedule (Table 11).

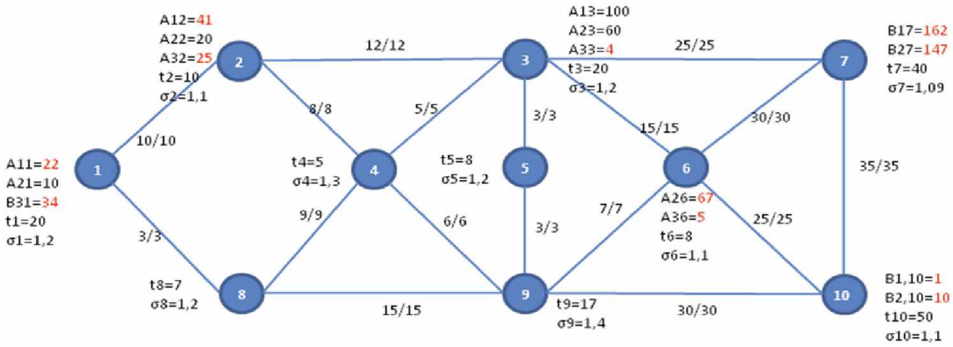


Figure 4. The results of the adjustment of the initial data for the second iteration (the correction of the transport network)

Table 11. The result of the train schedule adjustment inside the railway transport node

i	j	t_{i1}	Q_{i1}	t_{i2}	Q_{i2}	t_{i3}	Q_{i3}	t_{i4}	Q_{i4}	t_{i5}	Q_{i5}
1	**2**	60	26	282	17	465	26	696	12	865	6
2	**1**	-	15	203	0	472	23	758	13	1115	10
2	**3**	90	16	223	11	437	17	758	24	1047	23
3	**2**	-	16	417	14	658	29	997	9	1062	8
2	**4**	-	9	146	29	300	20	615	19	865	17
4	**2**	360	28	528	20	762	19	1073	23	1213	5
1	**8**	100	27	191	17	493	11	662	8	940	23
8	**1**	80	24	435	11	578	29	746	13	853	8
8	**4**	70	7	393	24	635	28	834	28	1129	21
4	**8**	60	14	340	10	566	11	816	28	1161	17
4	**3**	40	12	212	7	364	26	469	5	740	15
3	**4**	50	6	131	24	385	5	586	15	912	29
3	**5**	90	14	206	11	531	16	616	30	937	17
5	**3**	80	20	425	25	769	21	1006	24	1360	28
4	**9**	45	10	373	13	452	21	657	22	929	9
9	**4**	60	8	154	11	262	10	493	18	576	16
8	**9**	90	10	400	16	700	15	837	15	1098	21
9	**8**	120	28	227	17	467	18	731	16	1060	17
5	**9**	140	10	492	9	623	7	790	26	1111	5
9	**5**	300	22	508	21	797	11	1030	8	1302	19
3	**6**	200	12	346	7	490	13	718	14	784	9
6	**3**	120	28	474	10	818	10	1096	7	1260	30
3	**7**	-	8	564	15	836	24	1032	27	1145	12
7	**3**	30	27	265	16	381	25	451	9	692	9
9	**6**	15	21	233	5	535	6	711	29	812	6
6	**9**	-	15	340	21	468	15	560	28	896	16
6	**7**	-	13	211	7	549	12	838	20	1024	18
7	**6**	70	25	321	5	525	26	870	29	1065	16
6	**10**	90	10	428	28	572	5	666	16	736	13
10	**6**	80	25	225	5	386	10	635	18	950	26
9	**10**	120	14	471	16	580	21	712	26	999	30
10	**9**	100	7	394	27	685	25	752	28	961	27
7	**10**	30	7	180	8	471	15	626	27	918	15
10	**7**	20	25	253	6	389	21	577	6	654	24

Stages 2-7 of the described algorithm must be repeated until the very occurrence of undistributed railcar blocks. If there are such railcar blocks at the end of the estimated period, they are the leftover empty railcars carried forward to the next estimated period. This leftover can be eliminated by increasing the values Q_{ir} for the trains. After that, a full recalculation of the plan for the distribution of the empty railcars is required and should start with the first step of the algorithm.

4 Conclusion

The results of the present model are:

- a considerable cluster of the values x_{kij} that determines the optimal number of the railcars of each group in the blocks. These railcars are supposed to be delivered to the specific loading points (stations) during the estimated period (within one day);
- the optimal transit routes of the railcar blocks S_{ij} ;
- the scheduled number of the trains r for each station. The train size should include empty railcar blocks.

As a result, the proposed model, associated with the rational use of empty railcars, might lead to an around 15-20% decline in the dead time of empty railcars in the railway transport node.

The developed model, the method and the algorithm of its implementation can easily be integrated into the existing intelligent control systems of railway transport hubs. Current railway transport systems are ready and contain all the data necessary for the implementation of the present model.

At the same time, the disadvantage of this algorithm is the relatively low accuracy of compliance with the train schedule in the railway transport node and in the railway transport systems of industrial enterprises. In most cases, this type of schedule is not in place due to the fact that internal railway traffic is moderated by dispatchers and depends on the availability of specific railcars at the railway station, as well as on the current loading situation at this and closely located stations. Owing to the solid internal scheduled train flows in the railway transport node, there are still some stable freight traffic flows. However, it is worth noting that even for these trains frequent schedule breaches were observed due to uneven railway stations and the railway track workload.

Future studies are expected to bring about a solution to this problem. The prediction of the time of the train departure from the railway transport node stations by using BigData tools might be a possible way to carry it out. A promising approach to the improvement of the accuracy of train traffic forecasts inside the railway transport node implies using the simulation method in the operational mode. Based on the data of the availability and transit status of railcars, the modern simulation models of railway stations can enable an operational assessment of the possible scenarios of the operating workload of railway stations.

To sum it up, the current research study, specifically the promising tools and methods, might be helpful in improving the accuracy of the result of optimization during the distribution of empty railcars in the railway transport node.

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A TWO-PHASE FUZZY AHP – FUZZY TOPSIS MODEL FOR SUPPLIER EVALUATION IN MANUFACTURING ENVIRONMENT

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Abstract: *Supplier selection is one of the most important issues in supply chain management (SCM) which greatly affects its performance and market competitiveness. In the recent years, supplier selection in SCM has become imperative to balance between the ordinal and cardinal criteria. This paper proposes a two-phase model which aims to evaluate and select suppliers using an integrated Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (FTOPSIS) methods. A fully developed model consisting of several evaluation criteria, both quantitative and qualitative in nature, as assessed by FAHP method to estimate the criteria weights, while FTOPSIS method is used to rank the potential suppliers that have been singled out through expert assessment. The proposed model is a support tool in the optimization of the purchasing process, and it provides the possibility of realizing additional savings by developing stronger cooperation with the optimal supplier.*

Key words: *Supply chain management, Supplier selection, FAHP, FTOPSIS*

1. Introduction

According to Gunasekaran and Ngai, (2004), supply chain management (SCM) is one of the vital strategies in the 21st century to achieve global competitive advantage. Supply logistics plays a crucial role in today's SCM. In the last few decades, and especially in recent years; there is an evidential change in the role of SCM in business policies. According to Knežević et. al. (2012), acquisition is treated as an integrated strategic business function that aims to connect all other functions, enable smooth execution of all processes and activities in the company, and create a high added value based on the relationship with suppliers. From all the above, it is well understood that importance of SCM will continue to grow over time.

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Appropriate choice of suppliers is an issue of strategic importance and key activity for industries in modern SCs due of its central role in deciding price, quality, delivery and service to achieve organizational objectives (Kagnicioglu, 2006).

According to Lasch and Janker, (2005) effective supplier management that begins with the identification of potential suppliers is vital for a successful SCM. Ghodsypour and O'Brien, (2001) believed that satisfactory choice of suppliers significantly reduces costs which, according to Ghodsypour and O'Brien, (1998) represented up to 70% of the product price and increase competitiveness, while Önüt et. al. (2009) focused on end-user satisfaction associated with it.

The policy of relations and evaluation of sources of supply has a strategic importance for the whole procurement subsystem. This subsystem can effectively perform the tasks relating to the supply of the company, if it selects supplier or suppliers (not too many of them) that can meet the requirements of the procurement subsystem, and which are related to the quality, quantity, price, terms of delivery and other terms, reliability, flexibility, as well as other objectives that are to be met, satisfying other criteria too.

Search for suppliers that meets the above criteria is a permanent and primary task. To that end, it is necessary to continuously collect and process information about suppliers and establish and maintain adequate relations with them; further, it is necessary to develop and apply methods for the evaluation and ranking of potential suppliers. De Boer et. al. (2001), have identified four stages of the selection of suppliers, as follows: problem definition, formulation of criteria, qualification and, selection. The correct choice of suppliers from the start provides opportunity for a timely, continuous and quality production which brings above mentioned benefits making the production competitive.

The main activity of the company where the research was carried out is the production of pre-insulated pipes for heating; in order for the company to organize this production it is necessary to procure steel pipes. Out of a large number of companies which could be potential suppliers of steel pipes it is necessary to select those whose characteristics, according to the criteria of the procurement subsystem of the company, are the most adequate. After a complete and long-term market analysis performed by the company's expert team, they selected five suppliers that represent potential solutions. In addition, the expert team had set a total of nine criteria on the basis of which it is necessary to make the evaluation of suppliers. Considering the current market needs and requirements, and at the same time taking into account the knowledge and skills obtained through the years of work, the team of experts has evaluated the criteria as well in order to provide different weight value, which greatly affects the ranking of alternatives.

The primary objective and the contribution of this paper is to propose a two-phase model integrating Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Ordering Preference by Similarity to Ideal Solution (FTOPSIS) methods for supplier selection through establishing long-term cooperation with the selected supplier to gain additional market advantage.

This paper is structured as follows. Section 2 presents the literature review on supplier selection. Section 3 presents fundamentals of fuzzy sets, FAHP and FTOPSIS methods. Section 4 demonstrates the considered real time example and explains the results of the integrated multi-criteria model. Section 5 presents a sensitivity analysis which includes the experiment of 24 sets where the values of criteria are changed. This section also discuss about the stability of the model. Section 6 sets out the conclusions.

2. Literature review

There are numerous criteria for evaluating suppliers, but the question is how to choose the right ones from a given set, which will be used to choose the best solution. Dickson, (1966) is considered to be a pioneer in this field because he was the first to create a study on the evaluation of suppliers in which he defined a set of 23 criteria by which the evaluation and selection of the best suppliers could be carried out.

