Evaluating Annual Operation Performance of Serbian Railway System by using Multiple Criteria Decision-Making Technique

Nikola Petrović[1], Jelena Mihajlović[1], Vesna Jovanović[1], Dušan Ćirić[1], Tanja Živojinović[2]

[1] University of Niš, Faculty of Mechanical Engineering
Aleksandra Medvedeva 14, 18106 Niš, Serbia
petrovic.nikola@masfak.ni.ac.rs, jelena.mihajlovic@masfak.ni.ac.rs, vesna.jovanovic@masfak.ni.ac.rs, dusan.ciric@masfak.ni.ac.rs

[2] University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, 11010 Belgrade, Serbia
t.zivojinovic@sf.bg.ac.rs

Abstract: The railway is a complex dynamic system, including the railway infrastructure, vehicles and personnel, each of which has its own functions or goals. Evaluating operation performance for freight and passenger railway systems is important for the government, operators and passengers. This paper will use a well-known, Multiple Criteria Decision-Making (MCDM) technique, to evaluate the freight and passenger rail systems operational performance. Initially, the authors will create the evaluation indicator system based on official data, having 5 basic indicators and a total of 18 sub-indicators, for freight transport, as well as passenger transport. Also, these operational data/indicators will be used as the input for the MCDM approach. Next, a formulated approach to obtain the performance evaluation is used as follows: The Entropy weight method is employed to calculate the weight of each sub-indicator; the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, will be used to calculate the comprehensive evaluation values and rankings of performance for each year. Finally, the Serbian railway, with 7 years of data, will be chosen, as the case study, to test the MCDM approach; the related recommendations for freight transport, as well as passenger rail transport, will also be provided.

Keywords: Railway; Entropy; TOPSIS; Operation performance evaluation

1 Introduction

Rail transport is described as a reliable, efficient, safe and complex system of vehicles, infrastructure, equipment and technology, and people. This system is capable of transporting huge amounts of goods and people, over long distances at high speeds. But, it is less flexible and more expensive, in comparison to road transport, when lower traffic levels are considered. Thus, Rail is more efficient in urban and highly-populated areas. Rail transport has been the second largest block in the modal split, after private motorized transport in Germany in 2018 [1]. Freight transport by rail involves various actors, the most important of which are: Shippers, rail transport companies competing in an open market in the EU since 2007; infrastructure managers and national regulators, and safety authorities. At the European level, the railroad serves an important role in passenger transport. Although the EU has one of the densest railroad networks in the world, the national railroad systems in the EU, have different standards.

In order to modernize and increase efficiency, but simultaneously support cleaner, greener, smarter and sustainable transport, the European Commission adopted, at the end of the last year, a set of proposals [2] [3]. Those proposals refer to the increase of connectivity and the transportation of more passengers and freight to rail and inland waterways. By optimizing performance and greater use of more energy efficient modes of transport, 30% of road freight transport should be redirected to other modes such as rail and water transport by 2030, and more than 50% by 2050, connecting all airports by rail and providing sufficient measure the connection of all seaports to the rail freight and, where possible, inland waterways [2].

The best way of monitoring the performance of some organization or some process is by the properly defined indicator or the set of indicators that are more specifically aimed at the observation area of interest. This way the management could monitor the entire system and make proper decisions to enhance their operations. One of the examples of measuring performance is a key performance indicator (KPI). Actually, a KPI is a universal tool that represents a measurable value that shows the effectiveness of a company in achieving its goals. Consequently, the KPI can be applied to measure railway operation efficiency from available data [4]. In order to make an overall KPI of the railway system, many indicators and sub-indicators must be involved. Those indicators regard reliability, lead time, costs, flexibility and visibility, punctuality performance, mobility, capacity, business and financial performance, safety, etc.

In addition to the proper definition of the KPI and selecting the measuring units for each of them, the data acquisition and the quality of the data, are crucial. The data input could be done digitally, but often, the human factor is the dependent variable. Another perspective of the applied KPI on the railway operation depends on the viewpoint of the stakeholders. This means that the government perspective differs from the passenger perspective or the employee perspective.

