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Assessing Railway Transportation Performance of European Countries with CRITIC and ROV Techniques

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Abstract: Rail transport is among the modes of transport that provides safe and reliable logistics services for the transport of passengers, goods, and dangerous goods. The decrease in railway transport volumes in recent years reveals the necessity of examining the railway transport performance. In this research, it is aimed to determine the railway transport performance of European countries in 2020. Sixteen railway performance criteria have been determined. Three of these criteria are cost-based and thirteen criteria are benefit-based. The criterion weights have been calculated by the Criteria Importance Through Intercriteria Correlation (CRITIC) technique. The railway transport performance of twenty-three European countries is presented using the Range of Value (ROV) technique. The data set has been obtained from the Eurostat database. According to the research findings, the three criteria with the highest weight are determined as rail accidents victims, rail accidents, accidents involving transport of dangerous goods. The three countries with the highest railway transport performance are Germany, Italy, and Sweden. Suggestions for increasing the railway transportation performance levels of the countries are presented.

***Keywords**:* Railway transport performance, Multi criteria decision making, CRITIC, ROV

Avrupa Ülkelerinin Demiryolu Taşımacılığı Performansının CRITIC ve ROV Teknikleriyle Değerlendirilmesi

Öz: Demiryolu taşımacılığı yolcuların, malların ve tehlikeli maddelerin taşınmasında emniyetli ve güvenilir lojistik hizmet sunan ulaştırma modları arasında yer almaktadır. Son yıllarda demiryolu taşıma hacimlerinde düşüşlerin yaşanması demiryolu taşımacılık performansının incelenmesi gerekliliğini ortaya çıkarmaktadır. Bu araştırmada Avrupa ülkelerinin 2020 yılı demiryolu taşımacılık performansının belirlenmesi amaçlanmıştır. Araştırmada on altı demiryolu performans kriteri belirlenmiştir. Bu kriterlerin üç tanesi maliyet esaslı on üç tanesi fayda esaslı kriterdir. Kriter ağırlıkları kriterler arası korelasyon yoluyla kriterlerin önem tespiti (CRITIC) tekniğiyle tespit edilmiştir. Yirmi üç adet Avrupa ülkesinin demiryolu taşımacılık performansı değer aralığı (ROV) tekniğiyle hesaplanmıştır. Veri seti Eurostat'den elde edilmiştir. Araştırma bulgularına göre performans kriter ağırlığı en yüksek olan üç kriter demiryolu kaza kurbanları, demiryolu kazaları, tehlikeli madde taşımacılığındaki kazalar olarak belirlenmiştir. Demiryolu taşımacılık performansı en yüksek olan üç ülke ise Almanya, İtalya ve İsveç'tir. Ülkelerin demiryolu taşımacılık performans düzeylerinin artırılmasına yönelik öneriler sunulmuştur.

***Anahtar kelimeler**:* Demiryolu taşımacılık performansı, Çok kriterli karar verme, CRITIC, ROV

1. Introduction

Railway transport is an environmentally friendly type of transportation used to transport passengers and goods [1]. Although railway infrastructure installation costs are high, railway transport is among the safe transportation modes. The decrease in rail transportation demands in recent years has made it essential to consider rail transport in terms of performance, efficiency, and effectiveness [2]. The main factors that determine the performance of railway transport are infrastructure, equipment/train qualities and numbers, transportation volumes, safety, and

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security. In terms of sustainable performance, maintenance activities are decisive. Carrying out maintenance activities based on long-term strategies provides both cost and performance benefits [3]. With the increasing number of railway entrepreneurs, the need for the reorganization of the market structure and the fair distribution of capacity allocations arise. Thus, the trend towards deregulation in railway services can be prevented [4]. Reducing deregulation contributes to minimizing accidents/incidents by providing safe and reliable rail transport.

Railway transport network structure is realized with strategic decisions and long-term planning. At the same time, following the technological developments in the railway transport sector closely supports the correct strategic decisions. Past statistics and performance indicators of rail transport also shed light on making future-oriented decisions. For this reason, macro level decision makers and governments should be informed about rail transport performance levels. The main purpose of this research is to determine and compare the railway transport performances (RTP) of European countries in 2020. For this purpose, the research questions determined within the scope of the research are as follows:

- *Research question 1*: Is it possible to obtain information about railway performances of countries based on railway statistical data?
- *Research question 2*: Is the multi-criteria decision-making technique among the applicable methods in terms of railway performance determination?
- *Research question 3*: As a result of this research, can the performance evaluations of the countries help their national railway planning by providing information to the countries in terms of criteria?