In his paper Ellram, (1990), he tried to increase the importance of qualitative criteria that should enable long-term cooperation between the company and suppliers. He divided criteria into four groups: financial aspects, organizational culture and strategic issues, technology issues, and other. Further, the authors from the end of the last century attempted to answer this question, and Webber et. al. (1991) investigated the criteria for the selection of suppliers in manufacturing and retail environment. A group of authors concluded that quality, delivery and price prevail as dominant criteria, while geographical location, financial position and production capacity are secondary factors. After this, Verma and Pullman, (1998) conducted a survey among a large number of managers in order to examine how they reach compromise when selecting suppliers. Their research indicated that managers place highest priority to quality as the most important attribute of suppliers, followed by delivery and price. Research on the impact of the criteria in the SC continues at the beginning of this century, and Karpak et. al. (2001) recognized reliability of delivery as a criterion for selection, whereas Bhutta and Huq, (2002) used four criteria for evaluating suppliers: price, quality, technology and service. Research conducted in (Çebi and Bayraktar, 2003) singled out the following group of criteria: logistics, technology, commerce and business cooperation that contain both quantitative and qualitative criteria.

Combination FAHP and FTOPSIS methods are often used for evaluation performance in SC and selection supplier, for example evaluating performance for selection of suppliers in car manufacturing factory in Turkey (Zeydan et. al. 2011), for evaluation of the performance of suppliers in company which produced several types of electronic cards (Eraslan and Atalay, 2014). Shukla et. al. (2014) illustrates how FAHP and FTOPSIS can be integrated to allow for a more consistent evaluation and prioritization of SC partner. Chen and Yang, (2011) are used constrained FAHP and FTOPSIS for supplier selection. These integrated methods are also used for solving next problems: for the selection and development of reverse logistics partner in India (Prakash and Barua 2016), ranking of the industry alternatives for portfolio investments (Dincer et. al. 2016), for handling equipment selection (Yazdani, 2014), for mining method selection in zinc producer in Iran (Yazdani et. al. 2012) or combination more methods of MCDM with QFD for selection green supplier (Yazdani et. al. 2016), combination AHP, GIS and integer programming for evaluation in reverse logistics (Acar et. al. 2015), combination fuzzy VIKOR and AR-DEA method for supplier selection (Mohaghar et. al. 2013)

By using FAHP and FTOPSIS, uncertainty and vagueness from subjective perception and the experiences of decision maker can be effectively represented and reached to a more effective decision (Ertugrul and Karakasoglu, 2008).

3. Material and methods

3.1. Fuzzy Sets

Fuzzy sets are sets whose elements have degrees of membership. The theory of fuzzy sets was first introduced by Zadeh, (1965), whose application enables decision makers to effectively deal with the uncertainties. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition - an element either belongs or does not belong to the set. Fuzzy sets used generally triangular (TFN), trapezoidal and Gaussian fuzzy numbers.

A fuzzy number A˜ on R to be a TFN if its membership function leA μ_A~(x): R→[0,1] is equal to following Equation (1):

$$M_A\sim(x) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0, & otherwise \end{cases} \quad (1)$$

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

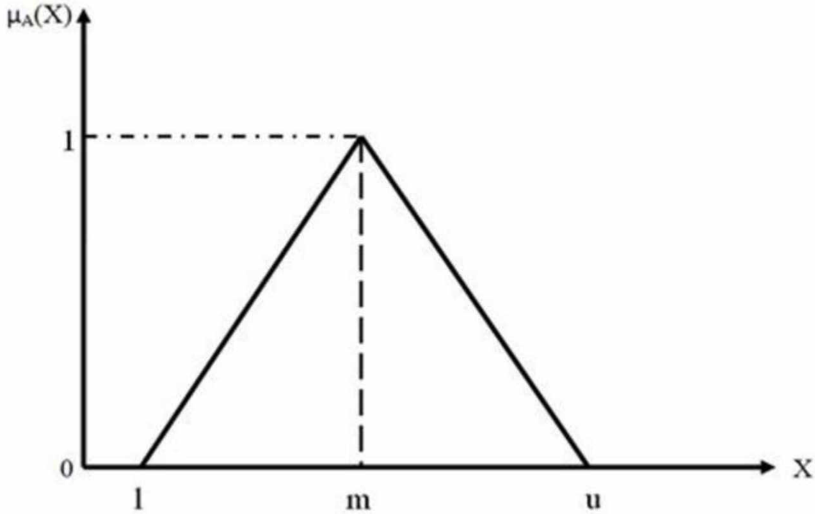

Figure 1. The membership functions of the TFN

The operational laws of TFN $\check{A}_1 = (l_1, m_1, u_1)$ and $\check{A}_2 = (l_2, m_2, u_2)$ are displayed as following equations.

Addition:

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

Multiplication:

$$\check{A}_1 x \check{A}_2 = (l_1, m_1, u_1) x (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \quad (3)$$

Subtraction:

$$\breve{A}_1 - \breve{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_{1-}l_2) \quad (4)$$

Division:

$$\frac{\breve{A}_1}{\breve{A}_2} = \frac{(l_1, m_1, u_1)}{(l_2, m_2, u_2)} = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \quad (5)$$

Reciprocal:

$$\breve{A}^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \text{ for } l_1 l_2 > 0;\ m_1 m_2 > 0;\ u_1 u_2 > 0 \quad (6)$$

3.2. Fuzzy AHP method

Analytic hierarchy process is created by Thomas Saaty (Saaty, 1980) and according to him, AHP is a measurement theory which deals with pairwise criteria comparisons and which relies on expert opinion in order to perform the priority scale.

AHP in a certain ways resolves the problem of subjective influence of the decision-maker because it measures the degree of consistency (CR), and informs the decision makers of the result. Depending on the size of the matrix the value of this ratio is recommended, so in (Lee et. al. 2008) we find that the maximum permissible level of consistency for the 3x3 matrix is 0.05, for the 4x4 matrix it is 0.08, and for larger matrices it is 0.1.

Kwong's method (Kwong and Bai, 2003) has been used to check the consistency of pairwise judgement of comparison matrix. A TFN, denoted as $M=(l,m,u)$, can be defuzzified to a crisp number as follows:

$$M_{-crisp} = \frac{(4m + l + u)}{6} \quad (7)$$

TFN, which were used in this work are marked as (lij,mij,uij). The parameters (l_{ij},m_{ij},u_{ij}) are the smallest possible value, the most promising value and highest possible value that describes a fuzzy event, respectively.

In this study, the extent analysis method by Chang, (1996) is adopted. Some advantages of this method are: Effectively handle both qualitative and quantitative data and easy to implement and understand (Tuysuz and Kahraman 2006), fuzzy AHP is preferable for widely spread hierarchies, where few importance/rating pairwise comparisons are required at lower level trees, can adopt linguistic variables (Ertugrul and Karakasoglu, 2008).

Let assume that X={x_1,x_2,...,xn} is number of objects, and U={u_1,u_2,...,um} is number of aims. According to the methodology of extended analysis set up by Chang, for each object an extended goal analysis is made. Values of the extended analysis "m" for each object can be represented as follows:

$$M_{gi,}^{1} M_{gi,}^{2} M_{gi,}^{m} i = 1,2, \ldots n., \quad (8)$$

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

Chang's expanded analysis includes following steps:

Step 1: the value of fuzzy synthetic extent S_i with respect to the i[th] criteria is defined as:

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{gi}^{j}\right]^{-1} \tag{9}$$

In order to obtain expression

$$\left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{gi}^{j}\right]^{-1} \tag{10}$$

it is necessary to perform additional fuzzy operations with "m" values of the extended analysis, which is represented by the following expressions:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{11}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{12}$$

Then it is necessary to calculate the inverse vector:

$$\left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{gi}^{j}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \tag{13}$$

Step 2: The degree of possibility of Sb ≥ Sa is defined as:

$$V(S_b \geq S_a) = \begin{cases} 1, & if\ m_b \geq m_a \\ 0, & if\ l_a \geq u_b \\ \frac{l_a - u_b}{(m_b - u_b) - (m_a - l_a)}, & otherwise \end{cases} \tag{14}$$

where „d“ ordinate of a largest cross-section in point D between µSa andi µSb as shown in figure 2.

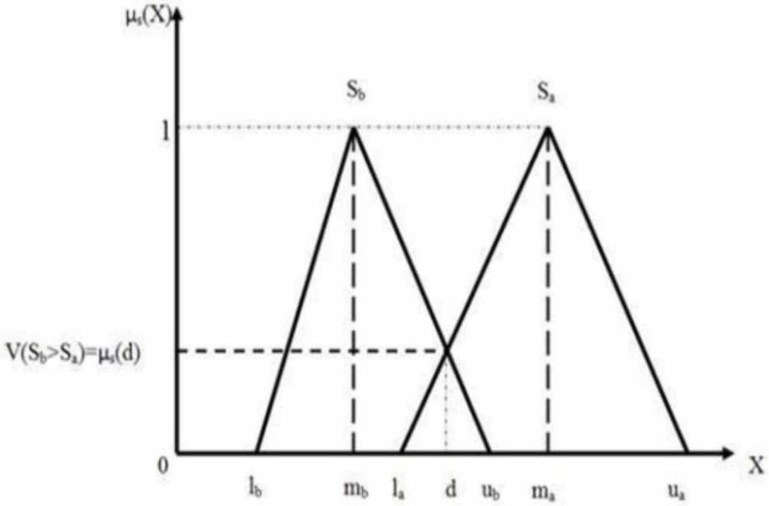

Figure 2. Intersection between Sa and Sb

To compare S_1 and S_2, both values $V(S_1 \geq S_2)$ and $V(S_2 \geq S_1)$ are needed.

Step 3: Level of possibility for convex fuzzy number to be greater than „k" convex number Si (i =1,2,...,k) can be defined as follows:

$$V(S_i \geq S_1, S_2, \dots, S_k) = \min V(S_i \geq S_k), = w'(S_i) \tag{15}$$

$$d'(A_i) = \min V(S_i \geq S_k), k \neq i, k = 1,2, \dots, n \tag{16}$$

The weight vector is given by the following expression:

$$W' = (\mathrm{d}'(A_1),\ \mathrm{d}'(A_2), \dots, \mathrm{d}'(A_n))^T, \tag{17}$$

Step 4: Through normalization, the weight vector is reduced to the phrase:

$$W = (\mathrm{d}(A_1),\ \mathrm{d}(A_2), \dots, \mathrm{d}(A_n))^T, \tag{18}$$

3.3. Fuzzy TOPSIS method

Due to its simple concept, TOPSIS method has become very popular and it is applied in many areas of decision-making. However, despite that, this method is often criticized because it lacks the ability to adequately handle uncertainty and imprecision in the moment when the decision maker needs accurate results. For this reason, in this paper we use the extended FTOPSIS method which allows proper handling of uncertainty and imprecision, and it is completely appropriate for the ranking of alternatives.

TOPSIS was first proposed by (Hwang and Yoon, 1981) and a Fuzzy TOPSIS method was later introduced by (Chen and Hwang, 1992).

The algorithm of the FTOPSIS method can be described as follows: (Chen, 2000)

Step 1: Form a committee of decision-makers, then identify the evaluation criteria.

Step 2: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives with respect to criteria.