The government evaluation of the railway system's performance, mostly favors financial performance and the subventions involved. In this way, proper improvements and optimizations can be applied. The employee process evaluation defers on the level of the hierarchy and the process itself. But, it is commonly observed as the process performance and whether the goals are achieved on time and on what level. The passenger evaluation of the railway system is based on accessibility, reliability, flexibility, time and money-saving, environmental impact, service quality, and satisfaction, etc.

Today, in addition to the accountable authorities, responsibility is divided between infrastructure managers and transport operators. In the modern rail system, infrastructure management can be independent of the infrastructure owner, although the latter is often responsible for marketing the train tracks. Traditionally, operation covered the entire spectrum from timetabling and dispatching to higher-level transport management. In addition, energy supply, infrastructure maintenance, or the operation of stations and other services can be integrated or located in separate companies or parts of companies. In the EU, these areas are increasingly being taken over by specialized companies that do not belong to the respective former state railroads. Another important role is played by transport service providers. These include transport companies that transport goods or passengers on their own behalf or on behalf of the state, or nowadays also on the basis of municipal orders [5].

The structure of this paper is as follows: The Introduction, discusses the importance and analysis of railway operational performance at the global (state) and local (service users), the second section is devoted to reviewing the literature on the application of approaches and methodologies for evaluating railway performance. There is a wide range of criteria that can be studied when it comes to the efficiency of railways as a system, and for that reason. The third section describes a general mathematical procedure, using multicriteria defining sets of input data, in the form of criteria for passenger and freight rail transport. Next, the fourth section gives a brief overview of the methods used, Entropy for calculating weights and Topsis for ranking the performance of rail transport in the Republic of Serbia, for the time period from 2013 to 2019, based on valid statistics for the railway system, of the Republic of Serbia. At the end of the paper, in fifth section, the main conclusions and an overview of future research tasks are presented.

2 Literature Review

There are a large number of methods and techniques that are applied in certain analyzes [6-8]. Methods of multi-criteria decision-making are most often used because they are based on decision-making when there are several defined and conflicting criteria [9-11]. When reviewing the literature on railway performance analysis, it is seen that in a limited number there are studies that use different decision-making methods with multiple criteria to obtain an assessment of rail transport efficiency. There are two well-known approaches to evaluating and measuring railway performance. First, parametric approaches are very rarely used because they need certain assumptions to establish the desired function, and second is refers to researchers who prefer using nonparametric approaches that involve fewer assumptions [12].

Various multi-decision making techniques are used to measure and evaluate performance in rail traffic such as AHP (Analytical Hierarchy Process), ANP (Analytical Network Process), DEMATEL (Decision making trial and evaluation laboratory), TOPSIS, SAW (Simple Additive Weighting) and etc. Also, the use of the DEA (Data Envelopment Analysis) method and machine learning can be found in different areas of the railway [13] [14]. DEA method can be used alone or in combination with MCDM methods.

Yu used the DEA method to conduct an efficiency and effectiveness study for a group of 40 large railway systems (passenger and freight) in 2002 [15]. The DEA method is used to evaluate the efficiency of European railway companies, taking into account different input and output configurations [16].

The authors in [17] developed a model for predicting the volume of railway transport that could be applied in different economic contexts and used as a means of transport planning. The model is made using common machine learning techniques that learn from past experience. Indicators defined by the World Bank were used as input parameters in the preparation of the model.

Based on the analysis of publicly available statistical data, taken from Eurostat service at a European level, the authors [18] enabled the identification and comparison of various indicators that affect the performance of the railway system from an infrastructural and operational perspectives. The paper highlights case studies for various parameters that are important for infrastructure managers, railway operators, policymakers and end-users.

