A HYBRID MCDM MODEL FOR EVALUATION OF RAIL FREIGHT TRANSPORTATION EFFICIENCIES OF BALKAN STATES

Omer Faruk Gorcun

Faculty of Applied Science at Kadir Has University, Cibali- Fatih, Istanbul 34083, Turkey

Abstract

The importance of Balkan Countries in the perspective of international transportation and logistics operations in addition to global trade has been ever-increasing. Especially, in addition to being countries of transit, each of them tries to be hub countries in the international trade thanks to investments, which were made in the fields of transportation and logistics by themselves. At the same time, while the import volume of the Balkan countries is shown an increase depending on their national incomes. As well as the range of products that subject to the export, the total revenue of countries is also increased day by day. Rail transportation plays an important role in logistics and transportation activities of these countries and it can be accepted as an indicator for logistics performance. In order to be important actors in international trade, they should be aware of their performance about rail freight transportation and should base on their decisions to these factors. Therefore, it is needed a methodology and model, which suggest a systematic and structural solution way in order to evaluate the performance of the Balkan countries in the fields of rail freight transportation. In this study, a hybrid model, which consist of integrated entropy and OCRA methods is proposed in order to analyze the rail freight transport effectivities of these countries. While the selected model can provide the calculation of the rail freight transport performance scores of countries and it provides an opportunity of comparison of effectivity and performance of these countries by focusing the output and input factors.

Keywords: *Rail Freight Transport, Performance Analysis, OCRA, Entropy, logistics, MCDM*

1. INTRODUCTION

In recent years, Balkan countries have shown get a forth effort to economic development and they have been a success though it is partially. On the other hand, they have need long-run economic growth in order to continue economic development. Although one of the most important factors is international stimuli and external economic aids, they are not limitless and they cannot continue the last forever. Unfortunately, they may confront economic risk in the short or mid-term. Therefore, Balkan countries have to find the best way to economic development without external supports. On the other hand, they have unique locations in aspects of international trade and logistics and they can be accepted as passageway between Asia and Europe. More importantly, if they can use these kinds of own advantages, they may have become very effective and determinative actors of the global economy and trade.

Their locations can provide various opportunities in aspects of logistics and transportation. Today the global world and its important actors focus on the different and unprecedented logistics operations such as intermodality, combined transportation, co-modality and so on. The most important elements of these kinds of operation are long-distance transportation modes such as maritime and railway transportation, which provide costs effectivity. Especially railway transportation can provide unique opportunities to conduct excellent logistics and transport operations and it can very important component of economic development for Balkan countries. On the other hand, railway transportation needs to a high volume of investments. Especially infrastructural and superstructural investments of railway transportation have an extremely heavy financial burden. Therefore, decision-makers have to be more sensitive and have to deal with the decision-making process more detailed when they confront with decision-making problem about railway system investments.

As well as railway transportation provide various advantages, it may also cause high investment costs for national economies. Therefore railway investments should be more rational and realistic. Immediately before, decision-makers have to aware of weakness and strong sides of their railway

systems and efficiency of railway transportation system should be analyzed. In order to obtain realistic and applicable results, policymakers need effective tools to measure the performance of railway systems. More importantly, performance analysis the railway transportation system is a multi-criteria decision-making problem and it can be solved with effective multi-criteria decision-making techniques. Accordingly, a hybrid multi-criteria decision-making model proposes in this study. This model consists of the Entropy method and The Operational Competitiveness Rating (OCRA) technique. While weight values of all input and output factors are calculated by using the entropy method, performance scores of decision options are computed with the help of OCRA technique.

The main objective of this study is to illustrate the performance values of the railway freight transport systems of the Balkan countries by using the proposed MCDM model and discuss whether this model is applicable for analysis of efficiency for railway freight transport systems. Suggested model can be a useful tool to make performance analysis of these kinds of systems for decision-makers and it can contribute further academic studies about railway performance analysis.

2. LITERATURE REVIEW

When the literature about railway performance analysis is reviewed, it is seen that any study does not exist related performance analysis of the rail freight systems by using OCRA method. although they are in limited number, some studies also exist that using the various multi-criteria decision-making methods in order to use evaluation of the efficiency of railway transportation systems. Yu (2008) examined the service effectiveness and technical effectiveness of the world's railways by using NDEA analysis. Woroniuk et al (2013) evaluated the railway freight service quality of the private sector in Europe with the help of time series approach. Marchetti and Wanke (2017) proposed Data Envelopment Analysis (DEA) method to make performance analysis for Brazilian railway companies. Similarly, Yu and Lin (2008) examined the efficiency and effectiveness in railway performance using a multi-activity network DEA model. Finger (2014) evaluated the relationship between performance and competition for European railways. Wetzel and Growitsch (2006) presented a study for evaluating the economies of scope in European railways in terms of efficiency analysis. Oum and Yu (1994) suggested using the DEA technique for analysis of economic efficiency of railways and Implications and by implementing for the OECD Countries' Railways, they tried to show that this method is working. WiegmanS and Donders (2007) evaluated benchmarking experiences of European railway companies in aspects of efficiency analysis. Bhanot and Singh (2012) examined the performance indicators of the Indian Railway container business using data envelopment analysis. Cantos, Pastor and Serrano (2000) made an analysis for the Efficiency Measures and Output Specification for the European Railways. Lan and Lin (2014) proposed to use the DEA method to evaluate the technical efficiency and service effectiveness of railways industry.

When studies realized for efficiency and performance analysis are reviewed, it can be seen that there are many studies using OCRA method in various fields. If they are summarized, some studies exist, which using the OCRA method such as Ozbek (2015a, 2015b, 2015c); Wang (2006); Parkan, Lam and Hang (1997); Jayanthia, Kochab and Sinha (1999); Somogyi (2011); Stanujkic et al. (2017).

3. MATERIALS AND METHODS

3.1 Materials

Used data and information in this study have been obtained from international institutions about railway transportation such as the International Union of Railways (UIC), Intergovernmental Organization for International Carriage by Rail (OTIF). In addition to those, statistical data, which related to the railway transportation, of other international organizations such as The Organization for Economic Co-operation and Development (OECD), World Bank, The United Nations Conference on Trade and Development (UNCTAD), and The United Nations Economic Commission for Europe (UNECE) were also reviewed. Afterward, input and output factors affecting the performance of the railway freight transportation systems of the Balkan countries have been determined as shown in Table-1 and Table-2.