Step 3: Aggregate the weight of criteria to get the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j, and pool the decision maker's opinions to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterion C_j

$$\tilde{R}_k = (a_k, b_k, c_k), k = 1,2,3, \dots K, \tag{19}$$

then the aggregated Fuzzy rating can be determined as

$$R = (a, b, c), k = 1,2,3, \dots K \tag{20}$$

$$a = min_k(a_k), b = \frac{1}{K}\sum_{k=1}^{K} b_k\,,\ c = max_k(c_k) \tag{21}$$

Step 4: Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.

$$\tilde{R}_k = [r_{ij}]_{mxn}\ i = 1,2,3, \dots, m;\ \ j = 1,2,3, \dots, n \tag{22}$$

where B and C are the set of benefit criteria and cost criteria, respectively, and

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right),\ j \in B \tag{23}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{c_{ij}}{a_{ij}}\right),\ j \in C \tag{24}$$

$c_j^* = \max_i c_{ij}$ if $j \in B$

$a_j^- = \min_i a_{ij}$ if $j \in C$

Step 5: Considering the different importance of each criterion, we can construct the weighted normalized fuzzy decision matrix as:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{mxn} \; i = 1,2,,\dots,m; \; j = 1,2,,\dots,n \quad (25)$$

$$\tilde{v}_{ij} = r_{ij}W \quad (26)$$

where W is the weighted vector of evaluating criteria.

Step 6: Determine the Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FNIS) where according (Yu et. al. 2011):

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) = (max_j v_{ij} \big| i \in B), \; (min_j v_{ij} | i \in C), i = 1,2 \dots m; \; j = 1,2 \dots n, \quad (27)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) = (min_j v_{ij} \big| i \in B), (max_j v_{ij} | i \in C), i = 1,2 \dots m; \; j = 1,2 \dots n, \quad (28)$$

where B and C are the set of benefit criteria and cost criteria, respectively.

Step 7: Calculate the distance of each alternative from FPIS and FNIS, respectively. The distance of each alternative from A* and A⁻ can be currently calculated as:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), i = 1,2, \dots m, \quad (29)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1,2, \dots m, \quad (30)$$

where d(.;.) is the distance measurement between two fuzzy numbers.

Step 8: Calculate the closeness coefficient of each alternative.

A closeness coefficient is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i(i=1;2;m) has been calculated. The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \; i = 1,2, \dots, m \quad (31)$$

Step 9: According to the closeness coefficient, the ranking order of all alternatives can be determined.

4. Numerical example

The criteria used in this study were selected based on two important factors: criteria which are commonly used in the same or similar research and based on the current needs of the company and the requirements that the company faces on the market. The criteria (Puška et al. 2018) applied in this study are: the price of material, pipe length, delivery time, payment method, geographical location, quality, financial stability, flexibility and communication system, and in this paper they are marked C_1-C_9 respectively. Therefore, there are four quantitative criteria and five criteria that are qualitative, as shown in Figure 3. Steps of the proposed model for supplier evaluation are shown in Figure 4. One of two components of multicriteria evaluation methods is represented by the values of the criteria weights (Ginevičius and Podvezko, 2008) and one of the main features of multi-criteria decision-making process is that the different criteria cannot have the same significance, so following the methodology described for decision making which applies the extended AHP method ie. FAHP to get the required results is necessary to perform criteria comparison on the basis of TFN, as shown in Table 2. The comparison was made based on the scale shown in Table 1.

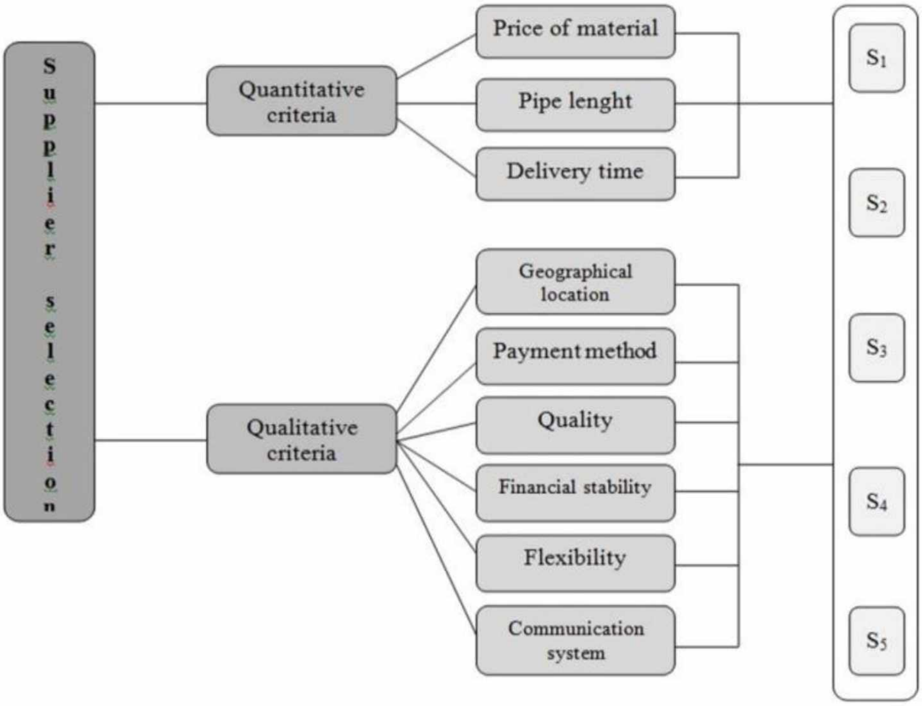

Figure 3. Hierarchical structure of the proposed model

Table 1. Triangular fuzzy scale

Linguistic Scale	TF Scale	TF Reciprocal Scale
Just equal	(1,1,1)	(1,1,1)
Equal important	(1/2,1,3/2)	(2/3,1,2)
Weakly more important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

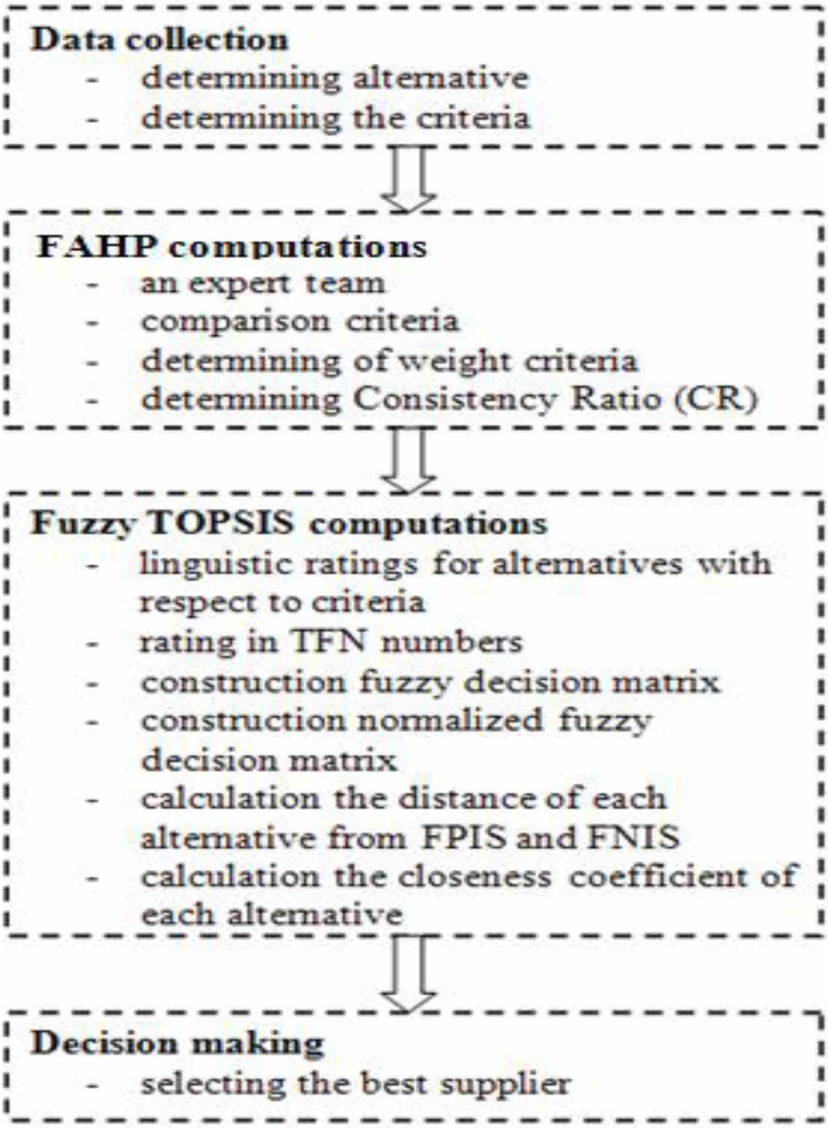

Figure 4. Steps of the proposed model

By comparing them, weight value criteria is determined, and that criteria plays very important role in the further implementation of methods, because on the base of these values the optimal solution is determined. If some variant is better according to criteria that are very important when deciding, it increases the possibility to have excatly this variant as an optimum.

Fuzzy important weight of the criteria is calculated by taking geometric mean of the responses of the experts (Lee, 2009), this is shown in Table 3. Example calculation of geometric mean for C_{42} is: $n^{-}=(1/2x2/5x2/5)^{1/3}=0{,}431$; $n=(2/3x1/2x1/2)^{1/3}=0{,}550$; $n^{+}=(1x2/3x2/3)^{1/3}=0{,}763$

Table 2. Comparison criteria by 3 experts

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
	E_1	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(1/2,1,3/2)
C_1	E_2	(1,1,1)	(2/3,1,2)	(2/3,1,2)	(1,3/2,2)	(1/2,1,3/2)	(2/3,1,2)	(1/2,1,3/2)	(1/2,1,3/2)	(1,3/2,2)
	E_3	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(2/7,1/3,2/5)	(1/2,1,3/2)	(1,3/2,2)	(1,3/2,2)
	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1,3/2,2)	(1,3/2,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)
C_2	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(1,3/2,2)	(1,1,1)	(2/3,1,2)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2,5/2,3)	(2,5/2,3)
	E_1	(1,3/2,2)	(1/2,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1/2,1,3/2)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
C_3	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(3/2,2,5/2)	(1/2,1,3/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(1/2,2/3,1)	(2,5/2,3)	(5/2,3,7/2)	(5/2,3,7/2)
	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/3,1,2)	(2/3,1,2)	(1/2,1,3/2)	(1,1,1)
C_4	E_2	(1/2,2/3,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1/2,2/3,1)	(2/3,1,2)	(2/3,1,2)	(1/2,1,3/2)
C_5	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(1,3/2,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1,3/2,2)
C_6	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(1,3/2,2)	(3/2,2,5/2)
	E_3	(5/2,3,7/2)	(3/2,2,5/2)	(1,3/2,2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)
	E_1	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(1,1,1)
C_7	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)
	E_1	(1,1,1)	(2/3,1,2)	(1/2,3/2,1)	(2/3,1,2)	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(2/3,1,2)
C_8	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_3	(1/2,2/3,1)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(2/3,1,2)	(2/3,1,2)	(2/7,1/3,2/5)	(2/3,1,2)	(1,1,1)	(1,1,1)
	E_1	(2/3,1,2)	(2/3,1,2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1,1,1)	(1/2,1,3/2)	(1,1,1)
C_9	E_2	(1/2,2/3,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E_3	(1/2,2/3,1)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(2/3,1,2)	(2/3,1,2)	(2/7,1/3,2/5)	(2/3,1,2)	(1,1,1)	(1,1,1)

