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USING FUZZY MULTI CRITERIA DECISION MAKING APPROACH FOR THE EVALUATION OF EFFICIENCY OF FREIGHT RAIL OPERATORS

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Abstract

The state railway deficit is enormous, and the issue of the efficiency of railway companies has become a reality in economic and political debates. Permanent rail deficits also indicate that the overcapacity in the entire industry, with the lack of efficiency of railways under the state administration, could be the main reason for the insufficient or negative return of invested capital. In times when there is a large public debt in the entire world, the state has a natural interest in adapting railway companies and making the capital allocated to them profitable. It is therefore of particular importance to restructure the railways and develop their competitive capabilities. The European Union is embarking on a comprehensive process of restructuring and commercialization of railway transport, which enables the reaffirmation and improvement of the quality of railway services and the efficiency of railways.The main objective of the European policy of rail transport is the development of a single railway area. The opening of railway sector to market competition imposes that railway undertakings behave like any other modern enterprises in other markets and in other industries. It means, they must constantly develop and maintain competitive advantages, and be better than others. In today's very intense competition conditions this is the most difficult to achieve. The railway undertakings are challenged to find optimal solutions to operate efficiently and effectively, in order not only to survive on the transport market, but also to develop and maintain a competitive advantage. A wide range of criteria can be studied when it comes to the efficiency of railway undertakings. In most cases there are several criteria that are often mutually conflicting. The aim of this study is to define and evaluate the criteria that influence the efficiency of railway undertakings and increasing of their competitive ability and to propose a model for the evaluation of the effectiveness and efficiency of railway undertakings in order to increase the competitive ability. To solve the problem of indicators selection, it was experimented with one of the most used methods for making decisions today - Fuzzy analytic hierarchy process (FAHP).

Keywords:Railway undertaking, efficiency, criteria, fuzzy AHP

INTRODUCTION

The application of the new European transport policy at the end of the last century caused major changes in Europe's transport system. Traffic is being developed in accordance with the goals of sustainable development. There is a major transformation of transport companies into efficient companies that will be operating in future in a liberalized European transport market. The railway, as a large business system, is in front of a major milestone in its operation. The business and development philosophy of the railway as a system, its management mechanisms and its organization is changing significantly. The state as a whole should assume responsibility for the functioning of the infrastructure, and the railway transport company for commercial activity and responsibility for the results. Liberalization of the railway transport market implies, above all, a free and non-discriminatory access to the railway infrastructure, with the fact that the transport function is carried out by a larger number of operators on the appropriate national rail network.With the market liberalization, railway operators are forced to act like all other modern companies in other markets and other industries, which means they must constantly develop and maintain competitive advantages, or be better than others. In today's competitive, very intensive conditions, this is most difficult to achieve. The challenge for railway operators is to find optimal solutions to operate efficiently and effectively, not only to survive on the transport market, but also to develop and maintain their competitive advantages.Measuring and improving the efficiency and effectiveness of the operation of the railway operator is a precondition for successful business and survival on the market. Measuring the efficiency of the company is one of the key managerial activities in modern companies that provides us with an insight into the current status of the company, goals to be achieved in the future, but also the current position on its way to achieve the set goals. Modern systems of performance/efficiency measurement do not only include business results in the form of financial indicators, but also the causes of the results that can be realized exclusively through certain indicators. Such system is undoubtedly of strategic importance for every company that wants to survive and develop in today's conditions and therefore must be adequately integrated into the system of strategic management.Given that in modern companies, it is necessary to constantly measure the causes of the achieved effect, then it is quite clear that the system for performance/efficiency measurement of the railway operator must include all the indicators that affect it. For railway companies undergoing a transformation process, it is very important to form a performance/efficiency measurement system that is appropriate to modern business conditions. Operations in today's dynamic and competitive intensive environment by railway operators require precisely constant measurement of non-financial indicators, which are identified as causes of the financial result, so that eventual negative trends can be corrected before their effect negatively affects the final result of operations, which is, as a rule, evaluated from a financial perspective. Bearing in mind that the efficiency of railway transport makes the number of services offered and the content of the services that have been implemented, it is necessary to determine the criteria that can define efficiency.Deciding on the selection of criteria for assessing the efficiency and effectiveness of railway operators is a very complex process and belongs to the domain of strategic decisions. The adoption of this decision is in the function of managing the railway operator and as such, this activity is complex, creative and permanent. In order to make a decision on the selection of criteria for evaluating the efficiency of railway operators, it is necessary to evaluate the proposed variant solutions of different criteria. In most cases there are several criteria that are very often conflicting with one another. To select the best method of evaluation or decision-making in the selection of criteria, previous experience and literature in this field indicate that the problem should be addressed by multi-criteria decision-making methods. In this paper, it is experimented with one of the most popular methods for decision making today - the Fuzzy Analytic Hierarchy Process (FAHP).).