A proposed method for the evaluation of service quality for measuring the performances of railway transit lines through passenger satisfaction surveys is given in [19]. Railway transit systems are one of the most desirable modes to avoid traffic congestion, especially during rush hours. The method combines statistical analysis, fuzzy trapezoidal numbers, and the TOPSIS method for estimating service quality levels. In the research conducted in Istanbul in 2012, 2013, and 2014, the authors [19] identified factors that need to be improved, gave recommendations for improving the work of certain lines, and guidance for future investments. Risk analysis is also an important aspect of railways [20].

The paper [21] presents the methodology for the assessment and classification of railway network performance along with the Trans-European Transport Network (TEN-T). Twenty-two infrastructural, economic and technological criteria for evaluating rail transport were used as input data. Based on the adopted criteria, countries are ranked using multi-criteria decision-making methods. The results show that the eight countries involved in the Orient–East Med corridor can be classified into three groups.

The authors [22] applied MCDM methods in presenting the planning process of an integrated urban transport system where the proposed approach has a universal character and can be applied by urban planners, traffic engineers, and municipal authorities in strategic planning of urban transport systems and design of advanced transport solutions.

The operation performance evaluation of the urban railway system in the Chinese city – Chengdu during 34 months using the Entropy – TOPSIS methods was performed in [23]. The authors created a set of evaluation indicators with 8 indicators and a total of 41 sub-indicators. The operational data of 41 sub-indicators were used as input data for access.

Based on the review of the literature and indicated models and methods, and with the aim of determining the operational performance, a multi-criteria analysis will be conducted for both passenger and freight railway transport of the Republic of Serbia.

3 MCDM Methodology and Input Data

Multi-criteria decision-making methods have been developed as mathematical tools to support decision-makers involved in the decision-making process [24]. Those methods are gaining importance as potential tools for analyzing and solving complex problems due to their inherent ability to evaluate different alternatives with respect to various criteria for possible selection as the best alternative [25]. The choice of the method which will be used for solving the specific multi-criteria analysis problem depends on the nature of the problem, the availability of information concerning a problem, the number of alternatives, as well as the knowledge, previous experience, and preferences of the decision-maker.

Indicators are often defined as quantitative measures that can be used "to simply illustrate and communicate complex phenomena, including trends and progress over time." Indicators can perform different functions. The data collected may be suitable for analysis by those involved in decision-making and thus contribute to better decision-making.

The largest data sources for comparative assessment are statistics and annual reports of companies, however, the main issue under consideration in the last few years is the data availability from privatized and divided transport companies and the fact that many privatized operators find it very difficult to some of the details from their business. Although the large number of entities that are vital for transport make the task of collecting data for comparative assessment more complex, their presence on the other hand, should increase the quality and scope of comparative assessment.

The data collected through regular monthly, quarterly and annual statistical reports were taken from [26] and shown in Table 1.

Table 1
Indicators and sub-indicators of rail transport

Indicator	Sub-indicator	Specification of each	Unit of each sub-indicator
Basic indicators of rail transport	f_1	Passenger transport (locomotive km)	train km, thous.
	f_2	Freight transport (locomotive km)	train km, thous.
	f_3	Passenger transport	gross-ton km, mill.
	f_4	Passenger transport	gross-ton km, mill.
	f_5	Number of transported passengers	thous.
	f_6	Realized pkm	passenger-kilometers, thous.
	f_7	Quantity of goods transported	thous. t
	f_8	Realized tkm	ton-km, thous.
Employees in rail transport	f_9	-	number
Generating power of rail transport	f_{10}	Internal-combustion engines	kW, thous.
	f_{11}	Electric engines	kW, thous.
Consumption of fuel and electricity in rail transport	f_{12}	Liquid fuels	thous. t
	f_{13}	Electricity	thous. MWh
Railway asset	f_{14}	Effective length of tracks	km
	f_{15}	Passenger wagon stock and motor trains	number
	f_{16}		seats thous.
	f_{17}	Freight wagon stock	number
	f_{18}		tons of carrying capacity, thous.