Table 3. Fuzzy important weight of the criteria calculated by taking geometric mean

	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(0.606,0.874,1.587)	(0.511,0.693,1.817)	(0.63,1.145,1.651)	(0.5,1,1.5)
C_2	(0.63,1.145,1.651)	(1,1,1)	(0.763,1,1.587)	(1.31,1.817,2.31)	(1.145,1.651,2.154)
C_3	(0.909,1.442,1.957)	(0.63,1,1.31)	(1,1,1)	(1.651,2.154,2.657)	(1.442,1.957,2.466)
C_4	(0.606,0.784,1.587)	(0.431,0.55,0.763)	(0.376,0.464,0.606)	(1,1,1)	(0.794,1,1.145)
C_5	(0.667,1,2)	(0.464,0.606,0.874)	(0.405,0.511,0.693)	(0.874,1,1.26)	(1,1,1)
C_6	(0.855,1.442,1.99)	(1.145,1.26,1.357)	(0.874,1.145,1.587)	(1.233,1.817,2.359)	(1.357,1.89,2.41)
C_7	(0.763,1,1.587)	(0.511,0.693,1.101)	(0.083,0.562,0.794)	(0.693,1,1.442)	(0.794,1,1.145)
C_8	(0.693,0.874,1.26)	(0.481,0.644,1)	(0.415,0.693,0.737)	(0.667,1,2)	(0.693,1,1.442)
C_9	(0.55,0.763,1.26)	(0.446,0.585,0.874)	(0.358,0.585,0.562)	(0.874,1,1.26)	(0.606,1,1.817)

	C_6	C_7	C_8	C_9
C_1	(0.503,0.694,1.17)	(0.63,1,1.31)	(0.794,1.145,1.442)	(0.794,1.31,1.817)
C_2	(0.737,0.794,0.874)	(0.909,1.442,1.957)	(1,1.554,2.08)	(1.145,1.71,2.241)
C_3	(0.63,0.874,1.145)	(1.26,1.778,2.289)	(1.357,1.89,2.41)	(1.778,2.289,2.797)
C_4	(0.424,0.55,0.811)	(0.693,1,1.442)	(0.5,1,1.5)	(0.794,1,1.142)
C_5	(0.415,0.529,0.737)	(0.874,1,1.26)	(0.874,1,1.442)	(0.55,1,1.651)
C_6	(1,1,1)	(1.077,1.651,2.19)	(1.077,1.651,2.19)	(1.554,2.08,2.596)
C_7	(0.457,0.606,0.928)	(1,1,1)	(0.794,1,1.145)	(0.693,1,1.442)
C_8	(0.457,0.606,0.928)	(0.874,1,1.26)	(1,1,1)	(0.763,1,1.587)
C_9	(0.385,0.481,0.644)	(0.693,1,1.442)	(0.63,1,1.442)	(1,1,1)

To determine Fuzzy combination expansion for each one of the criteria, first we calculate $\sum_{j=1}^{n} M_{gi}^{j}$ value for each row of the matrix.

C1=(1+0.606+0.511+0.630+...;1+0.874+0.693+1.145...;1+1.587+1.817+1.651+...)=(5.968; 8.861; 13.294) etc.

The $\sum_{i=1}^{n}\sum_{j=1}^{n} M_{gi}^{j}$ value is calculated as:

(5.968;8.861;13.294)+(8.639;12.113;15.854)+(10.657;14.384;18.031)+(5.618;7.348;10.296)+(6.123;7.646;10.917)+(10.172;13.936; 17.679)+...=(64.55;87.38;118.17)

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

S1=(5.968;8.861;13.294)x(1/118.17;1/87.38;1/64.55)=(0.050;0.101;0.206)

Now, the V values are calculated using these vectors.

$$V(S_1 \geq S_2) = \frac{0.073-0.206}{(0.101-0.206)-(0.139-0.073)} = 0.778$$

V(S1≥S3)=0.644; V(S1≥S4,S5)=1; V(S1≥S6)=0.670; V(S1≥S7,S8,S9)=1

The priorities of weights are calculated using:

d'=(C1)=0.644, d'=(C2)=0.857, d'=(C3)=1, d'=(C4)=0.464, d'=(C5)= 0.503, d'=(C6)=0.974, d'=(C7)= 0.497, d'=(C8)= 0.525, d'=(C9)= 0.467

After the equation is applied (17), weight values are obtained, and from the equation (18) normalized weights of criteria are received:

W'=(0.644;0.857;1;0.464;0.503;0.974;0.497;0.525;0.467)

W=(0.109;0.144;0.169;0.078;0.085;0.164;0.084;0.088;0.079)

Table 4. Defuzzification using Kwong's method

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	0.948	0.85	1.144	1	0.742	0.99	1.136	1.309
C_2	1.144	1	1.058	1.815	1.651	0.798	1.439	1.549	1.704
C_3	1.439	0.99	1	2.154	1.956	0.879	1.777	1.888	2.289
C_4	0.888	0.566	0.473	1	0.99	0.573	1.023	1	0.989
C_5	1.111	0.627	0.524	1.022	1	0.545	1.022	1.053	1.034
C_6	1.436	1.257	1.174	1.81	1.888	1	1.645	1.645	2.078
C_7	1.058	0.731	0.521	1.023	0.99	0.655	1	0.99	1.023
C_8	0.908	0.676	0.654	1.111	1.023	0.635	1.023	1	1.058
C_9	0.81	0.61	0.543	1.023	1.071	0.492	1.023	1.012	1

After defuzzification shown in the previous table, by applying the AHP method steps, we obtain the following values: λ_{max} = 9.262; CI = 0.033; CR = 0.023, which means that the degree of consistency is 0.023, which is much less than the maximum permitted limit of 0.1 according to the size of the matrix used in the paper.

On the basis of the procedure and obtained results the most important criterion for the decision on the selection of suppliers is the third criterion: the time of delivery, which has a relative importance of 16.9%, while the quality and length of pipes follow immediately after the time of delivery with a share of 16.4%, and 14.4%, respectively. The first criterion, the price of material, has the importance of 10.9%, while other criteria are somewhat lower in value. Delivery time, quality and price are the criteria that a large number of practical researches dealing with similar issues are of great importance. However, the length of the pipes as a criterion is rarely used, and even more rarely is of great importance as is the case in this study. The reason for such importance of this criteria is the activity in which the company is engaged, so this criterion can greatly contribute to an easier implementation of the finished product to the heating system, which is one of the current demands of end users in the market.

Table 5 shows the evaluation of suppliers by three experts using the linguistic variables. Based on the characteristics of the suppliers and the expert opinion Table 5 was formed.

Table 5. Rating of the suppliers in linguistic terms

Expert	Supp.	Criterion								
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
	S_1	VG	VG	VG	F	MG	VG	VG	VG	G
	S_2	G	VG	VG	VG	MG	VG	G	G	MG
E_1	S_3	G	G	G	G	VG	MG	VG	G	G
	S_4	MG	G	G	F	VG	MG	VG	VG	G
	S_5	MG	MG	MP	VG	G	G	G	G	MG
	S_1	VG	G	VG	MG	F	VG	G	G	VG
	S_2	G	G	VG	VG	F	VG	MG	MG	G
E_2	S_3	G	MG	MG	G	VG	G	G	MG	VG
	S_4	MG	F	G	MG	VG	G	G	VG	VG
	S_5	F	MG	MP	VG	MG	G	MG	MG	G
	S_1	G	VG	VG	F	MG	VG	VG	VG	VG
	S_2	G	VG	VG	VG	MG	G	MG	MG	G
E_3	S_3	G	F	G	G	VG	MG	VG	G	VG
	S_4	MG	G	G	F	VG	MG	G	VG	VG
	S_5	MG	VG	MP	G	MG	G	MG	G	MG

By applying the 3rd and 4th step of the FTOPSIS method we get the values that are presented in tables 6 and 7, which represent a fuzzy decision matrix and normalized fuzzy decision matrix.

Table 6. Fuzzy decision matrix

Supp.	Criterion				
	C_1	C_2	C_3	C_4	C_5
S_1	(7,9.667,10)	(7,9.667,10)	(7,9.667,10)	(3,5.667,9)	(3,6.333,9)
S_2	(7,9.333,10)	(7,9.667,10)	(9,10,10)	(9,10,10)	(3,6.333,9)
S_3	(7,9,10)	(3,7,10)	(5,8.333,10)	(7,9,10)	(9,10,10)
S_4	(5,7,9)	(3,7.667,10)	(7,9,10)	(3,5.667,9)	(9,10,10)
S_5	(3,6.333,9)	(5,8,10)	(1,3,5)	(7,9.667,10)	(5,7.667,10)

Supp.	C_6	C_7	C_8	C_9
S_1	(9,10,10)	(7,9.667,10)	(7,9.667,10)	(7,9.667,10)
S_2	(7,9.667,10)	(5,7.667,10)	(5,7.667,10)	(5,8.333,10)
S_3	(5,7.667,10)	(7,9.667,10)	(5,8.333,10)	(7,9.667,10)
S_4	(5,7.667,10)	(7,9.333,10)	(9,10,10)	(7,9.667,10)
S_5	(7,9,10)	(5,7.667,10)	(5,8.33,10)	(5,7.667,10)

Table 7. Normalized Fuzzy decision matrix

	Criterion				
	C_1	C_2	C_3	C_4	C_5
S_1	(0.3,0.31,0.429)	(0.7,0.967,1)	(0.1,0.103,0.143)	(0.3,0.567,0.9)	(0.3,0.633,0.9)
S_2	(0.3,0.321,0.429)	(0.7,0.967,1)	(0.1,0.1,0.111)	(0.9,1.0,1)	(0.3,0.633,0.9)
S_3	(0.3,0.333,0.429)	(0.3,0.7,1)	(0.1,0.12,0.2)	(0.7,0.9,1)	(0.9,1,1)
S_4	(0.333,0.429,0.6)	(0.3,0.767,1)	(0.1,0.111,0.143)	(0.3,0.567,0.9)	(0.9,1,1)
S_5	(0.333,0.474,1)	(0.5,0.8,1)	(0.2,0.333,1)	(0.7,0.967,1)	(0.5,0.767,1)

	C_6	C_7	C_8	C_9
S_1	(0.9,1,1)	(0.7,0.967,1)	(0.7,0.967,1)	(0.7,0.967,1)
S_2	(0.7,0.967,1)	(0.5,0.767,1)	(0.5,0.767,1)	(0.5,0.833,1)
S_3	(0.5,0.767,1)	(0.7,0.967,1)	(0.5,0.833,1)	(0.5,0.833,1)
S_4	(0.5,0.767,1)	(0.7,0.933,1)	(0.9,1,1)	(0.7,0.967,1)
S_5	(0.7,0.9,1)	(0.5,0.767,1)	(0.5,0.833,1)	(0.5,0.767,1)

By multiplying the values shown in Table 8 with the values of criteria which obtained by FAHP method we get weighted normalized fuzzy decision matrix shown in Table 8, while Table 9 shows the final results and ranking of alternatives.