It is aimed primarily to determine RTP criteria and to use multi-criteria decision making (MCDM) techniques. It is planned to use the Criteria Importance Through Intercriteria Correlation (CRITIC) technique in determining the criterion weights, and the Range of Value (ROV) technique in determining the country performances. Thanks to the results obtained, European countries will have information about their rail transport performance. In addition, determining the importance levels of the criteria will also play an active role in the decision makers' strategies.

This article, which is handled with the aim of determining the RTP of European countries in 2020, consists of five parts. In the second part, an in-depth literature review has been made. In the third part, the criteria and the sampling used in the research are presented. Also, CRITIC and ROV techniques are explained in this part. In the fourth part, the rail transport performances of European countries are determined. In the fifth part, the criteria weights and country performances are evaluated, and suggestions are presented.

2. Literature Review

There are studies on the relationship between railway performance metrics and logistics and supply chain metrics [5], [6]. But in this research, the railway transport success of countries has been pointed out. RTP basically points to the railway transport success of countries. In the literature, there are studies dealing with railway transportation performance, railway network performance, railway safety performance and trying to develop an index. At the same time, it is seen that performance determination approaches differ in research. In this literature review, studies on railway performance are included. Besides, the railway performance criteria used in the research are also presented.

Stenström et al. [7] divide railway infrastructure performance indicators into two main groups. These are managerial and condition indicators. Under the Managerial indicator, there are technical, organizational, economic, health, safety, and environment sub-criteria. Under the condition indicator, there are substructure, superstructure, rail yards, electrification, signaling, information and communication technology sub-criteria. Research on railway stations performance affecting railway transportation performance Harris et al. [8] explained the factors affecting performance as “train stopping position, dispatch delay, staff position relative to the critical door, excess customer service, passenger door forcing, and knock-on delays”. Kyriakidis et al. [9] examined 479 railway accidents and incidents. As a result of the examination, 12 criteria that affect the railway performance the most were determined. These criteria are “Safety culture, System design, Fatigue, Communication, Distraction, Quality of procedures, Perception, Training, Expectation, Quality of information Supervision, Workload”.

The 2012 European Railway Performance Index was created by The Boston Consulting Group. In this index, “Intensity of use, Quality of service and Safety” were used as the main criteria. Passenger and goods volumes were considered under the main criterion of Intensity of use. Quality of service sub-criteria are Punctuality of regional trains, Punctuality of long-distance trains, Percentage of high-speed rail, Average fare in euros. Accidents and Fatalities are evaluated within the scope of Safety [10]. Kyriakidis et al. [11] developed the Human Performance Railway Operational Index. In this index, opinions of 52 employees belonging to different railway operations were taken. Åhrén and Parida [12] compared the national railway management performances of Banverket and Jernbaneverket using maintenance performance indicators. According to the research findings, they concluded that each railway infrastructure has different locations and constraints, and maintenance performance indicators are suitable for comparison.

Yang et al. [13] argued that railway subsidence, which affects rail transport performance, should be measured regularly. They developed Persistent Scatterer Interferometric Synthetic Aperture Radar to measure and predict railway subsidence. Autoregression Moving Average (ARMA), artificial neural network and gray models were used in the research. Ranjan et al. [14] used DEMATEL and VIKOR techniques to determine the performance of sixteen Indian Railway zones. Nine criteria were used in the research. These criteria are “Route distance, Total number of locomotives, Number of passengers carried, Number of total staffs, Number of major stations, Number of accidents/derailments, Number of persons injured/deceased, Expenditure, Operating cost ratio”. Bhanot et al. [15] determined the performances of Indian Railway container business and select private players with data envelopment analysis (DEA). In the research, “handling terminals, employees, yard equipments, freight wagons, containers, freight kilometer net profit” variables were accepted as criteria. Tahir [16] presented the performance of Pakistan railways with DEA by comparing with Chinese and Indian railways. According to the research findings, it has been determined that a steady public investment and managerial autonomy are required for the railway performance to be sustainable.

Jitsuzumi and Nakamura [17], investigating the causes of railway underperformance in Japan, applied DEA analysis with the data of fifty-three Japanese railway operators. In the research, it was determined that six Japanese railway operators were at full efficiency level. Also Fixed assets, Employee, Operating expenditure is used as input variables. Passenger-km, The Externality index is used as output variables. Transportation density is used as Uncontrollable variable. Considering the 2002 data of twenty railways, Yu, and Lin [18] have simultaneously estimated the technical efficiency, service effectiveness and technical effectiveness of the passengers and freighters. In addition, it has been determined that there is a significant correlation between technical effectiveness and technical efficiency and service effectiveness.