FUZZY ANALYTIC HIERARCHY PROCESS (FAHP)

The analytic hierarchy process (AHP) method developed by Tomas Saaty is widely spread, has been in use for over 25 years and a number of softwares are developed to support its application. This method is a tool in decision making, designed to provide decision makers in solving complex decision-making issues involving a larger number of decision-makers, a greater number of criteria, and in multiple time periods. Detailed explanations of this method are provided in many references that deal with decision theory. In this regard, the paper presents a new approach to the AHP method using interval fuzzy numbers and the application of the modified fuzzy AHP method in defining and evaluating criteria that influence the evaluation of efficiency and effectiveness of railway undertakings. Different methods for transferring the previously mentioned AHP method into its fuzzy form are presented in the literature (Bottani, 2005). In addition, the paper (Van Laarhoven and Pedrcyz, 1983) is proposing a first study that introduces principles of fuzzy logic in the AHP method, using triangular fuzzy numbers. At the same time, a study from Buckley (1985), initiates that the trapezoidal fuzzy numbers are expressing assessments of decision makers, while the authors of the study (Boender et al., 1989) presented modification to the fuzzy multi-criteria method proposed in Chang's paper (1996). In the study (Chang, 1996), the severity of the criteria is calculated as the minimization of the logarithmic regression function. In this way, the weight alternatives are calculated by each criterion separately, while the aggregation of calculated weights can determine the fuzzy final result of the alternative. The study (Cebi and Bayraktar, 2003) presents a new approach to solving the AHP phase (FAHP) using triangular fuzzy numbers. This approach is called an extended analytical method that can be summarized as follows: define the association function for each attribute and sub-attribute, then calculate their degree of association and ultimately apply the AHP phase for weight aggregation. Also, Vesković S., et al. (2015) apply FAHP to evaluate the criteria for public transport obligations.Fuzzy sets generally use triangular, trapezoidal and Gaus fuzzy numbers, which convert uncertain numbers into fuzzy numbers. Using more complicated fuzzy numbers such as trapezoidal or Gaus, allows a more precise description of the problem of decision making. However, triangular fuzzy numbers are also widely used, especially in the following circumstances: when there is a greater complexity of calculation as a consequence of complexity of functions,when simplifying the fuzzy mathematical operations due to the use of triangular fuzzy numbers, 3) when it is more difficult to define the functions of association as a consequence of the complexity of fuzzy numbers andwhen the triangular fuzzy numbers effectively represent estimates made by a number of decision makers.

To solve the problem of defining and evaluating the criteria for assessing the efficiency and effectiveness of railway undertakings, this paper uses triangular fuzzy numbers (Chang, 1996).

CRITERIA FOR ASSESSING EFFICIENCY AND EFFECTIVENESS OF RAILWAY UNDERTAKINGS IN FREIGHT TRANSPORT

For the purpose of defining and evaluating the criteria, a research of the most frequently used literature criteria regarding efficiency and effectiveness of railway companies was carried out. An analysis of the railway undertakings from EU countries, as well as Bosnia and Herzegovina was performed. In addition, railway experts have been interviewed.Based on the conducted research, it was concluded that a number of criteria are used. Grouping of criteria in the railway system can be done in different ways. In terms of level of measurement, it is possible to define the criteria at strategic, tactical and operational level. Railway systems represent complex systems with numerous interconnected subsystems, processes and activities. Each subsystem, process or activity is characterized by certain criteria. Based on literature and knowledge, the following criteria of the freight transport operator are defined.

Table 1 Criteria for assessing the efficiency and effectiveness of railways undertakings in freight transport

Group	Criteria
Resource criteria (capacity)	Network length Available rolling stock Number of employees
Operational criteria	Commercial speed for freight trains Quantity of transported goods/freight Net tonne km Gross tonne km Train km
Financial criteria	Total income Profit per employee Electricity costs Fuel costs Railway infrastructure charges
Service quality criteria	Availability of services Suitability – ability of offered services Stability of services Reliability of services (overdue delivery time)
Safety criteria	Number of serious accidents per train km Number of accidents per train km Number of incidents per train km

Detailed explanations, essence and meaning of all groups of criteria were presented in the Doctoral Dissertation Blagojević, A., “Modeling the efficiency and effectiveness of railway undertakings”. All criteria are with linear preference and evaluated according to the linguistic scale of importance provided in Table 2.