Table 8. Weighted normalized Fuzzy decision matrix

	Criterion		
	C_1	C_2	C_3
S_1	(0.033,0.034,0.047)	(0.101,0.139,0.144)	(0.017,0.017,0.024)
S_2	(0.033,0.035,0.047)	(0.101,0.139,0.144)	(0.017,0.017,0.019)
S_3	(0.033,0.036,0.047)	(0.043,0.101,0.144)	(0.017,0.02,0.034)
S_4	(0.036,0.047,0.065)	(0.043,0.11,0.144)	(0.017,0.019,0.024)
S_5	(0.036,0.052,0.109)	(0.072,0.115,0.144)	(0.034,0.056,0.169)
	C_4	C_5	C_6
S_1	(0.023,0.044,0.07)	(0.026,0.054,0.077)	(0.148,0.164,0.164)
S_2	(0.07,0.078,0.078)	(0.026,0.054,0.077)	(0.115,0.159,0.164)
S_3	(0.055,0.07,0.078)	(0.077,0.085,0.085)	(0.082,0.126,0.164)
S_4	(0.023,0.044,0.07)	(0.077,0.085,0.085)	(0.082,0.126,0.164)
S_5	(0.055,0.075,0.078)	(0.043,0.065,0.085)	(0.115,0.148,0.164)
	C_7	C_8	C_9
S_1	(0.059,0.081,0.084)	(0.062,0.085,0.088)	(0.055,0.076,0.079)
S_2	(0.042,0.064,0.084)	(0.044,0.067,0.088)	(0.04,0.066,0.079)
S_3	(0.059,0.081,0.084)	(0.044,0.073,0.088)	(0.04,0.066,0.079)
S_4	(0.059,0.078,0.084)	(0.079,0.088,0.088)	(0.055,0.076,0.079)
S_5	(0.042,0.064,0.084)	(0.044,0.073,0.088)	(0.04,0.061,0.079)

Table 9 contains the final results and ranking of alternatives.

Table 9. Closeness coefficient of alternatives and their ranking

	d_i^*	d_i^-	$d_i^*+d_i^-$	CC_i	Rank
S_1	0.166	0.551	0.717	0.768	1
S_2	0.185	0.546	0.731	0.747	2
S_3	0.218	0.531	0.749	0.709	4
S_4	0.214	0.526	0.741	0.711	3
S_5	0.33	0.465	0.795	0.585	5

5. Sensitivity analysis

The sensitivity analysis includes the experiment of 24 sets where the values of criteria are changed. The first nine sets mean increasing each criterion separately by 8% starting from the first one to the last. Since there is no significant change in the ranking of suppliers the following nine sets are formed which include increasing the value of each criterion individually by 16%. The set number 19 includes reducing the three most relevant criteria (C_2, C_3 and C6) by 8%, while the other six criteria increase by 4%. The set number 20 represents an increase in the three most important criteria (C_2, C_3 and C_6) by 8%, while the remaining criteria are reduced by 4%. Next set number 21 analyses the increase of the three weakest criteria (C_4, C_7 and C_9) by 8%, while the rest are reduced by 4%. The set number 22 means equal weighting of all the criteria, while in the set number 23 the four most important criteria (C_1, C_2, C_3 and C_6) have equal values of 0.25, and the rest of the criteria are equal to zero or not taken into account. The last set number 24 analyses the change of the criteria in the following way: the first five criteria are equal to the value of 0.12, and the other four criteria are also identical in value of 0.1.

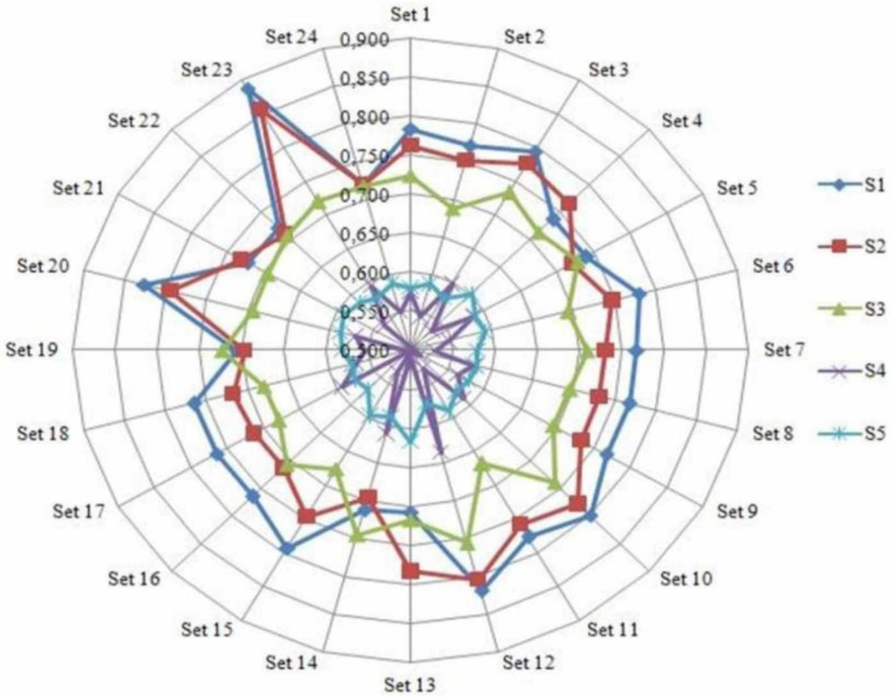

Figure 5. Results of sensitivity analysis

After the formation of sets and the analysis shown in Figure 5, it is evident that the first supplier is ranked as the most acceptable solution in 18 out of a total of 24 cases, therefore, he holds the first position. In the first nine sets only the change of the fourth criterion affect the change of preferred supplier, and then the second supplier becomes number one. In the nine sets that follow the number one supplier is ranked first in seven cases. The change occurs with the increase in the fourth criterion when the second supplier takes one the first place, i.e. with the change of the fifth criterion when supplier number three is ranked first. Set 19 also places third supplier as the first, because the values of the three most important criteria are reduced. Supplier number one is the most appropriate solution also in the sets number 20, 22 and 23, while in set 21 the second supplier has the rank one with a slight difference in comparison to the first supplier, while in the final set number 24 the first and the second supplier are almost identical. It is important to note that the first supplier in those six cases where he is not the most appropriate solution still holds second position, which speaks volumes about the qualities of the same. Even in the situation when all criteria are equally important with the same values, this supplier is the best solution.

6. Conclusion

This paper presents a two-phase model for evaluating suppliers in the manufacturing sector. Since today production is highly dependent on our own capacities but also on the capacity of suppliers, the importance of resolving this problem is evident. When it comes to a concrete example entertained in this paper, it is necessary to take into account a large number of criteria that can influence the formation of the final price of the product, and consequently the position that the company holds in the market. It is necessary to make decisions taking into account the importance of the criteria, i.e. the priorities that reflect market demands and needs, which was achieved in this paper through the creation of an expert team.

After the sensitivity analysis, it can be concluded that the model is well stable because supplier one emerged out as the best solution in a number of situations where the weight values of certain criteria were changed. This means that change of the obtained results would require significant turbulence in the market, both in terms of suppliers and their characteristics and end user perspectives.

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THE EVALUATION OF THE CRITERIA FOR SUSTAINABLE SUPPLIER SELECTION BY USING THE FUCOM METHOD

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Abstract. *The selection of a sustainable supplier has a strategic significance and represents the critical phase for the whole sustainable supply chain. The process of the functioning of the supply chain depends on this activity. This paper is aimed at defining the most important criteria for the assessment and selection of a sustainable supplier in the company for lime production. For the purpose of decision-making in this process, a team of experts was formed for the comparison and assessment of the criteria grouped at two levels. At the first level, there are the economic, social and environmental criteria which consist of the seven sub-criteria for each of the main groups. In order to determine the significance of the criteria, the Full Consistency method (FUCOM) was applied. The obtained results show the significance of the criteria at both decision-making levels with respect to the selection of a sustainable supplier. An adequate supplier selection is carried out by using the sustainable criteria that will ensure a possibility of having both timely and quality production. This generates competition growth in the market for companies.*

Key words*: sustainable supplier selection, FUCOM, evaluation of criteria, decision-making*

1. Introduction

Sustainable supply chains have a large influence on the modern market, so the problem of the selection of a sustainable supplier is very important and frequent in all fields. The selection of sustainable suppliers is a constant process that requires the consideration of a certain number of the criteria needed to make a decision on the selection of the most suitable suppliers (Büyüközkan and Çifçi, 2011; Luhtra et al. 2017; Ayadnia et al. 2015). Modern business conditions require a business to quickly adapt to changes in the environment. In line with developments in the market, business entities need adequate sustainable supply chains (Stojanović et al., 2017; Stević et al. 2019). A well-designed supply chain management system is important for improving competitive advantage in the era of international economics and the rapid development of information technology (Liu and Wang, 2007). Manufacturing companies are highly dependent on their suppliers. Due to the constant changes that the market is exposed to

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and the ever-growing demands, it is certainly challenging to maintain a competitive position (Stević, 2017). According to Kagnicioglu (2006), the selection of suppliers is a critical procurement activity in the supply chain management due to the key role of the supplier characteristics on the price, quality, delivery, and service in achieving the supply chain objectives.

The aim of the supplier selection is to identify suppliers with the greatest potential to meet the company's needs and at an acceptable price (De Boer et al. 2001). One of the important issues in the process of selecting a sustainable supplier is choosing the appropriate method and criteria for the selection of a supplier. Essentially, group decision-making according to multiple criteria is the problem in choosing a sustainable supplier in the supply chain system. In solving this problem, the degree of uncertainty, the number of decision-makers, and the nature of the criteria must be taken into account (Chen et al., 2006).

The rest of the paper is structured as follows: the second section describes the steps of the used method, i.e. the FUCOM method. In the third section, the problem postulate with the hierarchical structure of the model and a detailed explanation of the used criteria. In the fourth section, the FUCOM method is applied in the group decision-making process for the two levels of hierarchy. After that, the fifth section shows a discussion of the obtained results, while in the sixth section the conclusions of the study are presented.