Type	**Codes**	**Definition**	**Unit**
Rail Lines	I1	Lines not electrified	In kilometers
Rail Lines	I2	Lines electrified	In kilometers
Rail Lines	I3	Total length of lines	In kilometers
Rail Lines	I4	Track length	In kilometers
Actual stock (Loco)	I5	Diesel locomotives	Unit
Actual stock (Loco)	I6	Electric locomotives	Unit
Actual stock (Wagon)	I7	Total capacity in tones	Unit
Actual stock (Wagon)	I8	Total number of wagons	Unit
Actual stock (Wagon)	I9	Covered wagons	Unit
Actual stock (Wagon)	I10	High sided wagons	Unit
Actual stock (Wagon)	I11	Flat wagons	Unit
Actual stock (Wagon)	I12	Other wagons	Unit
Staff	I13	Infrastructure	Person
Staff	I14	Operation	Person
Staff	I15	Total staff	Person
Specific costs	I16	Staff costs	Millions Euros
Specific costs	I17	Depreciation and amortization	Millions Euros
Specific costs	I18	Total operating expenses	Millions Euros
Investments	I19	Railway investments	Million Euro
Cost of Accidents	I20	Accident and Injuries Cost	Euro

Table 1. Input Factors

Type	**Codes**	**Definition**	**Unit**
Train movements	O1	Total Train Mov.	Thousands of train-km
Train movements	O2	Diesel	Thousands of train-km
Train movements	O3	Electric	Thousands of train-km
Train movements	O4	Total Train	Millions gross tones-km
Train movements	O5	Diesel	Millions gross tones-km
Train movements	O6	Electric	Millions gross tones-km
Operator's train movements	O7	Total Train	In thousands train-km
Operator's train movements	O8	Diesel	In thousands train-km
Operator's train movements	O9	Electric	In thousands train-km
Gross hauled ton-km	O10	Total Train	Millions gross tones-km
Gross hauled ton-km	O11	Diesel	Millions gross tones-km

Gross hauled ton-km	O12	Electric	Millions gross tones-km
Revenue-earning	O13	Tones carried	Carriaged cargo volume
Revenue-earning	O14	Tonne-Km	Carriaged cargo volume
Revenue-earning	O15	Mean distance run by a ton	Carriaged cargo volume
Specific revenue	O16	Freight Traffic Turnover	Millions euros
Specific revenue	O17	Infrastructure Turnover	Millions euros
Specific revenue	O18	Total operating income	Millions Euros

Table 2. Output Factors

As seen in these table, twenty input and eighteen output factors are determined to analyze the railway freight performance of ten Balkan countries. Although Albania is a Balkan country, it has been left out of this evaluation process because there is not enough information and data about the railway transportation system of this country.

3.2 Methods

To make effective and applicable performance analysis for railway freight transport systems is crucial for decision-makers who direct national transport policies and it is a costly and time-consuming activity at the same time. In this study, an integrated MCDM approach based on entropy and ocra technique is suggested.

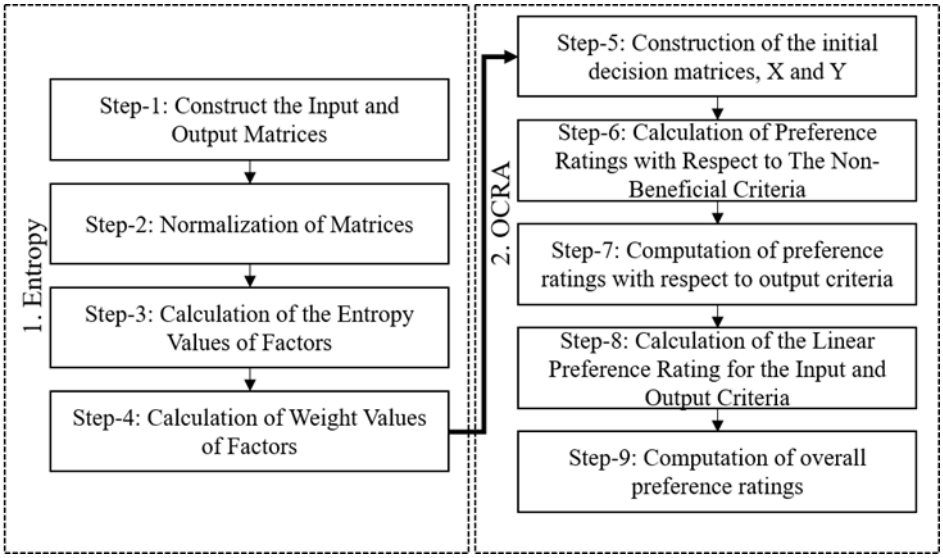

Fig. 1. Implementation Steps of the Model

After a short preparation process, in which determined input and output factors and decision alternatives, the Entropy method is applied to determine weight values of factors. Afterward, performance scores of the decision alternatives are calculated by using the OCRA technique and all decision options are ranked considering their performance scores. This model consists of nine implementation steps and these steps can be seen in fig 1.

3.2.1 The Entropy Technique

The entropy method used to calculate the weight values of input and output factors consists of four implementation steps and it can be reached to the solution with these steps. These steps can be seen below:

In this study, the entropy method was applied to determine the weight values of the input and output factors. The entropy technique is a term in information theory, also known as the average amount of information (Ding and Shi, 2005). Entropy method is highly reliable and can be easily adopted in information measurement (Zou et al., 2005). The implementation steps are as follows:

Step-1: Construct the Input and Output Matrices

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1k} & \dots & x_{1K} \\ x_{21} & x_{22} & \dots & x_{2k} & \dots & x_{2K} \\ \vdots & \vdots & \ddots & \vdots & \dots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ik} & \dots & x_{iK} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ x_{l1} & x_{l2} & \dots & x_{lk} & \dots & x_{lK} \end{bmatrix} \quad (1)$$

$\forall i = 1,2 \dots, l;\ \forall k = 1,2 \dots, K$

$$Y = \begin{bmatrix} y_{11} & y_{12} & \dots & y_{1j} & \dots & y_{1J} \\ y_{21} & y_{22} & \dots & y_{2j} & \dots & y_{2J} \\ \vdots & \vdots & \ddots & \vdots & \dots & \vdots \\ y_{i1} & y_{i2} & \dots & y_{ij} & \dots & y_{iJ} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ y_{l1} & y_{l2} & \dots & y_{lj} & \dots & y_{lJ} \end{bmatrix} \quad (2)$$