RESEARCH RESULTS

Different methods have been applied for the purpose of comprehensive research, and the obtained data should enable analysis of various aspects related to this problem, which refers to the definition and evaluation of criteria for assessing the efficiency of rail freight transport operators.The assessment of the criteria was based on the Fuzzy AHP (FAHP) method. For the possibility of variation the impact of certain criteria were introduced weights. Under conditions where the coefficients have the same impact on the selection of optimal variants of their weights must have the same value. A higher value ratios mean higher impact criteria.Each criterion is assigned a relative weight ratio. This relative weighting coefficient is practically defines the importance of each criterion. The sum of weights must be one.Experts from the railway sector participated in the process of evaluation of the relative importance of particular criteria for each group. They filled out a survey in which they evaluated the importance of each criterion to the linguistic preference scale for each group. Table 2 shows the conversion of linguistic variables into triangular fuzzy numbers (Kilincci and Onal, 2011).

Table 2 Linguistic variables and their corresponding fuzzy numbers

Linguistic variables	Triangular fuzzy numbers	Reciprocal value triangular fuzzy numbers
Equally preferred	(1.1,1)	(1,1,1)
Weakly preferred	(1/2,1,3/2)	(2/3,1,2)
Fairly strongly preferred	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly preferred	(5/2,3,7/2)	(2/7,1/3,2/5)
Absolutely preferred	(7/2,4,9/2)	(2/9,1/4,2/7)

Solving the problem of selecting the criteria of the highest importance for the purpose of assessing the efficiency and effectiveness of railway undertakings between the aforementioned groups was initiated by the application of the FAHP approach.For the illustrated example of selection of criteria of the highest importance in this paper, an example of the selection of criteria for a financial group is presented. Table 3 presents a fuzzy matrix of benchmarking criteria from a group of financial criteria. (Total revenue - C1, Profit per employee - C2, Electricity costs - C3, Fuel costs - C4 and Railway infrastructure charge - C5).

Table 3 Comparative matrix for financial criteria group of freight railway undertakings

		C_1	C_2	C_3	C_4	C_5
C_1	E1	(1,1,1)	(1,1,1)	(1/2,1,3/2)	(3/2,2,5/2)	(2/3,1,2)
	E2	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(3/2,2,5/2)	(1,1,1)
	E3	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(3/2,2,5/2)	(2/5,1/2,2/3))

	E4	(1,1,1)	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(2/5,1/2,2/3))
	E5	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(3/2,2,5/2)	(2/3,1,2)
C_2	E1	(1,1,1)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E2	(1/2,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)
	E3	(1/2,1,3/2)	(1,1,1)	(1/2,1,3/2)	(3/2,2,5/2)	(2/3,1,2)
	E4	(1,1,1)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E5	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)
C_3	E1	(2/3,1,2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)
	E2	(2/3,1,2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E3	(2/3,1,2)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)
	E4	(1/2,1,3/2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E5	(2/3,1,2)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)	(2/3,1,2)
C_4	E1	(2/5,1/2,2/3)	(2/3,1,2)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)
	E2	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E3	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)
	E4	(2/3,1,2)	(2/3,1,2)	(1,1,1)	(1,1,1)	(1,1,1)
	E5	(2/5,1/2,2/3)	(2/3,1,2)	(2/3,1,2)	(1,1,1)	(2/5,1/2,2/3)
C_5	E1	(1/2,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)
	E2	(1,1,1)	(1,1,1)	(1/2,1,3/2)	(1/2,1,3/2)	(1,1,1)
	E3	(3/2,2,5/2)	(1/2,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)
	E4	(3/2,2,5/2)	(1,1,1)	(1/2,1,3/2)	(1,1,1)	(1,1,1)
	E5	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)	(3/2,2,5/2)	(1,1,1)

The fuzzy weight of criteria is calculated by taking the geometric average of the response of the expert (Lee, 2009). An example of a geometric mean calculation is provided only for C_{12}, while the other values shown in Table 4 are calculated analogously. An example of the calculation of the geometric mean for C_{12}:n− = $(1x2/3x2/3x1x1/2)^{1/5}$ = 0.740; n− = $(1x1x1x1x1)^{1/5}$= 1; n+ = $(1x2x2x1x3/2)^{1/5}$= 1.431

Table 4 Fuzzy comparative matrix for financial criteria group

	C_1	C_2	C_3	C_4	C_5
C_1	1,1,1	0.740,1, 1.431	0.530,1, 1.589	1.204,1.741, 2.257	0.589,0.758, 1.121
C_2	0.699,1, 1.351	1,1,1	0.623,1.149, 1.661	0.776,1.444, 1.840	0.850,1, 1.319
C_3	0.629,1, 1.888	0.602,1, 1.605	1,1,1	0.758,1, 1.176	0.543,0.758, 1.288
C_4	0.443,0.574, 0.830	0.543,0.758, 1.289	0.922,1, 1.149	1,1,1	0.532,0.660, 0,901
C_5	0.563,1.319, 1.696	0.757,1, 1.176	0.776,1.319, 1.840	1.110,1.515, 1.879	1,1,1

In addition, this paper uses standard steps of the FAHP method (Stević, Ž. Et al. 2015). 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.