The key indicators that are used Basic indicators of rail transport, Employees in rail transport, Generating power of rail transport, Consumption of fuel and electricity in transport and Railway asset. After that, the Entropy method is utilized, for determining weighting factors and the TOPSIS method, for ranking alternatives.

The weight coefficients are values that can be obtained by any of the following methods (Eigenvector method, Least squares weight method, Entropy method, etc.). The entropy method is a method for determining the weighting coefficients of multi-criteria decision-making. The method was invented by Claude Shannon (1984) [27]. Determining the weight of coefficients based on the entropy method consists of normalization of the values of alternatives according to each of the criteria, calculation entropy of all alternatives in terms of criteria, the degree of divergence of the average internal information of each criterion, and the final relative weights of the criteria are obtained by additive normalization [27].

TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method was introduced by Hwang and Yoon (1981). The ordinary TOPSIS method is based on the concept that the best alternative should have the shortest Euclidian distance from the ideal solution (positive ideal solution – PIS) and at the same time the farthest from the anti-ideal solution (negative ideal solution – NIS). It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion [24]. This method can be implemented using develop decision matrix which needs to normalize and weighted then determine the positive ideal and the negative ideal solutions, calculated the distance from the ideal and anti-ideal solutions for each alternative using the two Euclidean distances and calculate the relative closeness of every alternative to the positive ideal solution. The higher values indicate that the rank is better.

Alternatives represent the years of observation, and the criteria are the operational performance of rail freight and passenger transport in the Republic of Serbia.

4 The Approach and Results Discussion for Case Study: The Serbian Railway

To make a good decision, it is necessary to define alternatives by specifying appropriate criteria [28]. It is also necessary to define the values of weight coefficients for each criterion; i.e. the importance of each criterion in relation to the others [29, 30]. Weights will show the importance of the participation of certain criteria in making a decision on the ranking of alternatives (years). Determining the objective weights of criteria according to the Entropy method is based on measuring the uncertainty of information contained in the decision matrix and directly generates a set of weight values of criteria based on the contrast of individual criteria values of alternatives for each criterion and then simultaneously for all criteria using formulas from.

The basic concept of the TOPSIS method is that the chosen alternative should have the smallest distance from the ideal solution and the largest distance from the negative ideal solution, in the geometric sense. During the normalization process, the transformation of minimization into maximization criteria is not performed. For each alternative, the distance from the ideal and negative ideal solution is calculated in relation to each criterion, taking into account the criteria that are minimized and maximized. The weight/significance of each alternative is finally determined based on the relative closeness of the alternatives to the ideal solution [17].

Based on the adopted indicators, for both passenger (Tab. 2) and freight transport (Tab. 3) - Transpose matrix, evaluation of operation performance of the Serbian railway was done by Entropy method for determining weight coefficients and the TOPSIS method for ranking the observed years. The calculation results of weighting coefficients show that for passenger rail transport the Passenger wagon stock and motor trains (0.1825) and for freight rail transport the Generating power of rail transport - Internal-combustion engines (0.2573) are the two most important indicators (sub-indicator) in the evaluation system.

Railway asset – Effective length of tracks has the smallest weighting coefficient for both passenger (0.0053) and freight (0.0090) rail transport and shows that this indicator has a minor impact in the operation performance evaluation process.

Table 2

Passenger railway transport – indicators, weighting coefficients and ranking

Criteria (Sub-indicator)/ Weight		**Year**						
f_i	w_i	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
f_1	0.1306	11531	11170	16256	10930	16644	10417	9030
f_3	0.0201	1745	1666	1624	1957	1529	1727	1486
f_5	0.0676	7158	6443	6258	6092	5638	5062	4190
f_6	0.1469	612	452	509	438	377	347	285
f_9	0.1504	18047	17078	16622	13641	10229	10207	10596
f_{10}	0.0841	190	180	153	191	129	123	133
f_{11}	0.0128	626	626	605	687	585	556	671
f_{12}	0.0256	9	9	10	10	10	11	12
f_{13}	0.0596	148	139	136	120	116	115	90
f_{14}	0.0053	3819	3819	3766	3766	3764	3724	3323
f_{15}	0.1145	786	748	833	883	691	542	467
f_{16}	0.1825	48	45	56	59	48	30	27
Rank		**4**	**5**	**1**	**2**	**3**	**6**	**7**