$\forall i = 1,2 \dots, l;\ \forall j = 1,2 \dots, J$

Step-2: Standardisation of the Matrices

By using Eqs 3 and 4, all elements of both matrices are standardized. Afterward, standardized matrices are constructed

$$x^*_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (3)$$

$$y^*_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \quad (4)$$

$$X^* = \begin{bmatrix} x^*_{11} & x^*_{12} & \dots & x^*_{1k} & \dots & x^*_{1K} \\ x^*_{21} & x^*_{22} & \dots & x^*_{2k} & \dots & x^*_{2K} \\ \vdots & \vdots & \ddots & \vdots & \dots & \vdots \\ x^*_{i1} & x^*_{i2} & \dots & x^*_{ik} & \dots & x^*_{iK} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ x^*_{l1} & x^*_{l2} & \dots & x^*_{lk} & \dots & x^*_{lK} \end{bmatrix} \quad (5)$$

$\forall i = 1,2 \dots, l;\ \forall k = 1,2 \dots, K$

$$Y^* = \begin{bmatrix} y^*_{11} & y^*_{12} & \cdots & y^*_{1j} & \cdots & y^*_{1J} \\ y^*_{21} & y^*_{22} & \cdots & y^*_{2j} & \cdots & y^*_{2J} \\ \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\ y^*_{i1} & y^*_{i2} & \cdots & y^*_{ij} & \cdots & y^*_{iJ} \\ \vdots & \vdots & \cdots & \vdots & \ddots & \vdots \\ y^*_{l1} & y^*_{l2} & \cdots & y^*_{lj} & \cdots & y^*_{lJ} \end{bmatrix} \quad (6)$$

$\forall i = 1,2 \ldots, l;\ \forall j = 1,2 \ldots, J$

Step-3: Calculation of Entropy Values of Factors

Entropy values of input and output factors are computed with the help of Eqs 7 and 8. As seen in below, entropy matrices are constructed.

$$e^*_{ij} = x^*_{ij} \,.\, lnx^*_{ij} \quad (7)$$

$$e^-_{ij} = y^*_{ij} \,.\, lny^*_{ij} \quad (8)$$

$$E^* = \begin{bmatrix} e^*_{11} & e^*_{12} & \cdots & e^*_{1k} & \cdots & e^*_{1K} \\ e^*_{21} & e^*_{22} & \cdots & e^*_{2k} & \cdots & e^*_{2K} \\ \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\ e^*_{i1} & e^*_{i2} & \cdots & e^*_{ik} & \cdots & e^*_{iK} \\ \vdots & \vdots & \cdots & \vdots & \ddots & \vdots \\ e^*_{l1} & e^*_{l2} & \cdots & e^*_{lk} & \cdots & e^*_{lK} \end{bmatrix} \quad (9)$$

$\forall i = 1,2 \ldots, l;\ \forall k = 1,2 \ldots, K$

$$E^- = \begin{bmatrix} e^-_{11} & e^-_{12} & \cdots & e^-_{1k} & \cdots & e^-_{1K} \\ e^-_{21} & e^-_{22} & \cdots & e^-_{2k} & \cdots & e^-_{2K} \\ \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\ e^-_{i1} & e^-_{i2} & \cdots & e^-_{ik} & \cdots & e^-_{iK} \\ \vdots & \vdots & \cdots & \vdots & \ddots & \vdots \\ e^-_{l1} & e^-_{l2} & \cdots & e^-_{lk} & \cdots & e^-_{lK} \end{bmatrix} \quad (10)$$

$\forall i = 1,2 \ldots, l;\ \forall j = 1,2 \ldots, J$

The entropy value of each factor can be calculated by using Eqs 11 and 12.

$$E^*_{ij} = \left(\frac{-1}{ln(m)}\right) \sum_{i=1}^{m} \left[x^*_{ij} \,.\, lnx^*_{ij}\right];\ \forall j \quad (11)$$

$$E^-_{ij} = \left(\frac{-1}{ln(m)}\right) \sum_{i=1}^{m} \left[y^*_{ij} \,.\, lny^*_{ij}\right];\ \forall j \quad (12)$$

Uncertainty value (dj) for each factor is calculated by using Eq. 13 and Eq.14.

$$d^*_{ij} = 1\text{-}E^*_{ij};\ \forall j \quad (13)$$

$$d^-_{ij} = 1\text{-}E^-_{ij};\ \forall j \quad (14)$$

Step-4: Calculation of the Weight Values of the Input&Output Factors

By using Eq. 15 and 16, weight values of all input and output factors can be calculated.

$$w^*_{ij} = \frac{d^*_{ij}}{\sum_{i=1}^{m} d^*_{ij}};\ \forall j \quad (15)$$

$$w^{-}_{ij} = \frac{d^{-}_{ij}}{\sum_{i=1}^{m} d^{-}_{ij}};\ \forall j \tag{16}$$

3.2.2 The Operational Competitiveness Rating (OCRA) Technique

The OCRA method is a multi-criteria decision-making technique that using for performance analysis. It can be used for computation of efficiency scores of decision alternatives. The method uses an intuitive approach for incorporating the decision maker's preferences about the relative importance of the criteria (Parkan & Wu, 1997). OCRA technique can be applied with five implementation steps and these steps are as follows:

Step-1: Construct the Decision Matrices

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1k} & \dots & x_{1K} \\ x_{21} & x_{22} & \dots & x_{2k} & \dots & x_{2K} \\ \vdots & \vdots & \ddots & \vdots & \dots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ik} & \dots & x_{iK} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ x_{l1} & x_{l2} & \dots & x_{lk} & \dots & x_{lK} \end{bmatrix} \tag{17}$$

$\forall i = 1,2 \dots, l;\ \forall k = 1,2 \dots, K$

$$Y = \begin{bmatrix} y_{11} & y_{12} & \dots & y_{1j} & \dots & y_{1J} \\ y_{21} & y_{22} & \dots & y_{2j} & \dots & y_{2J} \\ \vdots & \vdots & \ddots & \vdots & \dots & \vdots \\ y_{i1} & y_{i2} & \dots & y_{ij} & \dots & y_{iJ} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ y_{l1} & y_{l2} & \dots & y_{lj} & \dots & y_{lJ} \end{bmatrix} \tag{18}$$