2. FUCOM (Full Consistency Method)

The FUCOM method was developed by Pamučar et al. (2018) for the purpose of determining criteria weights. So, for now, the method has been applied in a few studies (Prentkovskis et al. 2018; Zavadskas et al. 2018; Fazllolahtabar 2019; Matić et al 2019).

The steps of the FUCOM method are as follows:

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

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

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

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

Step 3 In this step, the final values of the weight coefficients of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the following two conditions: (1) 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:

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

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

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

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

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

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

3. Problem Postulate

This research study was performed with the aim of determining the most important criteria for the selection of a sustainable supplier, which depends on the precise determination and selection of adequate criteria. The evaluation of the criteria was performed by a group of the experts employed in the company which is the subject matter of the research study (a lime production company). Figure 1 shows the hierarchical structure of the criteria evaluation at both levels of decision-making:

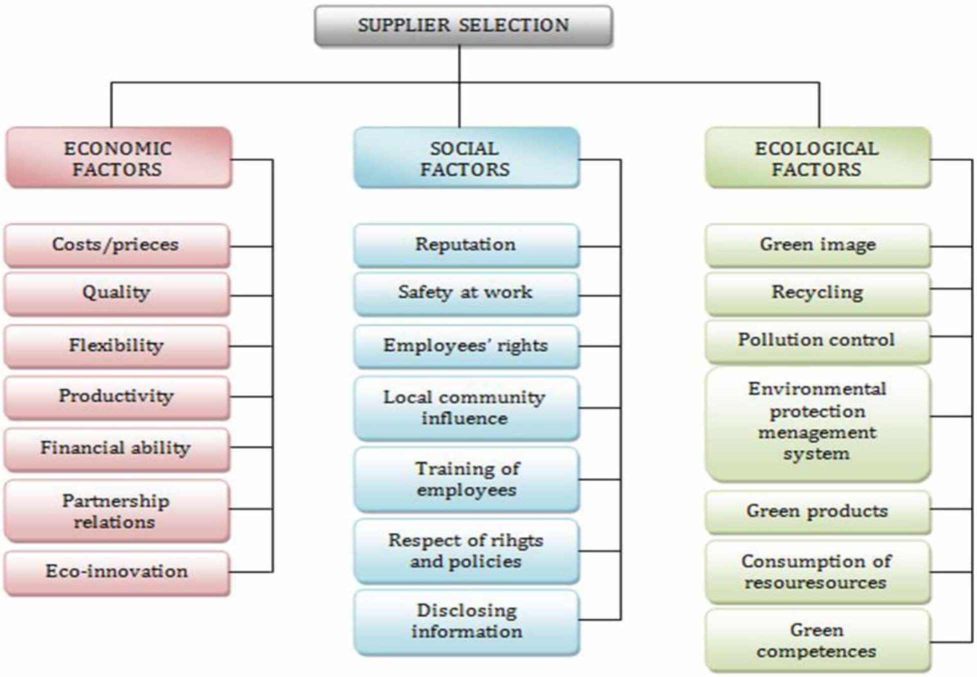

Figure 1. The hierarchical structure of the proposed model

Table 1 shows the criteria for the selection of a sustainable supplier and their respective definitions. All of the criteria displayed below were used in this study.

Table 1. The criteria for the selection of a sustainable supplier and their respective definitions

Seq. no	Name	Definition
C1	**Economic**	
C11	Costs/prices	The final cost of purchasing a unit of raw or semi-finished product
C12	Quality	Quality is the degree to which a set of product characteristics meet customer requirements
C13	Flexibility	The demand that can be profitably sustained, and the time or the cost required for adding new products to the existing production operations
C14	Productivity	Satisfying customer needs and delivery on time
C15	Financial ability	The capital needed to maintain the normal business activities of an enterprise during a certain period of time
C16	Partnership relations	Determining the willingness to establish long-term and close business relations with suppliers to jointly develop the market
C17	Technology capability	The sum of all the knowledge of an enterprise in support of technological innovation.
C2	**Social**	
C21	Reputation	Reputation marks the general opinion of the supplier which relates to the supplier's reputation
C22	Safety and health at work	This criterion concerns the safety, health, and welfare of people at work
C23	Employees' rights	A group of legal rights and claimed human rights related to the labor relations between workers and their employers

C24	Local community influence	Neighboring relations between the company and the local government, the community and all the residents, representing the public image of the organization
C25	Training of employees	The process of enhancing the employees' skills and capabilities for and knowledge of a particular job
C26	Respect of rights and policies	Enterprises comply with all the laws and regulations of the country, assume legal obligations, and promote good social public morals
C27	Disclosing information	Providing information to stakeholders about the materials used, carbon emissions, toxins released during production, and so on
C3	**Environmental**	
C31	Green image	The identity that consumers prioritize environmental conservation and sustainable business practices
C32	Recycling	The reuse of the used materials and energy
C33	Pollution control	The control of the pollutants released into the air, water, or soil
C34	Environmental protection management system	A system that comprehensively evaluates the internal and external environmental performances of an organization.
C35	ECO design	An approach to designing products, with a special consideration for the environmental impacts of a product during its whole lifecycle.
C36	Consumption of resources	The use of nonrenewable or, less frequently, renewable resources
C37	Green competences	The capacity to balance the containment relationships between economic and environmental performance

4. The Evaluation of the Criteria for the Selection of a Sustainable Supplier

4.1. The Determination of the Criteria Weights at the First Level of Decision-Making

First, the decision-makers (DMs) ranked and made a comparison of the criteria at the first level of decision-making. After that, the steps of the FUCOM method for the calculation of their normalized values were applied as follows:

Step 1: In this step, the team of experts performed the ranking of the criteria. DM1: C1>C2>C3; DM2: C1>C2>C3; DM3: C1>C2>C3;

Step 2: In this step, the decision-makers performed a comparison of the previously ranked criteria. In that way, the significance of the criteria ($\varpi_{C_{j(k)}}$) (Table 2) was obtained.

Table 2. The significance of the criteria at the first level

DM1			
Criteria	C1	C3	C2
Significance ($\varpi_{C_{j(k)}}$)	1	1.9	2.5
DM2			
Criteria	C1	C2	C3
Significance ($\varpi_{C_{j(k)}}$)	1	2.1	2.5
DM3			
Criteria	C1	C3	C2
Significance ($\varpi_{C_{j(k)}}$)	1	1.8	2.4

Based on the obtained significance of the criteria, it is necessary to calculate the comparative priority of the criteria for each one of the decision-makers:

DM1: $\varphi_{C_1/C_2}=1.9/1=1.9$, $\varphi_{C_2/C_3}=2.5/1.9=1.32$; DM2: $\varphi_{C_1/C_2}=2.1/1=2.1$, $\varphi_{C_2/C_3}=2.5/2.1=1.19$; DM3: $\varphi_{C_1/C_2}=1.8/1=1.8$, $\varphi_{C_2/C_3}=2.4/1.8=1.33$

Step 3: In this step, the final values of the weight coefficients were calculated and they should meet the two conditions (3) and (4):
Condition (3):
DM1: $w_1/w_2=1.9$, $w_2/w_3=1.32$; DM2: $w_1/w_2=2.1$, $w_2/w_3=1.19$; DM3: $w_1/w_2=1.8$, $w_2/w_3=1.33$

and the condition (4):

$w_1/w_3=2.51$, $w_1/w_3=2.50$, $w_1/w_3=2.39$

By applying Expression (5), the final model for the determination of the weight coefficients can be defined as follows:

$DM1$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_1}{w_2}-1.9\right|=\chi,\ \left|\frac{w_2}{w_3}-1.32\right|=\chi,\\ \left|\frac{w_1}{w_3}-2.51\right|,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_1}{w_2}-2.1\right|=\chi,\ \left|\frac{w_2}{w_3}-1.19\right|=\chi,\\ \left|\frac{w_1}{w_3}-2.50\right|,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

$DM3$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_1}{w_2}-1.8\right|=\chi,\ \left|\frac{w_2}{w_3}-1.33\right|=\chi,\\ \left|\frac{w_1}{w_3}-2.39\right|,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

By solving the presented model by using the Lingo 17 software, the final values of the weight coefficients were obtained for the first level of decision-making (Table 3).

Table 3. The final values of the weight coefficients obtained for the first level of decision-making

	DM1	DM2	DM3
C1	0.519	0.533	0.507
C2	0.273	0.254	0.282
C3	0.208	0.213	0.211
DFC	0.000	0.000	0.000

4.2. The Determination of the Criteria Weights at the Second Level of Decision-Making

The DMs performed the ranking of the criteria at the second level, and the significances of the criteria were obtained for each group. The calculation of the criteria weights for the second level of decision-making was done in the same way as for the first level. The obtained final values for the sub-criteria are shown in Tables 4 and 5 for the group of the economic criteria, in Tables 6 and 7 for the group of the social criteria, and in Tables 8 and 9 for the group of the environmental criteria.

4.2.1. Determining the sub-criteria weights of the group of the economic criteria

Step 1: DM1: C2>C1>C4>C6>C5>C7>C3; DM2: C2>C4>C3>C5>C1>C6>C7; DM3: C2>C1>C4>C6>C3>C5>C

Step 2:

Table 4. The significance of the criteria at the second level for the group of the economic criteria

			DM1				
Economic factors	C12	C11	C14	C16	C15	C17	C13
$\varpi_{C_{j(k)}}$	1	1.2	1.7	2.0	2.4	2.8	3.1
			DM2				
Economic factors	C12	C14	C13	C15	C11	C16	C17
$\varpi_{C_{j(k)}}$	1	1.4	1.7	2.2	2.4	2.6	3.0
			DM3				
Economic factors	C12	C11	C14	C16	C13	C15	C17
$\varpi_{C_{j(k)}}$	1	1.6	1.8	2.2	2.6	2.9	3.1

DM1: $\varphi_{C_2/C_1}=1.2/1=1.2$, $\varphi_{C_1/C_4}=1.7/1.2=1.42$, $\varphi_{C_4/C_6}=2.0/1.7=1.18$ $\varphi_{C_6/C_5}=2.4/2.0=1.2$ $\varphi_{C_5/C_7}=2.8/2.4=1.17$, $\varphi_{C_7/C_3}=3.1/2.8=1.11$;

DM2: $\varphi_{C_2/C_4}=1.4/1=1.4$, $\varphi_{C_4/C_3}=1.7/1.4=1.21$, $\varphi_{C_3/C_5}=2.2/1.7=1.29$ $\varphi_{C_5/C_1}=2.4/2.2=1.09$, $\varphi_{C_1/C_6}=2.6/2.4=1.08$, $\varphi_{C_6/C_7}=3.0/2.6=1.15$;

DM3: $\varphi_{C_2/C_1} = 1.6/1 = 1.6$, $\varphi_{C_1/C_4} = 1.8/1.6 = 1.13$, $\varphi_{C_4/C_6} = 2.2/1.8 = 1.22$, $\varphi_{C_6/C_3} = 2.6/2.2 = 1.18$, $\varphi_{C_3/C_5} = 2.9/2.6 = 1.12$, $\varphi_{C_5/C_7} = 3.1/2.9 = 1.07$;