Table 3

Freight railway transport – indicators, weighting coefficients and ranking

Criteria (Sub-indicator)/ Weight		**Year**						
f_i	w_i	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
f_2	0.0198	5947	5878	5919	5103	4997	5424	5540
f_4	0.0153	5520	5464	5731	4870	5081	5390	5809
f_7	0.0154	10463	10826	11887	11896	12352	12297	11475
f_8	0.0097	3022	2988	3249	3087	3288	3187	2861
f_9	0.2524	18047	17078	16622	13641	10229	10207	10596
f_{10}	0.2573	190	180	153	191	129	89	133
f_{11}	0.0606	626	626	605	687	585	462	671
f_{12}	0.0429	9	9	10	10	10	11	12
f_{13}	0.1055	148	139	136	120	116	110	90
f_{14}	0.0090	3819	3819	3766	3766	3764	3752	3323
f_{17}	0.0921	8452	8486	8486	7277	6781	6589	5661
f_{18}	0.1200	431	432	432	411	342	371	259
Rank		**5**	**4**	**6**	**1**	**2**	**7**	**3**

By ranking with TOPSIS method on the basis of adopted indicators for passenger transport of the Serbian railways in the time frame from 2013 to 2019, it can be seen that the best operation performances were in 2015, while in 2019 they recorded the worst-case scenario (Tab. 2). When it comes to the obtained results for freight transport of the Serbian railways by ranking the appropriate indicators, it can be seen that the best operation performances were in 2016, while in 2018 they recorded the worst-case scenario (Tab. 3).

Conclusions

Increasingly modern rail transport, provides a more convenient and less expensive mode of daily passenger and goods transport, so the support of the State is necessary. It is important to set operational goals in advance and optimize the allocation of resources. In this paper, based on literature reviews, the evaluation of the railway operation efficiency in the Republic of Serbia is performed, based on data collected by the regular statistical reports, of traffic business entities, with that help, are formed into two sets of indicators, for passenger and for freight transport.

The total number of used indicators is 5 and 18 sub-indicators, i.e. individually for passenger and freight, 5 indicators and 12 sub-indicators, based on which the input matrices were formed in the observed period from 2013 to 2019. The importance of each indicator was calculated by the Entropy method, while the TOPSIS method was used to evaluate operation performance; i.e. to rank the results on an annual basis.

The calculation results of weighting coefficients show that for passenger rail transport the Passenger wagon stock and motor trains (f_{14}) and for freight rail transport the Generating power of rail transport - Internal-combustion engines (f_{10}) are the two most important indicators (sub-indicator) in the evaluation system. Railway asset – Effective length of tracks (f_{14}) has the smallest weighting coefficient for both passenger and freight rail transport and shows that this indicator is the least important indicator (sub-indicator).

Using the TOPSIS method, the adopted indicators, for the passenger rail transport system of the Republic of Serbia, were ranked in the time frame from 2013 to 2019, based on which, it is shown that the best operational performances were in 2015, while in 2019, showed the worst scenario. When it comes to the obtained results for freight transport of the Serbian railways, by ranking the appropriate indicators, it can be seen that the best operational performances were in 2016, while in 2019, showed the worst-case scenario.

Increasing the efficiency and competitiveness of railroads, to promote the market share of environmentally friendly rail, is one of the most important transport policy objectives of the EU and national transport policies are needed to meet the current and future challenges of transport markets, in particular, the increasing demand for long-distance passenger and freight transport.

The framework and goals of future research will be reflected in the use of this approach, to assess the performance of other transport modes or systems, using appropriate indicators.

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