$\forall i = 1,2 \dots, l;\ \forall j = 1,2 \dots, J$

Step-2: Computation of Preference Ratings with Respect to Input Factors

In the second step, values of input factors are considered and they are accepted as cost elements, which have to be minimized. Therefore, decision-makers want to prefer an option that taken minimum value among all alternatives. Consequently, input factors with lower values are more preferable. By using Eqs 19 is used to calculate the aggregate performance value of each option.

$$i^{k} = \sum_{m=1}^{M} a_m \frac{max_{n=1,\dots K}(X_m^n) - \left(X_m^k\right)}{min_{n=1,\dots K}(X_m^n)}, \forall n = 1, \dots, K;\ \ X_m^k > 0;\ \ \forall k = 1, \dots, K \tag{19}$$

Afterward, the linear preference ratings for non-beneficial factors are determined with the help of the following equation.

$$I^{k} = i^{k} - min_{n=1,\dots K}\ i^{n}, \forall k = 1, \dots, K \tag{20}$$

Step-3: Computation of Preference Ratings with Respect to Output Factors

By using Eqs 21, preference rating values of the output factors are calculated. The aggregate performance values of these factors can be calculated with the help of the following equation.

$$o^{k} = \sum_{m=1}^{M} b_h \frac{(Y_h^n) - min_{n=1,\dots K}(X_m^n)}{min_{n=1,\dots K}(Y_h^n)}, \forall n = 1, \dots, K;\ \ Y_h^n > 0;\ \ \forall k = 1, \dots, K \tag{21}$$

After these computations, the linear preference ratings for beneficial criteria are calculated by using Eqs 22.

$$O^k = o^k - min_{n=1,....K}\ o^n, \forall k = 1, \dots, K \quad (22)$$

Step-4: Calculation of the Linear Preference Rating for the Input and Output Factors

The general preference score of each option is calculated with the help of Eq 23 and all options are ranked considering the preference values of alternatives. As shown in below, E^k represents the general preference score of i^{th} alternative.

$$E^k = I^k + O^k - min_{n=1,....K}\ (I^n + O^n), \forall k = 1, \dots, K \quad (23)$$

4. A NUMERICAL EXAMPLE

In this study performance analysis of rail freight systems of the Balkan countries were realized as of 2017. Only some countries such as Albania and Kosovo were excluded from the scope of this study because there are no data and information about these countries. These selected countries for performance analysis involved are Bosna Herzegovina, Bulgaria, Croatia, Greece, Montenegro, Macedonia, Romania, Serbia, Slovenia, and Turkey.

Input and output factors about rail freight transport performance of the Balkan countries were determined and examined in this study. Related data were collected from the statistical database from international institutions and organizations. These data of evaluation indexes of the rail freight systems are shown in table 3 and 4. While table 2 was constructed for inputs, table 3 was constructed for output factors.

		Rail Lines				Actual stock (Loco)		Actual stock (Wagon)						Staff			Specific costs				Accidents
		in kilometers				Unit		Unit						Person			millions Euros			**M. Euro**	Euro
		Lines not electrified	Total	Total length of lines	Track length	Diesel	Electric	Total capacity in tones	Total number	Covered	High sided	Flat	Other	Infrastructure	Operation	Total	Staff costs	Depreciation amortization	Total operating expenses	Investments	Cost of Accidents
C	Country	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**	**I10**	**I11**	**I12**	**I13**	**I14**	**I15**	**I16**	**I17**	**I18**	**I19**	**I20**
BA	Bosna Herzigova	271	747	1.018	1.184	93	75	225.079	2.773	176	1.422	1.027	148	3.048	2.273	6.033	61	21	102	16	13.863.241
BG	Bulgaria	1.160	2.870	4.030	6.458	104	165	265.637	3.231	94	1.830	418	889	11.409	9.593	21.167	166	130	453	86	14.146.804
GR	Greece	3.343	1.502	4.845	6.706	143	30	24.129	293	112	67	104	11	1.206	596	1.878	43	175	264	260	22.267.590
HR	Croatia	1.635	970	2.605	3.942	126	70	289.689	3.024	2.289	432	201	102	4.837	3.196	8.372	154	34	350	83	13.701.975
ME	Montenegro	25	224	249	328	17	16	16.947	206	88	45	29	44	812	66	1.878	37	26	279	19	7.777.478
MK	Macedonia	449	234	683	907	26	16	73.555	895	572	132	91	100	1.055	981	2.036	41	17	244	21	9.380.266
RO	Romania	6.736	4.030	10.766	19.837	671	850	1.504.963	22.941	3.458	9.057	4.215	6.105	528	17.201	46.670	471	105	1.246	222	63.626.535
RS	Serbia	2.457	1.279	3.736	5.483	82	91	342.392	3.574	1.400	896	962	316	6.255	5.433	28.584	69	23	113	136	78.796.493
SI	Slovenia	599	610	1.209	2.177	74	78	155.097	2.121	643	913	381	184	2.095	2.939	7.403	242	36	486	38	9.803.124
TR	Turkey	6.042	4.165	10.207	12.608	424	118	810.402	14.471	2.575	5.360	5.923	613	13.953	9.377	23.330	911	481	2.093	1.408	66.794.044