__Step 3:__

1) DM1: $w_2/w_1 = 1.2$, $w_1/w_4 = 1.42$, $w_4/w_6 = 1.18$, $w_6/w_3 = 1.2$, $w_5/w_7 = 1.17$, $w_3/w_3 = 1.11$; DM2: $w_2/w_4 = 1.4$, $w_4/w_3 = 1.21$, $w_3/w_5 = 1.29$, $w_5/w_1 = 1.09$, $w_1/w_6 = 1.08$, $w_6/w_3 = 1.15$; DM3: $w_2/w_1 = 1.6$, $w_1/w_4 = 1.13$, $w_4/w_6 = 1.22$, $w_6/w_3 = 1.18$, $w_3/w_5 = 1.12$, $w_5/w_7 = 1.07$;

2) DM1: $w_2/w_4 = 1.7$, $w_1/w_6 = 1.68$, $w_4/w_5 = 1.42$, $w_6/w_3 = 1.4$, $w_3/w_3 = 1.3$;
DM2: $w_2/w_3 = 1.69$, $w_4/w_3 = 1.56$, $w_3/w_1 = 1.41$, $w_3/w_6 = 1.18$, $w_1/w_3 = 1.24$;
DM3: $w_2/w_4 = 1.81$, $w_1/w_6 = 1.38$, $w_4/w_3 = 1.44$, $w_6/w_3 = 1.32$, $w_3/w_7 = 1.20$;

$$DM1$$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_2}{w_1} - 1.2\right| = \chi,\ \left|\frac{w_1}{w_4} - 1.42\right| = \chi, \left|\frac{w_4}{w_6} - 1.18\right| = \chi,\ \left|\frac{w_6}{w_5} - 1.2\right| = \chi, \left|\frac{w_5}{w_7} - 1.17\right| = \chi, \\ \left|\frac{w_7}{w_3} - 1.11\right| = \chi, \left|\frac{w_2}{w_4} - 1.7\right| = \chi, \left|\frac{w_1}{w_6} - 1.68\right| = \chi, \left|\frac{w_4}{w_5} - 1.42\right| = \chi, \left|\frac{w_6}{w_7} - 1.4\right| = \chi, \\ \left|\frac{w_5}{w_3} - 1.3\right| = \chi, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

$$DM2$$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_2}{w_4} - 1.4\right| = \chi,\ \left|\frac{w_4}{w_3} - 1.21\right| = \chi, \left|\frac{w_3}{w_5} - 1.29\right| = \chi,\ \left|\frac{w_5}{w_1} - 1.09\right| = \chi, \left|\frac{w_1}{w_6} - 1.08\right| = \chi, \\ \left|\frac{w_6}{w_7} - 1.15\right| = \chi, \left|\frac{w_2}{w_3} - 1.69\right| = \chi, \left|\frac{w_4}{w_5} - 1.56\right| = \chi, \left|\frac{w_3}{w_1} - 1.41\right| = \chi, \left|\frac{w_5}{w_6} - 1.18\right| = \chi, \\ \left|\frac{w_1}{w_7} - 1.24\right| = \chi, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

$DM3$

$\min \chi$

$$s.t.\begin{cases} \left|\frac{w_2}{w_1}-1.6\right|=\chi,\ \left|\frac{w_1}{w_4}-1.13\right|=\chi, \left|\frac{w_4}{w_6}-1.22\right|=\chi,\ \left|\frac{w_6}{w_3}-1.18\right|=\chi, \left|\frac{w_3}{w_5}-1.12\right|=\chi, \\ \left|\frac{w_5}{w_7}-1.07\right|=\chi, \left|\frac{w_2}{w_4}-1.81\right|=\chi, \left|\frac{w_1}{w_6}-1.38\right|=\chi, \left|\frac{w_4}{w_3}-1.44\right|=\chi, \left|\frac{w_6}{w_5}-1.32\right|=\chi, \\ \left|\frac{w_3}{w_7}-1.2\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

Table 5. The values of the criteria for the second level of decision-making for each of the DMs for the group of the economic criteria

	DM1	**DM2**	**DM3**
C1	0.207	0.107	0.170
C2	0.249	0.257	0.271
C3	0.080	0.151	0.104
C4	0.146	0.184	0.151
C5	0.104	0.117	0.094
C6	0.124	0.099	0.123
C7	0.089	0.086	0.087
DFC	0.000	0.000	0.000

4.2.2. Determining the sub-criteria weights for the group of the social criteria

Step 1: DM1: C2>C6>C1>C3>C5>C7>C4; DM2: C2>C7>C5>C6>C3>C1>C4; DM3: C1>C2>C6>C7>C3>C5>C4

Step 2:

Table 6. The significance of the criteria at the second level for the group of the social criteria

DM1							
Social factors	C22	C26	C21	C23	C25	C27	C24
$\varpi_{C_{j(k)}}$	1	1.5	1.6	1.9	2.1	2.3	2.5
DM2							
Social factors	C22	C27	C25	C26	C23	C21	C24
$\varpi_{C_{j(k)}}$	1	1.3	1.6	1.9	2.3	2.5	2.8
DM3							
Social factors	C21	C22	C26	C27	C23	C25	C24
$\varpi_{C_{j(k)}}$	1	1.3	1.6	2.0	2.2	2.5	3.0

DM1: $\varphi_{C_2/C_6} = 1.5/1 = 1.5$, $\varphi_{C_6/C_1} = 1.6/1.5 = 1.07$, $\varphi_{C_1/C_3} = 1.9/1.6 = 1.19$, $\varphi_{C_3/C_5} = 2.1/1.9 = 1.11$, $\varphi_{C_5/C_7} = 2.3/2.1 = 1.10$, $\varphi_{C_7/C_4} = 2.5/2.3 = 1.09$;

DM2: $\varphi_{C_2/C_7} = 1.3/1 = 1.3$, $\varphi_{C_7/C_5} = 1.6/1.3 = 1.23$, $\varphi_{C_5/C_6} = 1.9/1.6 = 1.19$, $\varphi_{C_6/C_3} = 2.3/1.9 = 1.21$, $\varphi_{C_3/C_1} = 2.5/2.3 = 1.09$, $\varphi_{C_1/C_4} = 2.8/2.5 = 1.12$;

DM3: $\varphi_{C_1/C_2} = 1.3/1 = 1.3$, $\varphi_{C_2/C_6} = 1.6/1.3 = 1.23$, $\varphi_{C_6/C_7} = 2.0/1.6 = 1.25$, $\varphi_{C_7/C_3} = 2.2/2.0 = 1.1$, $\varphi_{C_3/C_5} = 2.5/2.2 = 1.14$, $\varphi_{C_5/C_4} = 3.0/2.5 = 1.2$;

<u>Step 3:</u>

1) DM1: $w_2/w_6 = 1.5$, $w_6/w_1 = 1.07$, $w_1/w_3 = 1.19$, $w_3/w_5 = 1.11$, $w_5/w_7 = 1.1$, $w_7/w_4 = 1.09$; DM2: $w_2/w_7 = 1.3$, $w_7/w_5 = 1.23$, $w_5/w_6 = 1.19$, $w_6/w_3 = 1.21$, $w_3/w_1 = 1.09$, $w_1/w_4 = 1.12$; DM3: $w_1/w_2 = 1.3$, $w_2/w_6 = 1.23$, $w_6/w_7 = 1.25$, $w_7/w_3 = 1.1$, $w_3/w_5 = 1.14$, $w_5/w_4 = 1.2$;

2) DM1: $w_2/w_1 = 1.61$, $w_6/w_3 = 1.27$, $w_1/w_6 = 1.32$ $w_3/w_7 = 1.22$ $w_5/w_4 = 1.2$; DM2: $w_2/w_5 = 1.6$, $w_7/w_6 = 1.46$, $w_5/w_3 = 1.44$, $w_6/w_1 = 1.32$, $w_3/w_4 = 1.22$; DM3: $w_1/w_6 = 1.6$, $w_2/w_7 = 1.54$, $w_6/w_3 = 1.38$, $w_7/w_5 = 1.25$, $w_3/w_4 = 1.37$;

$$DM1$$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_2}{w_6} - 1.5\right| = \chi,\ \left|\frac{w_6}{w_1} - 1.07\right| = \chi, \left|\frac{w_1}{w_3} - 1.19\right| = \chi,\ \left|\frac{w_3}{w_5} - 1.11\right| = \chi, \left|\frac{w_5}{w_7} - 1.1\right| = \chi, \\ \left|\frac{w_7}{w_4} - 1.09\right| = \chi, \left|\frac{w_2}{w_1} - 1.61\right| = \chi, \left|\frac{w_6}{w_3} - 1.27\right| = \chi, \left|\frac{w_1}{w_5} - 1.32\right| = \chi, \left|\frac{w_3}{w_7} - 1.22\right| = \chi, \\ \left|\frac{w_5}{w_4} - 1.2\right| = \chi, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_2}{w_7}-1.3\right|=\chi,\ \left|\frac{w_7}{w_5}-1.23\right|=\chi,\left|\frac{w_5}{w_6}-1.19\right|=\chi,\ \left|\frac{w_6}{w_3}-1.21\right|=\chi,\left|\frac{w_3}{w_1}-1.09\right|=\chi, \\ \left|\frac{w_1}{w_4}-1.12\right|=\chi,\left|\frac{w_2}{w_5}-1.60\right|=\chi,\left|\frac{w_7}{w_6}-1.46\right|=\chi,\left|\frac{w_6}{w_3}-1.44\right|=\chi,\left|\frac{w_6}{w_1}-1.32\right|=\chi, \\ \left|\frac{w_3}{w_4}-1.22\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

$DM3$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_1}{w_2}-1.3\right|=\chi,\ \left|\frac{w_2}{w_6}-1.23\right|=\chi,\left|\frac{w_6}{w_7}-1.25\right|=\chi,\ \left|\frac{w_7}{w_3}-1.1\right|=\chi,\left|\frac{w_3}{w_5}-1.14\right|=\chi, \\ \left|\frac{w_5}{w_4}-1.2\right|=\chi,\left|\frac{w_1}{w_6}-1.6\right|=\chi,\left|\frac{w_2}{w_7}-1.54\right|=\chi,\left|\frac{w_6}{w_3}-1.38\right|=\chi,\left|\frac{w_7}{w_5}-1.25\right|=\chi, \\ \left|\frac{w_3}{w_4}-1.37\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

Table 7. The values of the criteria for the second level of decision-making for each of the DMs for the group of the social criteria

	DM1	**DM2**	**DM3**
C1	0.151	0.097	0.245
C2	0.242	0.243	0.188
C3	0.127	0.106	0.111
C4	0.097	0.087	0.082
C5	0.115	0.152	0.098
C6	0.161	0.128	0.153
C7	0.105	0.187	0.122
DFC	0.000	0.000	0.000