Stoilova et al. [19] calculated the rail network performance of The Orient–East Med (OEM) corridor countries (Germany, Czech Republic, Austria, Slovakia, Hungary, Romania, Bulgaria, Greece) using Sequential Interactive Modeling for Urban Systems (SIMUS) technique. Infrastructural, economic, and technological main criteria and twenty-two sub-criteria were used in the research. In addition, clustering analysis was made, and OEM countries were clustered.

Sangiorgio et al. [20] applied the AHP technique in the index developed to predict the safety performance of railway transportation systems. "Signals passed at danger, Broken wheels, Broken axles, Broken rails, Track buckle, Wrong-side signaling failures" criteria were used in the research. In addition, considering the maintenance costs, increasing the level of reliability, safety and usability is among the performance targets of railway transportation ([3]).

As a result of the literature review, it has been clearly seen that MCDM techniques are used in performance determination studies. However, there are limited studies in the literature on the determination of railway performance. It has been observed that AHP, DEMATEL, VIKOR, ARMA, DEA and SIMUS techniques are used in these studies. In this study, the CRITIC technique was preferred to determine the criterion weights. The reason for this preference is the creation of a data set based on data collected from secondary data sources, namely international organizations. The CRITIC technique allows the criterion weights to be determined at this point. It was decided to apply the ROV technique in the performance rankings of the alternatives. The reason for this is the performance value ranking of the countries. Considering the order of values, this technique was preferred. In addition, as a result of the application of these techniques, European countries can observe their performance compared to other countries by obtaining the railway performance evaluation ranking.

3. Methodology

In this part, the methodology of the research is given. Previously, information is given about the criteria used in the research and the sample area. Then, the techniques used in the research are explained. The application for determining the performance rankings of European countries is discussed in the next part.

3.1. Criteria and sampling

Rail transport performance can be considered both at the country level and at the national level. Efficiency analyzes are carried out with the criteria of railway transportation performance at the national level ([21]). In this study, performance comparisons between countries are discussed. In this context, the rail transport performances of European countries were determined by considering 16 criteria. These criteria are *Length of tracks* (C1), *Electrified railway tracks* (C2), *Non-electrified railway tracks* (C3), *Length of lines* (C4), *Locomotives* (C5), *Wagons* (C6), *Railway enterprises* (C7), *Goods trains train movements* (C8), *Passenger trains train movements* (C9), *Rail accidents victims* (C10), *Rail accidents* (C11), *Accidents involving transport of dangerous goods* (C12), *Passengers transported* (C13), *Goods transported* (C14), *Transported of dangerous goods* (C15), and *Volume of containers transported* (C16).

A railway track consists of the rails, fasteners, ties, ballast, and underlying subgrade. The length of the railway track that the countries have shown the level of preparation for railway transportation as infrastructure. Countries with a high railway track length are in a more advantageous position in terms of railway transportation. For this reason, the "Length of tracks" criterion is among the benefit criteria. Developing technologies have triggered the development of systems based on electricity and signal systems in rail transportation. Electrical systems, which provide great advantages in energy consumption and are environmentally friendly, are more reliable. The lengths of the electrified railway tracks of the countries indicate the modernized railway infrastructure. At this point, "Electrified railway tracks" has been determined as the second criterion. Non-electrified railway tracks infrastructure allows the use of diesel-powered trains and hydrogen fuel cells trains. Hydrogen fuel cells trains consume more environmentally friendly fuel than Diesel-powered trains. But it does not provide economic advantage. Currently, most of the country's railway infrastructures are non-electrified railway tracks. "The length of non-electrified railway tracks" is considered as one of the basic criteria for the railway transport performance. Rail lines are railway routes for train transport service. “The length of the rail lines” is another criterion that expresses the railway transportation capacity of the countries. Length of lines supports countries to be more successful in terms of railway infrastructure performance. In the literature, there are studies that accept rail and line lengths as criteria ([22]). For this reason, it has been accepted among the research criteria.

“Locomotives” demonstrate the power of rail transport. The locomotive power and numbers of the countries show the railway performance. In this study, the existing numbers of locomotives were evaluated as criteria, regardless of their power. Likewise, “Wagons” also refer to railway carrying capacity. Considering the linear relationship between the number of wagons and the rail transport service, the number of wagons is among the benefit criteria. The development of the rail transport sector depends on entrepreneurial initiatives. The number of “railway enterprises” owned by the countries explains the size of the investments. For this reason, Railway enterprises have been accepted as a benefit criterion.