Table 3. Original Data for Input Factors

		Train movements			Train movements			Operator's train movements			Gross hauled tonne-kilometres			Revenue-earning Freight Traffic			Specific revenue		
		thousands of train-kilometers			millions gross tonnes-kilometres			in thousands train-kilometers			millions gross tonnes-kilometres			Carriaged Cargo Volume			millions Euros		
		Total Train	Diesel	Electric	Total Train	Diesel	Electric	Total Train	Diesel	Electric	Total Train	Diesel	Electric	Tones carried	Tonne-kilometres	Mean distance run by a ton (Km)	Freight Traffic Turnover (O.R.)	Infrastructure Turnover (O.R.)	Total operating income
C	Country	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18
BA	Bosna Herzegovina	2462,0	495,4	1965,6	2017,1	362,5	1654,6	2729,0	534,4	2203,6	2017,1	362,5	1655,6	13214,2	1114,6	179,6	58,2	13,3	93,5
BG	Bulgaria	8245,0	926,0	7319,0	8653,0	501,0	8152,0	7738,4	450,5	6483,0	6630,9	243,2	5693,5	11549,1	3172,7	791,2	223,9	195,3	419,2
GR	Greece	863,0	509,0	354,0	786,0	447,0	340,0	371,0	21,6	349,4	382,0	283,7	98,3	1100,0	538,0	83,7	323,2	21,2	82,4
HR	Croatia	5819,0	1505,0	4314,0	4923,0	1052,0	3871,0	4166,0	242,5	3923,5	3859,0	2865,8	993,2	8544,0	1970,0	230,6	55,3	153,2	346,6
ME	Montenegro	1958,0	105,0	1853,0	288,0	77,0	211,0	2846,0	165,7	2680,3	2636,3	1957,8	678,5	1603,0	168,9	105,4	17,6	12,8	76,6
MK	Macedonia	476,0	147,0	329,0	1250,0	68,0	1182,0	508,0	29,6	478,4	441,0	327,5	113,5	1558,0	276,6	177,6	10,2	17,5	69,3
RO	Romania	23862,0	5170,0	18556,0	31687,0	4947,0	26739,0	16668,0	1987,0	6995,0	21016,0	1538,0	9455,0	44933,0	10171,0	1332,9	330,1	236,7	1249,7
RS	Serbia	5547,0	1205,0	4342,0	4146,0	1033,0	3113,0	4997,0	1273,0	3724,0	5081,0	1190,0	3891,0	10158,0	2790,4	274,7	82,6	37,3	119,9
SI	Slovenia	10099,6	1314,9	8776,6	9949,0	986,5	8954,1	8079,0	993,0	7086,0	7342,0	666,0	6676,0	18695,0	4534,6	242,6	158,3	122,5	517,4
TR	Turkey	21799,0	17044,0	4957,0	20971,0	15637,0	5334,0	21800,0	16843,0	4957,0	21020,0	15682,0	5338,0	28081,0	12648,0	450,0	335,1	81,8	697,4

Table 4. Original Data for Output Factors

Step-2: Standardisation of the Matrices

By using Eqs 3 and 4, all elements of both matrices were standardized. Afterward, standardized matrices were constructed.

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20
BA	0,012	0,045	0,026	0,020	0,053	0,050	0,061	0,052	0,015	0,071	0,077	0,017	0,067	0,044	0,041	0,028	0,020	0,018	0,007	0,046
BG	0,051	0,173	0,102	0,108	0,059	0,109	0,072	0,060	0,008	0,091	0,031	0,104	0,252	0,186	0,144	0,076	0,124	0,080	0,038	0,047
GR	0,147	0,090	0,123	0,112	0,081	0,020	0,007	0,005	0,010	0,003	0,008	0,001	0,027	0,012	0,013	0,020	0,167	0,047	0,114	0,074
HR	0,072	0,058	0,066	0,066	0,072	0,046	0,078	0,056	0,201	0,021	0,015	0,012	0,107	0,062	0,057	0,070	0,033	0,062	0,036	0,046
ME	0,001	0,013	0,006	0,006	0,010	0,011	0,005	0,004	0,008	0,002	0,002	0,005	0,018	0,001	0,013	0,017	0,025	0,050	0,008	0,026
MK	0,020	0,014	0,017	0,015	0,015	0,011	0,020	0,017	0,050	0,007	0,007	0,012	0,023	0,019	0,014	0,019	0,016	0,043	0,009	0,031
RO	0,297	0,242	0,274	0,333	0,381	0,563	0,406	0,429	0,303	0,449	0,316	0,717	0,012	0,333	0,317	0,214	0,100	0,221	0,097	0,212
RS	0,108	0,077	0,095	0,092	0,047	0,060	0,092	0,067	0,123	0,044	0,072	0,037	0,138	0,105	0,194	0,031	0,022	0,020	0,059	0,263
SI	0,026	0,037	0,031	0,037	0,042	0,052	0,042	0,040	0,056	0,045	0,029	0,022	0,046	0,057	0,050	0,110	0,035	0,086	0,017	0,033
TR	0,266	0,250	0,259	0,211	0,241	0,078	0,219	0,270	0,226	0,266	0,444	0,072	0,309	0,182	0,158	0,415	0,459	0,372	0,615	0,223

Table 5. Standardized Data for Input Factors

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18
BA	0,030	0,017	0,037	0,024	0,014	0,028	0,039	0,024	0,057	0,029	0,014	0,048	0,095	0,030	0,046	0,036	0,015	0,025
BG	0,102	0,033	0,139	0,102	0,020	0,137	0,111	0,020	0,167	0,094	0,010	0,165	0,083	0,085	0,205	0,140	0,219	0,114
GR	0,011	0,018	0,007	0,009	0,018	0,006	0,005	0,001	0,009	0,005	0,011	0,003	0,008	0,014	0,022	0,203	0,024	0,022
HR	0,072	0,053	0,082	0,058	0,042	0,065	0,060	0,011	0,101	0,055	0,114	0,029	0,061	0,053	0,060	0,035	0,172	0,094
ME	0,024	0,004	0,035	0,003	0,003	0,004	0,041	0,007	0,069	0,037	0,078	0,020	0,011	0,005	0,027	0,011	0,014	0,021
MK	0,006	0,005	0,006	0,015	0,003	0,020	0,007	0,001	0,012	0,006	0,013	0,003	0,011	0,007	0,046	0,006	0,020	0,019
RO	0,294	0,182	0,352	0,374	0,197	0,449	0,238	0,088	0,180	0,298	0,061	0,273	0,322	0,272	0,345	0,207	0,265	0,340
RS	0,068	0,042	0,082	0,049	0,041	0,052	0,071	0,056	0,096	0,072	0,047	0,112	0,073	0,075	0,071	0,052	0,042	0,033
SI	0,124	0,046	0,166	0,118	0,039	0,150	0,116	0,044	0,182	0,104	0,027	0,193	0,134	0,121	0,063	0,099	0,137	0,141
TR	0,269	0,600	0,094	0,248	0,623	0,090	0,312	0,747	0,127	0,298	0,624	0,154	0,201	0,338	0,116	0,210	0,092	0,190

Table 6. Standardized Data for Output Factors

Step-3: Calculation of Entropy Values of Factors

Entropy values of input and output factors were computed with the help of Eqs 7 and 8. As seen in below, entropy matrices were constructed. Afterward, the entropy value of each factor was calculated by using Eqs 11 and 12. Uncertainty value (dj) for each factor was calculated by using Eq. 13 and Eq.14.