4.2.3. Determining the sub-criteria weights for the group of the environmental criteria

Step 1: DM1: C3>C1>C5>C2>C4>C7>C6; DM2: C3>C2>C4>C5>C7>C6>C1; DM3: C3>C2>C1>C5>C7>C4>C6;

Step 2:

Table 8. The significance of the sub-criteria for the group of the environmental criteria

DM1							
Environmental factors	C33	C31	C35	C32	C34	C37	C36
$\varpi_{C_{j(k)}}$	1	1.2	1.3	1.4	1.7	2.0	2.3
DM2							
Environmental factors	C33	C32	C34	C35	C37	C36	C31
$\varpi_{C_{j(k)}}$	1	1.1	1.3	1.6	1.9	2.3	2.5
DM3							
Environmental factors	C33	C32	C31	C35	C37	C34	C36
$\varpi_{C_{j(k)}}$	1	1.3	1.6	1.9	2.1	2.4	2.9

DM1: $\varphi_{C_3/C_1}=1.2/1=1.2$, $\varphi_{C_1/C_5}=1.3/1.2=1.08$, $\varphi_{C_5/C_2}=1.4/1.3=1.08$, $\varphi_{C_2/C_4}=1.7/1.4=1.21$, $\varphi_{C_7/C_4}=2.0/1.7=1.18$, $\varphi_{C_7/C_6}=2.3/2.0=1.15$;

DM2: $\varphi_{C_3/C_2}=1.1/1=1.1$, $\varphi_{C_2/C_4}=1.3/1.1=1.18$, $\varphi_{C_4/C_5}=1.6/1.3=1.23$, $\varphi_{C_5/C_7}=1.9/1.6=1.19$, $\varphi_{C_7/C_6}=2.3/1.9=1.21$, $\varphi_{C_6/C_1}=2.5/2.3=1.09$;

DM3: $\varphi_{C_3/C_2}=1.3/1=1.3$, $\varphi_{C_2/C_1}=1.6/1.3=1.23$, $\varphi_{C_1/C_5}=1.9/1.6=1.19$, $\varphi_{C_5/C_7}=2.1/1.9=1.11$, $\varphi_{C_7/C_4}=2.4/2.1=1.14$, $\varphi_{C_4/C_6}=2.9/2.4=1.21$;

Step 3:

1) DM1: $w_3/w_1=1.2$, $w_1/w_5=1.08$, $w_5/w_2=1.08$, $w_2/w_4=1.21$, $w_4/w_7=1.18$, $w_7/w_6=1.15$; DM2: $w_3/w_2=1.1$, $w_2/w_4=1.18$, $w_4/w_5=1.23$, $w_5/w_7=1.19$, $w_7/w_6=1.21$, $w_6/w_1=1.09$; DM3: $w_3/w_2=1.3$, $w_2/w_1=1.23$, $w_1/w_5=1.19$, $w_5/w_7=1.11$, $w_7/w_4=1.14$, $w_4/w_6=1.21$;

2) DM1: $w_3/w_5=1.3$, $w_1/w_2=1.17$, $w_5/w_4=1.31$, $w_2/w_7=1.43$, $w_4/w_6=1.36$; DM2: $w_3/w_4=1.3$, $w_2/w_5=1.45$, $w_4/w_7=1.46$, $w_5/w_6=1.44$, $w_7/w_1=1.32$; DM3: $w_3/w_1=1.6$, $w_2/w_5=1.46$, $w_1/w_7=1.32$, $w_5/w_4=1.27$, $w_7/w_6=1.38$;

$DM1$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_1}-1.2\right|=\chi,\ \left|\frac{w_1}{w_5}-1.08\right|=\chi, \left|\frac{w_3}{w_2}-1.08\right|=\chi,\ \left|\frac{w_2}{w_4}-1.21\right|=\chi, \left|\frac{w_4}{w_7}-1.18\right|=\chi, \\ \left|\frac{w_7}{w_6}-1.15\right|=\chi, \left|\frac{w_3}{w_5}-1.3\right|=\chi, \left|\frac{w_1}{w_2}-1.17\right|=\chi, \left|\frac{w_5}{w_4}-1.31\right|=\chi, \left|\frac{w_2}{w_7}-1.43\right|=\chi, \\ \left|\frac{w_4}{w_6}-1.36\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_2}-1.1\right|=\chi,\ \left|\frac{w_3}{w_4}-1.18\right|=\chi, \left|\frac{w_3}{w_5}-1.23\right|=\chi,\ \left|\frac{w_5}{w_7}-1.19\right|=\chi, \left|\frac{w_7}{w_6}-1.21\right|=\chi, \\ \left|\frac{w_6}{w_1}-1.09\right|=\chi, \left|\frac{w_2}{w_4}-1.3\right|=\chi, \left|\frac{w_3}{w_5}-1.45\right|=\chi, \left|\frac{w_4}{w_7}-1.46\right|=\chi, \left|\frac{w_5}{w_6}-1.44\right|=\chi, \\ \left|\frac{w_7}{w_1}-1.32\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

$DM3$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_2}-1.3\right|=\chi,\ \left|\frac{w_2}{w_1}-1.23\right|=\chi, \left|\frac{w_1}{w_5}-1.19\right|=\chi,\ \left|\frac{w_5}{w_7}-1.11\right|=\chi, \left|\frac{w_7}{w_4}-1.14\right|=\chi, \\ \left|\frac{w_4}{w_6}-1.21\right|=\chi, \left|\frac{w_3}{w_1}-1.6\right|=\chi, \left|\frac{w_2}{w_5}-1.46\right|=\chi, \left|\frac{w_1}{w_7}-1.32\right|=\chi, \left|\frac{w_5}{w_4}-1.27\right|=\chi, \\ \left|\frac{w_7}{w_6}-1.38\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

Table 9. The values of the criteria for the 2nd level of decision-making for each of the DMs for the group of the environmental criteria

	DM1	DM2	DM3
C1	0.172	0.086	0.150
C2	0.148	0.195	0.185
C3	0.207	0.214	0.240
C4	0.122	0.165	0.100
C5	0.159	0.134	0.127
C6	0.090	0.093	0.083
C7	0.103	0.113	0.115
DFC	0.000	0.000	0.000

Table 10 accounts for the final values of the criteria and the sub-criteria weights (the global and the local ranks). The final values for the global rank were obtained by the multiplication of the values of the main criteria by the obtained values within the group which they belong to.

Table 10. The final results of the proposed model

	Criteria	wj		Sub-criteria	Local weights	Global weights	Local rank	Global rank
1.	Economic	0.520	1.1	Cost/prices	0.161	0.084	2	2
			1.2	Quality	0.259	0.135	1	1
			1.3	Flexibility	0.112	0.058	5	6
			1.4	Productivity	0.160	0.083	3	3
			1.5	Financial ability	0.105	0.055	6	7
			1.6	Partnership relations	0.115	0.060	4	4
			1.7	Tech.-innovation	0.087	0.045	7	9
2.	Social	0.270	2.1	Reputation	0.164	0.044	2	10
			2.2	Safety at work	0.224	0.060	1	5
			2.3	Employees' rights	0.115	0.031	6	15
			2.4	Local community influence	0.089	0.024	7	19
			2.5	Training of employees	0.122	0.033	5	14
			2.6	Respect of rights and policies	0.147	0.040	3	11
			2.7	Disclosing information	0.138	0.037	4	13
3.	Environmental	0.211	3.1	Green image	0.136	0.029	4	17
			3.2	Recycling	0.176	0.037	2	12
			3.3	Pollution control	0.220	0.046	1	8
			3.4	Environmental protection management system	0.129	0.027	5	18
			3.5	Green products	0.140	0.030	3	16
			3.6	Consumption of resources	0.089	0.019	7	21
			3.7	Green competences	0.110	0.023	6	20

5. Discussion

According to the respective decisions of all the three experts, when selecting a sustainable supplier, the economic factors have the greatest influence at the first level of decision-making. Those factors are followed by the social and, finally, the ecological factors, as the second- and the third-ranked (having the least influence), respectively. The obtained results showing the criteria values were expected at the beginning of the research study because the standards of environmental protection and human life and health are still insufficiently developed in the territory of Bosnia and Herzegovina, where the company is located and operates. At the second level of decision-making, quality is the most important criterion in the group of the economic factors, and is also the most important criterion in general our of all the other criteria, which is understandable given the fact that the selection of a sustainable supplier of input resources for production is carried out. In order to achieve a good quality of the output product, it is necessary that the quality of the input resource should be satisfactory. The price, productivity and partner relationships are also the criteria ranked the same in the local and the global ranks of the criteria. Once, the price was the most important criterion; with the development of the market and an increase in the number of competitors, however, quality began gaining in importance, whereas the price became less important; in this case, it ranks the second. In order to meet the conditions and the needs of the customers of the final product, it is important to provide the required quantity of products at the required time, which is achieved by timely and continuous production, for which reason it is important that the selected supplier should be reliable and make his/her deliveries at the right time. For this reason, reliability is the decision-makers' third highest priority in this research study. The selection of a supplier is a strategic decision, and therefore it is very important that the supplier should be ready to develop long-term partnerships and joint market development, due to which fact partnership relations rank the fourth. The fifth-ranked is safety at work in the global ranking, simultaneously being the first-ranked in the group of the social factors. In the course of its business, the company pays great attention to its employees' safety at work, for the reason of which fact this criterion is of great importance in the selection of suppliers. The sixth and the seventh ranks in the global ranking are assigned to the criteria of the group of the economic factors, namely to flexibility and the financial ability. As a consequence of the lesser importance of the group of the social factors, the reputation ranked the second in the local ranking, whereas it ranked the tenth in the global ranking. Out of the group of the environmental factors, pollution control is highlighted, which ranks much more importantly than the other criteria belonging to this group, out of which it ranks the eighth in the global ranking, and it is understandable for that reason that it is of the highest importance and ranks the first at the local level. Given the fact that green competence and resource consumption rank the last in the global ranking, they are the criteria least considered in the evaluation and selection of suppliers.

6. Conclusion

Nowadays, increasing attention is paid to the selection of a supplier given the fact that the establishment of long-term cooperation with a reliable supplier can affect a reduction in the total production costs and reaching a competitive position on the market. Considering the fact that manufacturing processes are both numerous and complex, the manufacturer's requirements for suppliers are very complex as well. Such requirements, i.e. criteria, have increasingly been growing in number, making it difficult for decision-makers to choose suppliers. In order to facilitate the selection of a sustainable supplier, the multi-criteria FUCOM method for criteria evaluation was applied in this paper. In order to assess the significance of the criteria formed at two levels, an expert team of three decision-makers was selected. The results obtained by the applied methodology demonstrate that the most important criteria for the selection of suppliers are the quality, the price, productivity, partnership relations, safety at work, flexibility and the financial ability. Based on the most important criteria mentioned in this paper, future research should study the application of certain MCDM methods for the assessment and selection of suppliers in the company for the production of lime.

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