The mobility of goods trains and passenger trains explains the vitality of rail transport. Goods trains train movements of countries show national and international shipments of goods. It also indicates the preference of rail transport for shipments of goods. For this reason, “goods trains train movements” are among the railway performance criteria. In the same way, passenger trains train movements of countries are among the factors that affect people's turn to railway transportation among transportation modes. In our research, passenger trains train movements were accepted as the benefit criterion. In addition, “Passengers transported”, “Goods transported”, “Transport of dangerous goods” and “Volume of containers transported” amounts also reflect the preference level of rail transport. The level of preference also affects rail transport performance. In addition, the amount of railway passengers is accepted as the key performance criteria ([23]). For this reason, these criteria are among the research criteria.

RTP success depends on the level of infrastructure, equipment, goods, and people mobility, as well as the low level of accidents and incidents. The low number of accidents and incidents in railway transport makes railway transport more reliable. As a natural consequence of this, transportation performance also increases. There are three main criteria that reflect the railway safety performance of countries. These are “Rail accidents”, “Rail accidents victims” and “Accidents involving transport of dangerous goods”. Especially risk factors such as radiation accidents and hazardous chemical leakage are among the risk factors in dangerous goods transportation ([24]). These criteria have been accepted as cost criteria, that is, criteria that reduce performance.

The European Union provides data on economic, political, industrial, and similar performance indicators of the European Union and candidate countries through Eurostat. The data of the 2020 railway transport performance criteria are also published by Eurostat in this context. The dataset of this research was prepared by using railway transport data of twenty-three European countries published by Eurostat ([25]). The criteria and information about the sample area are presented in the Table 1.

Table 1. Criteria and sampling

Criteria	Units	Benefit/Cost	Countries
C1- Length of tracks	km	Benefit	Bulgaria (BG), Czechia
C2- Electrified railway tracks	km	Benefit	(CZ), Germany (DE),
C3- Non-electrified railway tracks	km	Benefit	Estonia (EE), Greece
C4- Length of lines	km	Benefit	(GR), Spain (ES),
C5- Locomotives	number	Benefit	France (FR), Croatia
C6- Wagons	number	Benefit	(HR), Italy (IT), Latvia
C7- Railway enterprises	number	Benefit	(LV), Lithuania (LT),

C8- Goods trains Train movements	Thousand-km	Benefit	Luxembourg (LU),
C9- Passenger trains Train movements	Thousand-km	Benefit	Hungary (HU), Poland
C10- Rail accidents victims	number	Cost	(PL), Portugal (PT),
C11- Rail accidents	number	Cost	Romania (RO), Slovenia
C12- Accidents involving transport of dangerous goods	number	Cost	(SI), Slovakia (SK), Finland (FI), Sweden
C13- Passengers transported	Thousand	Benefit	(SE), Montenegro (ME),
C14- Goods transported	Thousand tones	Benefit	North Macedonia (MK),
C15- Transport of dangerous goods	Thousand tones	Benefit	Turkey (TR)
C16- Volume of containers transported	TEU	Benefit	

3.2. Criteria importance through intercriteria correlation technique (CRITIC)

It is a method developed by Diakoulaki et al. [26] to determine criterion weights in multi-criteria decision making (MCDM) methods. In this method, it is aimed to calculate the weights of the criteria with the correlation between the criteria. The most important reason for preferring this method can be seen as avoiding subjectivity. Three basic steps are applied in this technique ([26], [27], [28], [29]). These steps are as follows:

Step 1-1: *Creating the decision matrix*: The decision matrix consisting of *m* alternatives and *n* criteria is shown in Equation 1.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \dots & x_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mj} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

x_{ij} presents the performance value of i^{th} alternative on j^{th} criterion. x_{ij} $(i = 1, 2, \dots, m;\ j = 1, 2, \dots, n)$

Step 1-2: *Normalizing the decision matrix*: The decision matrix is normalized using Equation 2. for the benefit criterion and Equation 3. for the cost criterion.

$$x_{ij}{}^{*} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, i = 1, 2, \dots, m \ and\ j = 1, 2, \dots, n \tag{2}$$

$$x_{ij}{}^{*} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, i = 1, 2, \dots, m \ and\ j = 1, 2, \dots, n \tag{3}$$

Step 1-3: *Determining the importance weights of the criteria*: Here, C_j represents the amount of information contained in the j^{th} criterion and is calculated by Equation 4. The importance weights of the criteria are calculated by Equation 5.