Step-4: Calculation of the Weight Values of the Input&Output Factors

As shown in Table 7 and 8, weight values of all input and output factors were calculated by using Eq. 15 and 16.

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20
BA	-0,05	-0,14	-0,09	-0,08	-0,16	-0,15	-0,17	-0,15	-0,06	-0,19	-0,20	-0,07	-0,18	-0,14	-0,13	-0,10	-0,08	-0,07	-0,03	-0,14
BG	-0,15	-0,30	-0,23	-0,24	-0,17	-0,24	-0,19	-0,17	-0,04	-0,22	-0,11	-0,24	-0,35	-0,31	-0,28	-0,20	-0,26	-0,20	-0,12	-0,14
GR	-0,28	-0,22	-0,26	-0,25	-0,20	-0,08	-0,03	-0,03	-0,05	-0,02	-0,04	-0,01	-0,10	-0,05	-0,06	-0,08	-0,30	-0,14	-0,25	-0,19
HR	-0,19	-0,17	-0,18	-0,18	-0,19	-0,14	-0,20	-0,16	-0,32	-0,08	-0,06	-0,05	-0,24	-0,17	-0,16	-0,19	-0,11	-0,17	-0,12	-0,14
ME	-0,01	-0,06	-0,03	-0,03	-0,04	-0,05	-0,02	-0,02	-0,04	-0,01	-0,01	-0,03	-0,07	-0,01	-0,06	-0,07	-0,09	-0,15	-0,04	-0,09
MK	-0,08	-0,06	-0,07	-0,06	-0,06	-0,05	-0,08	-0,07	-0,15	-0,03	-0,03	-0,05	-0,09	-0,08	-0,06	-0,07	-0,07	-0,14	-0,04	-0,11
RO	-0,36	-0,34	-0,35	-0,37	-0,37	-0,32	-0,37	-0,36	-0,36	-0,36	-0,36	-0,24	-0,05	-0,37	-0,36	-0,33	-0,23	-0,33	-0,23	-0,33
RS	-0,24	-0,20	-0,22	-0,22	-0,14	-0,17	-0,22	-0,18	-0,26	-0,14	-0,19	-0,12	-0,27	-0,24	-0,32	-0,11	-0,08	-0,08	-0,17	-0,35
SI	-0,10	-0,12	-0,11	-0,12	-0,13	-0,15	-0,13	-0,13	-0,16	-0,14	-0,10	-0,08	-0,14	-0,16	-0,15	-0,24	-0,12	-0,21	-0,07	-0,11
TR	-0,35	-0,35	-0,35	-0,33	-0,34	-0,20	-0,33	-0,35	-0,34	-0,35	-0,36	-0,19	-0,36	-0,31	-0,29	-0,36	-0,36	-0,37	-0,30	-0,33
eij	0,69	0,74	0,72	0,71	0,69	0,59	0,66	0,62	0,67	0,58	0,56	0,41	0,70	0,69	0,71	0,66	0,64	0,71	0,52	0,74
dj	0,31	0,26	0,28	0,29	0,31	0,41	0,34	0,38	0,33	0,42	0,44	0,59	0,30	0,31	0,29	0,34	0,36	0,29	0,48	0,26
wj	0,04	0,04	0,04	0,04	0,04	0,06	0,05	0,05	0,05	0,06	0,06	0,08	0,04	0,04	0,04	0,05	0,05	0,04	0,07	0,04

Table 7. Entropy Matrix for Input Factors

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18
BA	0,030	0,017	0,037	0,024	0,014	0,028	0,039	0,024	0,057	0,029	0,014	0,048	0,095	0,030	0,046	0,036	0,015	0,025
BG	0,102	0,033	0,139	0,102	0,020	0,137	0,111	0,020	0,167	0,094	0,010	0,165	0,083	0,085	0,205	0,140	0,219	0,114
GR	0,011	0,018	0,007	0,009	0,018	0,006	0,005	0,001	0,009	0,005	0,011	0,003	0,008	0,014	0,022	0,203	0,024	0,022
HR	0,072	0,053	0,082	0,058	0,042	0,065	0,060	0,011	0,101	0,055	0,114	0,029	0,061	0,053	0,060	0,035	0,172	0,094
ME	0,024	0,004	0,035	0,003	0,003	0,004	0,041	0,007	0,069	0,037	0,078	0,020	0,011	0,005	0,027	0,011	0,014	0,021
MK	0,006	0,005	0,006	0,015	0,003	0,020	0,007	0,001	0,012	0,006	0,013	0,003	0,011	0,007	0,046	0,006	0,020	0,019
RO	0,294	0,182	0,352	0,374	0,197	0,449	0,238	0,088	0,180	0,298	0,061	0,273	0,322	0,272	0,345	0,207	0,265	0,340
RS	0,068	0,042	0,082	0,049	0,041	0,052	0,071	0,056	0,096	0,072	0,047	0,112	0,073	0,075	0,071	0,052	0,042	0,033
SI	0,124	0,046	0,166	0,118	0,039	0,150	0,116	0,044	0,182	0,104	0,027	0,193	0,134	0,121	0,063	0,099	0,137	0,141
TR	0,269	0,600	0,094	0,248	0,623	0,090	0,312	0,747	0,127	0,298	0,624	0,154	0,201	0,338	0,116	0,210	0,092	0,190
eij	0,70	0,51	0,71	0,65	0,47	0,64	0,71	0,38	0,79	0,69	0,52	0,71	0,72	0,67	0,73	0,74	0,72	0,71
dj	0,30	0,49	0,29	0,35	0,53	0,36	0,29	0,62	0,21	0,31	0,48	0,29	0,28	0,33	0,27	0,26	0,28	0,29
wj	0,05	0,08	0,05	0,06	0,08	0,06	0,05	0,10	0,03	0,05	0,08	0,05	0,05	0,05	0,04	0,04	0,04	0,05

Table 8. Entropy Matrix for Output Factors

Step-5: Construct the Decision Matrices

Both decision matrices for input and output factors were constructed as seen in the first step. The original data from statistical databases were used similarly. In order to don't repeat, we didn't show these matrices in below again.

Step-6: Computation of Preference Ratings with Respect to Input Factors

With the help of Eqs 19, preference ratings with respect to input factors were computed and the matrix P is constructed.