C_1=(1+0.740+0.530+1.204+0.589;1+1+1+1.741+0.758;1+1.431+1.589+2.257+1.121) = (4.063; 5.499; 7.398).
C_2=(0.699+1+0.623+0.776+0.850;1+1+1.149+1.144+1;1.351+1+1.661+1.840+1.319) = (3.948; 5.593;7.171).
C_3=(0.629+0.602+1+0.758+0.543;1+1+1+1+0.758;1.888+1.605+1+1.176+1.288) = (3.532;4.758;6.957).
C_4=(0.443+0.543+0.922+1+0.532;0.574+0.758+1+1+0.660;0.830+1.289+1.149+1+0.901) = (3.44;3.992;5.169).
C_5=(0.563+0.757+0.776+1.110+1;1.319+1+1.319+1.515+1;1.696+1.176+1.840+1.879+1) = (4.206;6.153;7.591).

The $\sum_{i=1}^{n}\sum_{j=1}^{n} M_{gi}^{j}$ value is calculated as:(4.063;5.499;7.398)**+(**3.948; 5.593;7.171)**+(**3.532;4.758;6.957)**+(**3.44;3.992;5.169)**+**(4.206;6.153;7.591)**=(19.189;25.995;34.286).**

Then, $S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$:
S_1=(4.063;5.499;7.398)x(1/34.286;1/25.995;1/19.189)=(0.119;0.212;0.386),
S_2=(3.948;5.593;7.171)x(1/34.286;1/25.995;1/19.189)=(0.115;0.215;0.374),
S_3=(3.532;4.758;6.957)x(1/34.286;1/25.995;1/19.189)=(0.103;0.183; 0.363),
S_4=(3.44;3.992;5.169)x(1/34.286;1/25.995;1/19.189)=(0.100;0.154;0.270) i
S_5=(4.206;6.153;7.591)x(1/34.286;1/25.995;1/19.189)=(0.123;0.236;0.396).

The degree of possibility for Si over Si (i≠j) was determined by using expression:

$$V(S_b \geq S_a) = \begin{cases} 1, & if\ m_b \geq m_a \\ 0, & if\ l_a \geq u_b \\ \dfrac{l_1 - u_2}{(m_b - u_b) - (m_a - l_a)}, & otherwise \end{cases} \quad (1)$$

$V(S_1 \geq S_2)$=00.993;	$V(S_1 \geq S_3)$=1;	$V(S_1 \geq S_4)$=1;	$V(S_1 \geq S_5)$=0.916;
$V(S_2 \geq S_1)$=1;	$V(S_2 \geq S_3)$=1;	$V(S_2 \geq S_4)$=1;	$V(S_2 \geq S_5)$=0.919;
$V(S_3 \geq S_1)$=0.890;	$V(S_3 \geq S_2)$=0.886;	$V(S_3 \geq S_4)$=1;	$V(S_3 \geq S_5)$=0.816;
$V(S_4 \geq S_1)$=0.719;	$V(S_4 \geq S_2)$=0.718;	$V(S_4 \geq S_3)$=0.852;	$V(S_4 \geq S_5)$=0.639;
$V(S_5 \geq S_1)$=1;	$V(S_5 \geq S_2)$=1;	$V(S_5 \geq S_3)$=1;	$V(S_5 \geq S_4)$=1;

With the help of $d'(A_i) = \min V(S_i \geq S_k), k \neq i, k = 1,2,\dots,n$), the minimum degree of possibility was stated as below:

d'(C_1)=min(0.993;1;1;0.916)=**0.916**;d'(C_2)=min(1;1;1;0.919)=**0.919**; d'(C_3)= min(0.890; 0.886;1;0.816)=**0.816**; d'(C_4) min(0.719;0.718;0.852;0.639)=**0.639**;d'(C_5)=min(1;1;1;1)=**1**

The weight vector is given by the following expression:

$$W' = (\mathrm{d}'(C_1), \mathrm{d}'(C_2), \dots, \mathrm{d}'(C_n))^T, \quad (2)$$

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

$$W = (\mathrm{d}(C_1), \mathrm{d}(C_2), \dots, \mathrm{d}(C_n))^T, \quad (3)$$

After the equation is applied (2), weight values are obtained, and from the equation (3) normalized weights of criteria are received. The relative fuzzy weights of each criterion are presented in Table 5.