$$C_j = \sigma_j \sum_{j'=1}^{n} (1 - r_{jj'}) \tag{4}$$

$$w_j = \frac{C_j}{\sum_{j\_1}^{n} C_j} \tag{5}$$

σ_j represents the standard deviation (Standard deviation describes dispersion of a set of values, $\sigma_j = \sqrt{\frac{\sum_{j=1}^{n}(X_j-\bar{X})^2}{n-1}}$) of the j[th] criterion in the normalized decision matrix obtained by Eq. 2 and Eq. 3, and $r_{jj'}$ represents the correlation coefficient of the two criteria (Correlation coefficient describes the statistical relationship between two variables, $r_{jj'} = \frac{\sum(x_j x_{j'})-(\sum x_j)(\sum x_{j'})/n}{\sqrt{(\sum x_j{}^2-(\sum x_j)^2/n)\,(\sum x_{j'}{}^2-(\sum x_{j'})^2/n)}}$).

3.3. Range of value technique (ROV)

The ROV method is a MCDM method performed in three simple steps ([30]). The ranking of the alternatives is made by obtaining the best and worst utility values for each alternative ([31], [32]). Three basic steps are applied in this technique ([30], [33]). These steps are as follows:

Step 2-1: *Creating the decision matrix*: The decision matrix is formed by Equation 1.

Step 2-2: *Normalizing the Decision Matrix*: The normalized decision matrix is formed by Equation 2. and Equation 3.

Step 2-3: *Calculating u_i^+, u_i^- and u_i values and determining the best alternative*: Equation 6. calculates the best utility function and Equation 7. calculates the worst utility function. The utility functions for the best utility function and the cost functions for the worst utility functions are considered. Alternative ranking is made according to the total score values u_i calculated by Equation 8.

$$u_i^+ = \sum_{j=1}^{n} \bar{x}_{ij} w_j \tag{6}$$

$$u_i^- = \sum_{j=1}^{n} \bar{x}_{ij} w_j \tag{7}$$

$$u_i = \frac{u_i^+ + u_i^-}{2} \tag{8}$$

All the steps of the CRITIC and ROV techniques described above are applied in the next part. As a result of the application, the railway performance rankings of the European countries will be obtained.

4. Application of Railway Transport Performance of European Countries

In this application, railway transport performances of European countries were calculated by considering the performance criteria. To determine the performances of European countries, 23 alternatives *(m)* and 16 criteria *(n)* were determined. In the application, the weights of the criteria were calculated with the CRITIC technique. Then, the alternatives were listed with the ROV technique. The application was carried out with the steps presented in the methodology section.

Step 1-1: *Creating the decision matrix*: The data from Eurostat has been transformed into a decision matrix with Equation 1. The decision matrix is shown in Table 2.

Table 2. The decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8
BG	5464	3729	1735	4029	458	9907	12	8432
CZ	15360	6917	8443	9542	1999	30219	67	29525
DE	67400	42333	25067	38394	4571	103991	400	259799
EE	2143	138	2005	1167	188	22852	8	1247
GR	3039	1355	1684	2345	72	715	4	7500
ES	22274	16528	5746	16135	464	13458	18	22067
FR	53382	38269	15113	26838	3225	68099	64	53940
HR	3950	1635	2315	2617	306	5197	12	5786
IT	24515	19720	4794	16782	2490	25665	50	47239
LV	2216	502	1714	1859	201	6107	11	4795
LT	2346	318	2029	1911	214	7514	4	9535
LU	628	596	32	271	75	3154	2	399
HU	11393	5560	5833	7787	1154	8640	80	15612
PL	37269	25145	12124	19383	3671	83011	91	65351
PT	3224	2394	831	2526	132	2719	5	5874
RO	20071	8528	11543	10769	2205	39573	0	20269
SI	2178	1465	713	1209	150	2762	1	8340
SK	3631	1586	2045	3627	901	12967	24	12075
FI	8599	5180	3419	5918	390	8763	6	13921
SE	15557	12166	3391	10909	620	20000	27	35051
ME	328	303	25	250	30	561	3	288
MK	907	327	580	683	43	1238	2	561
TR	12472	5753	6719	10378	690	21210	4	25263
	C9	C10	C11	C12	C13	C14	C15	C16
BG	19702	22	33	1	16808	16374	4118	79814
CZ	137515	34	90	0	129308	90902	12839	1679221
DE	790000	137	294	6	1752198	325303	72862	7087674
EE	5329	2	5	0	5984	15801	10390	44957
GR	7403	2	9	0	10220	1328	67	164492
ES	136103	13	51	7	333397	22254	2109	616793
FR	375000	44	104	14	723852	83143	13974	4000000
HR	12781	10	22	0	13100	14992	1399	162740
IT	272268	43	89	0	389883	90529	6359	3092077
LV	5921	6	9	0	12862	24056	8276	65345
LT	6067	6	9	0	3238	53430	9078	149779
LU	7530	0	1	0	14527	3627	407	69384
HU	83620	31	98	0	146010	51892	8166	293051
PL	156834	148	179	1	295394	218381	28682	2349161
PT	27474	27	43	0	102247	8426	469	421691
RO	57377	79	102	0	50559	49670	6171	296830
SI	7611	2	5	0	7924	19398	1714	519643
SK	34099	27	52	0	49421	41572	5080	579307
FI	33804	4	12	3	59550	38406	4211	54004
SE	116302	4	31	1	169163	69805	3536	703568
ME	806	5	43	0	473	1154	119	4400
MK	885	6	97	0	253	1765	111	2
TR	13327	32	66	7	99470	34374	2810	1140980