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20
BA	0,00	0,00	0,00	0,00	-0,01	0,00	-0,01	-0,01	0,00	-0,01	-0,01	0,00	-0,01	-0,01	0,00	0,00	0,00	0,00	0,00	0,00
BG	-0,01	-0,02	-0,01	-0,01	-0,01	-0,01	-0,01	-0,01	0,00	-0,01	0,00	-0,01	-0,03	-0,02	-0,02	-0,01	-0,01	-0,01	0,00	0,00
GR	-0,02	-0,01	-0,02	-0,01	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,02	0,00	-0,01	-0,01
HR	-0,01	-0,01	-0,01	-0,01	-0,01	0,00	-0,01	-0,01	-0,03	0,00	0,00	0,00	-0,01	-0,01	-0,01	-0,01	0,00	0,00	0,00	0,00
ME	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MK	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RO	-0,04	-0,03	-0,04	-0,04	-0,04	-0,06	-0,05	-0,05	-0,05	-0,06	-0,04	-0,08	0,00	-0,04	-0,04	-0,02	-0,01	-0,02	-0,01	-0,03
RS	-0,02	-0,01	-0,01	-0,01	0,00	-0,01	-0,01	-0,01	-0,02	-0,01	-0,01	0,00	-0,02	-0,01	-0,02	0,00	0,00	0,00	-0,01	-0,03
SI	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	-0,01	0,00	0,00	0,00	-0,01	0,00	-0,01	0,00	-0,01	0,00	0,00
TR	-0,04	-0,04	-0,04	-0,03	-0,03	-0,01	-0,03	-0,03	-0,03	-0,03	-0,06	-0,01	-0,04	-0,02	-0,02	-0,05	-0,05	-0,04	-0,07	-0,03

Table 9. Preference Ratings with Respect to Input Factors

Afterward, the linear preference ratings for non-beneficial factors are determined with the help of the Eq 20.

	Sum of Preference Ratings	Measured Input Preference Ratings
BA	-0,08	0,69
BG	-0,22	0,55
GR	-0,12	0,65
HR	-0,14	0,63
ME	-0,01	0,77
MK	-0,03	0,74
RO	-0,77	0,00
RS	-0,21	0,56
SI	-0,09	0,68
TR	-0,69	0,08

Table 10. Measured Input Preference Ratings

Step-7: Computation of Preference Ratings with Respect to Output Factors

By using Eqs 21, preference rating values of the output factors were calculated. The aggregate performance values of these factors were calculated with the help of the following equation 21.

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18
BA	0,20	0,29	0,23	0,33	0,37	0,39	0,30	2,37	0,18	0,21	0,04	0,75	0,50	0,30	0,05	0,19	0,00	0,02
BG	0,78	0,61	0,98	1,61	0,54	2,17	0,92	1,98	0,60	0,82	0,00	2,69	0,43	0,95	0,36	51,60	0,64	0,23
GR	0,04	0,30	0,00	0,10	0,47	0,04	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,12	0,00	1,27	0,03	0,01
HR	0,54	1,04	0,56	0,89	1,22	1,00	0,48	1,02	0,35	0,46	0,84	0,43	0,31	0,57	0,07	0,18	0,49	0,19
ME	0,15	0,00	0,21	0,00	0,01	0,00	0,31	0,67	0,23	0,30	0,55	0,28	0,02	0,00	0,01	0,03	0,00	0,00
MK	0,00	0,03	0,00	0,19	0,00	0,27	0,02	0,04	0,01	0,01	0,03	0,01	0,02	0,03	0,05	0,00	0,02	0,00
RO	2,35	3,78	2,57	6,06	6,06	7,25	2,04	9,08	0,65	2,71	0,41	4,49	1,82	3,16	0,64	1,30	0,78	0,79
RS	0,51	0,82	0,56	0,74	1,20	0,79	0,58	5,78	0,33	0,62	0,30	1,82	0,38	0,83	0,10	0,29	0,09	0,03
SI	0,97	0,90	1,19	1,86	1,14	2,39	0,96	4,49	0,66	0,91	0,13	3,16	0,73	1,38	0,08	0,60	0,38	0,30
TR	2,15	12,64	0,65	3,99	19,33	1,40	2,68	77,71	0,45	2,71	4,92	2,52	1,12	3,94	0,19	1,32	0,24	0,42

Table 11. Preference Ratings with Respect to Output Factors

After these computations, the linear preference ratings for beneficial criteria were computed by using Eqs 22.

	Sum of Preference Ratings	Measured Output Preference Ratings
BA	6,72	6,02
BG	67,93	67,22
GR	2,39	1,68
HR	10,64	9,93
ME	2,76	2,06
MK	0,71	0,00
RO	55,94	55,23
RS	15,78	15,07
SI	22,25	21,54
TR	138,38	137,67

Table 12. Measured Output Preference Ratings

Step-4: Calculation of the Linear Preference Rating for the Input and Output Factors

The general preference score of each option is calculated with the help of Eq 23 and all options were ranked considering the preference values of alternatives. As shown in below, E^k represents the general preference score of i^{th} alternative.

	Non-measured General preference ratings	Measured General preference ratings	Ranking
BA	6,71	5,97	7
BG	67,77	67,02	2
GR	2,33	1,59	9
HR	10,56	9,82	6
ME	2,82	2,08	8
MK	0,74	0,00	10
RO	55,23	54,49	3
RS	15,63	14,88	5
SI	22,22	21,48	4
TR	137,76	137,01	1

Table 13. Measured General Preference Ratings and Ranking

5. DISCUSSION

Because the efficiency of rail freight systems is affected by many factors and variables, making proper and effective performance analysis related to this field is a difficult task and it is extremely complex due to limited data and quite scarce information about performance and activities of the railway sector.

Although there are a large number of mathematical approach and model to make performance analysis, OCRA technique may be suitable method because it can provide an opportunity to evaluate all decision options comparatively and can use data related previous years make performance analysis. This study tries to introduce a hybrid model consists of entropy and OCRA method and it discusses whether this proposed model is applied to make performance analysis of national railway transport systems.

In addition to that, as well as researchers who will realize studies and research about performance analysis of railway transport systems, evaluation of this MCDM model in aspects of its advantages and new perspectives that can provide by this model may be valuable for decision-makers, who are responsible to make policies about railway transport of the countries.