Table 5 Average and normalized relative weight of financial criteria group

Criteria	W'	W
Total income – C_1	0.916	0.213
Profit per employee – C_2	0.919	0.214
Electricity costs – C_3	0.816	0.190
Fuel costs – C_4	0.639	0.149
Railway infrastructure charges – C_5	1	**0.233**

Comparative analysis was performed using the FAHP method which showed that by comparing five criteria from the financial group that influence the assessment of efficiency and effectiveness of railway undertakings, the greatest weight according to the experts has the criterion of charges for the use of railway infrastructure with a relative weight of 0.233. Also, analogously to the same principle, a comparison of the criteria by pairs for each group was made. The relative ranking of the importance of particular criteria, based upon comparison of the criteria by pairs, for all groups in fright transport, has been presented in Table 6.

Table 6 Relative ranking of importance of separate criteria based on comparison of pairs of all groups in freight transport

Group	**Criteria**	**W'**	**W**
Resource criteria (capacity)	Network length	0.101	0.065
	Available rolling stock	1	**0.654**
	Number of employees	0.430	0.281
Operational criteria	Commercial speed of freight trains	0.683	0.162
	Quantity of transported goods/freight	1	**0.237**
	Net tonne km	0.794	0.189
	Gross tonne km	0.843	0.200
	Train km	0.895	0.212
Financial criteria	Total income	0.916	0.213
	Profit per employee	0.919	0.214
	Electricity costs	0.816	0.190
	Fuel costs	0.639	0.149
	Railway infrastructure charges	1	**0.233**
Service quality criteria	Availability of service	0.738	0.256
	Suitability – ability of offered services	0.512	0.177
	Stability of services	0.638	0.221
	Reliability of services (overdue delivery time)	1	**0.346**
Safety criteria	Number of serious accidents per train km	1	**0.558**

Number of accidents per train km	0.473	0.264
Number of incidents per train km	0.318	0.178

Based on the table results, it can be concluded that for the group of resource criteria, the greatest relative weight has the available rolling stock (0.654), for the group of operational criteria, the quantity of goods transported (0.237), for the group of financial criteria, the cost of charges for the use of railway infrastructure (0.233), service reliability – overdue delivery deadline (0.346) and for the group of safety criteria, the highest relative weight has the criterion number of serious accidents (0.558) based on the survey of railway experts.

CONCLUSION

Efficient railway transport is a very important component of economic development on a global and national level. It is therefore of particular importance to restructure the railways and develop their competitive capabilities. In order not only to survive on the transport market, but also to develop and maintain competitive advantages, they must operate effectively and efficiently.

Effectiveness and efficiency of transport activities significantly affect the profitability of the business of all entities involved in the process, but they cannot be provided without much effort in the process of quality management and transport activities. Measuring the efficiency and effectiveness of railway undertakings inevitably becomes a condition for their survival in a unique transport sector. Efficiency and effectiveness has a positive impact on a number of other important indicators of the functioning of railway undertakings, such as better use of resources, more rational energy consumption, increased security, increased quality of service, etc. In order to assess the proper performance of operations in the railway freight transport i.e. the efficiency of railway operations, it is necessary to define and determine appropriate indicators. Bearing in mind that the effectiveness of the railway transport makes the number of services offered and the content of services that have been implemented, it was necessary to determine the criteria that can define efficiency. Based on the definition, the efficiency depends on the number of performed in relation to the number of scheduled rides, taking into consideration the reasons that led to the travel being not realized (weather conditions, technical malfunction and lack of staff).Based on the analysis of the railway undertakings and the review of the available literature in this area, there has come to the identification of the criteria for the transport of goods (freight transport), that influence the assessment of efficiency and effectivness (a total of 20 crietria)andthat are sorted into groups.The FAHP method used has shown criteria from each group that were a priority for assessing the efficiency and effectiveness of railway undertakings.

Using these criteria, the management of railway undertakings can monitor the process of quality management and transport activities, and also define appropriate corrective actions. This would overcome certain limitations and improve the process of evaluating the efficiency and effectiveness of railway undertakings.

This paper opens the possibility/directions for further research that can identify new criteria related to the efficiency and effectiveness of railway undertakings and explore other methods for evaluating criteria using different techniques of multi-criteria analysis.

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