Step 1-2: *Normalizing the decision matrix*: The decision matrix is normalized with Equation 2. and Equation 3. The normalized decision matrix is shown in Table 3.

Table 3. The normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8
BG	0,08	0,09	0,07	0,10	0,09	0,09	0,03	0,03
CZ	0,22	0,16	0,34	0,24	0,43	0,29	0,17	0,11
DE	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
EE	0,03	0,00	0,08	0,02	0,03	0,22	0,02	0,00
GR	0,04	0,03	0,07	0,05	0,01	0,00	0,01	0,03
ES	0,33	0,39	0,23	0,42	0,10	0,12	0,05	0,08
FR	0,79	0,90	0,60	0,70	0,70	0,65	0,16	0,21
HR	0,05	0,04	0,09	0,06	0,06	0,04	0,03	0,02
IT	0,36	0,46	0,19	0,43	0,54	0,24	0,13	0,18
LV	0,03	0,01	0,07	0,04	0,04	0,05	0,03	0,02
LT	0,03	0,00	0,08	0,04	0,04	0,07	0,01	0,04
LU	0,00	0,01	0,00	0,00	0,01	0,03	0,01	0,00
HU	0,16	0,13	0,23	0,20	0,25	0,08	0,20	0,06
PL	0,55	0,59	0,48	0,50	0,80	0,80	0,23	0,25
PT	0,04	0,05	0,03	0,06	0,02	0,02	0,01	0,02
RO	0,29	0,20	0,46	0,28	0,48	0,38	0,00	0,08
SI	0,03	0,03	0,03	0,03	0,03	0,02	0,00	0,03
SK	0,05	0,03	0,08	0,09	0,19	0,12	0,06	0,05
FI	0,12	0,12	0,14	0,15	0,08	0,08	0,02	0,05
SE	0,23	0,29	0,13	0,28	0,13	0,19	0,07	0,13
ME	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00
MK	0,01	0,00	0,02	0,01	0,00	0,01	0,01	0,00
TR	0,18	0,13	0,27	0,27	0,15	0,20	0,01	0,10
	C9	C10	C11	C12	C13	C14	C15	C16
BG	0,02	0,85	0,89	0,93	0,01	0,05	0,06	0,01
CZ	0,17	0,77	0,70	1,00	0,07	0,28	0,18	0,24
DE	1,00	0,07	0,00	0,57	1,00	1,00	1,00	1,00
EE	0,01	0,99	0,99	1,00	0,00	0,05	0,14	0,01
GR	0,01	0,99	0,97	1,00	0,01	0,00	0,00	0,02
ES	0,17	0,91	0,83	0,50	0,19	0,07	0,03	0,09
FR	0,47	0,70	0,65	0,00	0,41	0,25	0,19	0,56
HR	0,02	0,93	0,93	1,00	0,01	0,04	0,02	0,02
IT	0,34	0,71	0,70	1,00	0,22	0,28	0,09	0,44
LV	0,01	0,96	0,97	1,00	0,01	0,07	0,11	0,01
LT	0,01	0,96	0,97	1,00	0,00	0,16	0,12	0,02
LU	0,01	1,00	1,00	1,00	0,01	0,01	0,00	0,01
HU	0,10	0,79	0,67	1,00	0,08	0,16	0,11	0,04
PL	0,20	0,00	0,39	0,93	0,17	0,67	0,39	0,33
PT	0,03	0,82	0,86	1,00	0,06	0,02	0,01	0,06
RO	0,07	0,47	0,66	1,00	0,03	0,15	0,08	0,04
SI	0,01	0,99	0,99	1,00	0,00	0,06	0,02	0,07
SK	0,04	0,82	0,83	1,00	0,03	0,12	0,07	0,08
FI	0,04	0,97	0,96	0,79	0,03	0,11	0,06	0,01
SE	0,15	0,97	0,90	0,93	0,10	0,21	0,05	0,10
ME	0,00	0,97	0,86	1,00	0,00	0,00	0,00	0,00
MK	0,00	0,96	0,67	1,00	0,00	0,00	0,00	0,00
TR	0,02	0,78	0,78	0,50	0,06	0,10	0,04	0,16