- Inclusion of the potential many factors, which can affect the results probably, can be accepted as the most important advantages of this model. A decision-maker can add too many inputs or output factors to the evaluation process. Foremost, decision-makers should determine which factors should be kept out.
- Secondly, the ocra method can provide very realistic and applicable results. If evaluated the financial positions of the selected banks, it can be seen clearly that these figures are very similar to the results obtained with this study.
- The ocra method can provide another advantage that data obtained from previous years can be evaluated together, so it can show performance score and ranking position of the selected banks over the last years. Consequently, it provides opportunity evaluation of performance in a wider perspective.

6. CONCLUSIONS

This study summarizes the results of the financial and operational performance analysis of the rail freight transport systems of the Balkan countries for a 12 month period between January 2017 and December 2017 by using a hybrid multi-criteria decision-making model consists of the entropy and OCRA techniques.

Results of the ocra method shown that the criteria such as I6, I10, I11, and I12 have higher importance than others. These input criteria are related to the actual locomotive and wagon stock. When the output criteria are evaluated, O2, O5, O8, and O11 are the important factors compared to the other output factors. Also, they are related to rail freight train movement in terms of thousand of train km for diesel locomotives. Obtained results by using the proposed model verified that except for Bulgaria and Turkey, performances about rail freight transport activities of other Balkan countries are lower. It can be seen that Turkey is the best in aspects of railway freight performance, also Bulgaria is the second-best country. Both of these countries obtained excellent results in terms of outputs such as rail train movements and financial revenue from rail freight activities in 2017.

If obtained results are considered, it can be seen that the proposed MCDM model is working and it can provide very effective results. In addition to that it can be applied to various fields required performance analysis such as transportation modes, logistics activities, urban transportation, and supply chain operations. Moreover, it has serious potential to solve complex decision-making problems. Therefore, this model can help to studies that will be realized in the future, due to it proposes a structural and systematic approach, which can be used for performance analysis. In addition to that, decision-makers can use this model when they need a multi-criteria decision-making tool for efficiency analysis, because it can be used more easily by decision-makers and all relevant persons.

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REFERENCES

1. Yu MM 2008, "Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world's railways through NDEA analysis", *Transportation Research Part A,* vol. A42, pp. 1283–1294.
2. Woroniuk C, Marinov M, Zunder T, Mortimer P 2013, "Time series analysis of rail freight services by the private sector in Europe", *Transport Policy,* vol. 25, pp. 81–93.
3. Marchetti D, Wanke P 2017, "Brazil's rail freight transport: Efficiency analysis using two-stage DEA and cluster-driven public policies", *Socio-Economic Planning Sciences,* vol. 59, pp. 26–42.
4. Yu MM, Lin ETJ 2008, "Efficiency and effectiveness in railway performance using a multi-activity network DEA model", *Omega,* vol. 36, pp. 1005 – 1017.
5. Finger M 2014, "Governance of competition and performance in European railways: An analysis of five cases", *Utilities Policy*, vol. 31, 278-288.
6. Wetzel H, Growitsch C 2006 "Economies of Scope in European Railways: An Efficiency Analysis", IWH Discussion Papers, No. 5/2006, Leibniz-Institut für Wirtschaftsforschung Halle (IWH), Halle (Saale).
7. Oum TH, Yu C 1994, "Economic efficiency of railways and implications for public policy: a comparative study of the OECD countries' railways", *Journal of Transport Economics and Policy,* vol. 28, no. 2, pp. 121-138.
8. Wiegmans BW, Donders AGT (2007), "Benchmarking European rail freight transport companies", Transportation Journal, vol. 46, no. 2, pp. 19-34.
9. Bhanot N, Singh H 2014 "Benchmarking the performance indicators of Indian Railway container business using data envelopment analysis", *Benchmarking: An International Journal*, vol. 21, no. 1, pp. 101-120.
10. Cantos P, Pastor JM, Serrano L 2000, "Efficiency measures and output specification: the case of European railways, *Journal of Transportation and Statistics,* vol. 23, pp. 61-68.
11. Lan W, Lin TJ 2003, "Technical efficiency and service effectiveness for Railways industry: DEA approaches", *Journal of the Eastern Asia Society for Transportation Studies,* vol.5, pp. 2932-2947.
12. Ozbek A 2015a, "Efficiency analysis of foreign-capital banks in turkey by OCRA and MOORA", *Research Journal of Finance and Accounting,* vol.6, no.13, pp. 21-30.
13. Wang S 2006, "Comments on operational competitiveness rating analysis (OCRA)", *European Journal of Operational Research*, vol. 169, no. 1, pp. 329-331.
14. Ozbek A 2015b, "Efficiency analysis of non-governmental organizations based in Turkey", *International Business Research,* vol. 8, no. 9, pp. 95-104.
15. Ozbek A 2015c, "Efficiency analysis of the Turkish Red Crescent between 2012 and 2014", *International Journal of Economics and Finance*, vol. 7, no. 9; pp. 322-334.

16. C Parkan, K Lam & G Hang (1997) Operational competitiveness analysis on software development, *Journal of the Operational Research Society*, vol. 48, no. 9, pp. 892-905.
17. Jayanthia S, Kochab B, Sinha KK 1999, Competitive analysis of manufacturing plants: An application to the US processed food industry, *European Journal of Operational Research*, vol. 118, no. 2, pp. 217-234.
18. Somogyi RM 2011, "Review and systematization of efficiency measurement methods used in the transport sector, *Promet – Traffic&Transportation*, vol. 23, no. 1, pp. 39-47.
19. Stanujkic D, Kazimieras EZ, Liu S, Karabasevic D, Popovic P 2017, "Improved OCRA method based on the use of interval grey numbers, *The Journal of Grey System*, vol. 29, no.4, pp. 46-60.
20. Ding SF Shi Z 2005. "Studies on incidence pattern recognition based on information entropy". *Journal of Information Science*, vol. 31, no. 6, pp. 497–502.
21. Zou Z, Sun J, and Ren G 2005, "Study and application on the entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment", *ACTA Scientiae Circumstantiae*, vol. 25, no. 4, pp. 552 – 556.
22. Parkan C, Wu ML 1997, "On the equivalence of operational performance measurement and multiple attribute decision making", International Journal of Production Research, vol. 35, no. 11, pp. 2963-2988