Step 1-3: *Determining the importance weights of the criteria*: Equation 4. and Equation 5. determined the weights of the criteria. The criteria weights are presented in Table 4.

Table 4. The criteria weight

	C1	C2	C3	C4	C5	C6	C7	C8
w_j	0,0446	0,0506	0,0415	0,0431	0,0523	0,0473	0,0361	0,0342
	C9	C10	C11	C12	C13	C14	C15	C16

w_j	0,0365	0,1723	0,1507	0,1387	0,0360	0,0400	0,0367	0,0394

Step 2-1: *Creating the decision matrix*: The data from Eurostat has been transformed into a decision matrix with Equation 1. The decision matrix is shown in Table 2.

Criteria	Units	Benefit/Cost	Countries
C1- Length of tracks	km	Benefit	Bulgaria (BG), Czechia (CZ), Germany (DE), Estonia (EE), Greece (GR), Spain (ES), France (FR), Croatia (HR), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Hungary (HU), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SI), Slovakia (SK), Finland (FI), Sweden (SE), Montenegro (ME), North Macedonia (MK), Turkey (TR)
C2- Electrified railway tracks	km	Benefit	
C3- Non-electrified railway tracks	km	Benefit	
C4- Length of lines	km	Benefit	
C5- Locomotives	number	Benefit	
C6- Wagons	number	Benefit	
C7- Railway enterprises	number	Benefit	
C8- Goods trains Train movements	Thousand-km	Benefit	
C9- Passenger trains Train movements	Thousand-km	Benefit	
C10- Rail accidents victims	number	Cost	
C11- Rail accidents	number	Cost	
C12- Accidents involving transport of dangerous goods	number	Cost	
C13- Passengers transported	Thousand	Benefit	
C14- Goods transported	Thousand tones	Benefit	
C15- Transport of dangerous goods	Thousand tones	Benefit	
C16- Volume of containers transported	TEU	Benefit	

Step 2-2: *Normalizing the Decision Matrix*: The decision matrix is normalized with Equation 2 and Equation 3. The normalized decision matrix is shown in Table 3.

Step 2-3: *Calculating u_i^+, u_i^- and u_i values and determining the best alternative*: Using Equation 6, Equation 7, and Equation 8, u_i^+, u_i^- *and* u_i were calculated. Table 5. shows the u_i^+, u_i^- *and* u_i values and the rankings of the alternatives.

Table 5. The u_i^+, u_i^- *and* u_i values and the rankings of the alternatives

Countries	u_i^+	u_i^-	u_i	Rank
Bulgaria	0,0318	0,4097	0,2207	18
Czechia	0,1245	0,3763	0,2504	5
Germany	0,5383	0,0920	0,3152	1
Estonia	0,0260	0,4573	0,2416	6
Greece	0,0117	0,4553	0,2335	10
Spain	0,0972	0,3515	0,2244	15
France	0,2881	0,2188	0,2535	4
Croatia	0,0219	0,4392	0,2306	13
Italy	0,1686	0,3664	0,2675	2
Latvia	0,0202	0,4506	0,2354	9
Lithuania	0,0258	0,4506	0,2382	7
Luxembourg	0,0041	0,4617	0,2329	11
Hungary	0,0767	0,3757	0,2262	14
Poland	0,2602	0,1879	0,2241	16
Portugal	0,0187	0,4087	0,2137	21
Romania	0,1140	0,3178	0,2159	20
Slovenia	0,0150	0,4573	0,2362	8
Slovakia	0,0438	0,4040	0,2239	17
Finland	0,0435	0,4217	0,2326	12
Sweden	0,0878	0,4317	0,2598	3
Montenegro	0,0005	0,4343	0,2174	19
North Macedonia	0,0028	0,4053	0,2041	22
Turkey	0,0725	0,3217	0,1971	23

By applying both CRITIC and ROV techniques above, findings regarding criterion weights and alternative rankings were obtained. The conclusions and implications for these findings are presented in the next part.

5. Results and Conclusion

Despite the high infrastructure installation costs of railway transportation, it provides advantages in transporting heavy and bulky loads at low cost in transportation services. In addition to the transportation of passengers and goods in railway transportation, it is also used effectively in the transportation of dangerous goods. At the macro level, railway transport is preferred as an alternative mode of transport by directly contributing to the logistics activities of countries. In this research, the railway transportation performances of European countries in 2020 were determined. In this context, 16 performance-determining criteria were determined. CRITIC technique was applied to determine the weights of the criteria. The criterion with the highest level of importance is *Rail accidents victims* (17.23%). The least important criterion is *goods trains train movements* (3.42%). Weights of other criteria are *rail accidents* (15.07%), *accidents involving transport of dangerous goods* (13.87%), *locomotives* (5.23%), *electrified railway tracks* (5.06%), *wagons* (4.73%), *length of tracks* (4.46%), *length of lines* (4.31%), *non-electrified railway tracks* (4.15%), *goods transported* (4.00%), *volume of containers transported* (3.94%), *transport of dangerous goods* (3.67%), *passenger trains are train movements* (3.65%), *railway enterprises* (3.61%), *passengers transported* (3.60%).

According to the criteria weights, the most important criterion contributing to the railway performance of European countries is the number of people and goods damaged in railway accidents. This criterion is a cost-based criterion. The target point to be reached in rail transport performance is to realize zero accident and loss. Victims in accidents reduce rail transport performance. The second important criterion is Rail accidents. Safe and secure transportation of passengers and goods indicates the superior success of rail transport services. The third important criterion is the accidents that occur during the transportation of dangerous goods. This criterion is a cost-based criterion. In other words, the fact that trains carrying dangerous goods have an accident and adversely affect the environment reduces the performance of the railway. Considering the damage caused by dangerous substances to people and the environment, it provides a high effect compared to other criteria. Other criteria are benefit-based criteria. It is also seen that the criterion weights are very close to each other.

Railway transportation performances of European countries were determined by ROV technique. The country with the highest rail transport performance was determined as Germany (u_i=0.3152). In particular, the low rate of " Rail accidents victims, rail accidents, accidents involving transport of dangerous goods", which are cost criteria, makes a great contribution to Germany's ranking in the first place in railway transportation performance. In addition, it is seen that Germany is superior to other countries in terms of benefit criteria. Italy (u_i=0.2675) ranks second in rail transport performance. Italy is superior to other countries in terms of railway infrastructure, number of equipment and transport volumes. Considering the number of accidents and incidents in railway transportation, the number is higher than in other countries. However, it is understood that accidents and incidents are low when compared to total transport volumes. Sweden (u_i=0.2598) is third in the rail transport performance ranking. France (u_i=0.2535) is fourth and Czechia (u_i=0.2504) is fifth. When comparing the rail transport performances of Sweden, France, and Czechia, it is observed that there are very few differences. The three countries with the lowest performance rankings are Portugal (u_i=0.2137), North Macedonia (u_i=0.2041) and Turkey (u_i=0.1971).

The recommendations for European countries to improve their rail transport performance are as follows. (i) A culture of safety needs to be established to minimize train accidents. (ii) Legal procedures should be strictly applied to prevent trains carrying dangerous goods. (iii) Investment should be made in railway infrastructure projects. (iv) Railway equipment should be modernized, and maintenance plans should be made correctly, and the plans should be strictly followed. (v) Passenger and goods train movements should be determined according to need. (vi) Railway transport initiatives should be supported by governments. (vii) Strategic level programs should be established by developing a safety-based national rail transport vision. Suggestions for researchers are as follows. (i) The results obtained by determining the railway performance criteria with different MCDM techniques can be compared with these research findings. (ii) Railway transport performances of countries in different regions can be applied with the same methodology. (iii) A worldwide rail transport index could be developed. (iv) Comparisons between years can be made by making European railway performance rankings based on different years. In fact, with the panel data set and data envelopment analysis, it is possible to research the change trends over the years. The limitations of the research are as follows. (i) The findings were determined according to 16 performance criteria. (ii) The sample area was determined as 23 European countries. (iii) Safety-based criteria are accepted as cost criteria and other criteria as benefit criteria.

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