Evaluating the operation performance of the Serbian transport freight system by using Multiple Criteria Decision-Making technique

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ABSTRACT

Freight transport is a composite dynamic system that forms the unity of the infrastructure, vehicles, and personnel and which has its purpose or aim. Evaluating operation performance for freight transport systems is important for the government, companies, and users. This paper will use one of the most famous Multiple Criteria Decision-Making (MCDM) techniques to assess the operational performance of freight transport systems. At beginning, the authors will create the evaluation indicator system based on official data with four basic indicators and two sub-indicators for freight transport. These operational data/indicators represent the input of the chosen MCDM method. After that, the Analytic Hierarchy Process (AHP) method will use to calculate the indicator and sub-indicators weight and also will use to calculate the universal evaluate values and rankings of each transport mode performance. The Serbian freight transport system for the 2021st year will be selected as a case study for testing the AHP method within the MCDM approach; the associated suggestions to freight transport will also be given.

KEYWORDS

Freight transport, Operation performance, MCDM, AHP

1. INTRODUCTION

Every change that takes place in the economy and production of a country affects all segments of the development of the country as a business entity. If an economic entity does not have a certain flexibility and ability to adequately respond to changes that occur and affect its development, stagnation or cessation of economic growth of that entity occurs. Such events affect the development of all transport modes both in the world and in the Republic of Serbia. Although the Republic of Serbia has an extremely favorable geographical position as a transit country, transport has a very important role in the constant development of the economic development of our country. Trade internationalization increases the demand for modern freight services. Freight transport is a vital in the supply chain industry due to increasing concerns about the environmental impact[1, 2].

As the development of our country has been noticeable in the last few years, especially in the development of road infrastructure, the challenges faced by freight transport are different. Today, freight transport users expect better service, fewer delays, and congestion, less time lost at border crossings, etc. Performance measurement allows the service provider to compare the goals they set and the results they managed to achieve. According to the White Book [3], performance optimization implies greater use of more energy-efficient transport modes. The 30% of road freight
transport over 300 km should be directed to other modes such as rail and water transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To fulfill this goal, the development of appropriate infrastructure is also required. By 2050, it is necessary to connect all airports with a railway network, preferably at high speeds; provide sufficient connectivity of all seaports with railways for freight transport, and where possible, with inland waterways [3].

In order to remain competitive and respond to the rapidly changing market, companies must increase flexibility and adaptability in today’s world market. In this sense, based on the measurement of operational performance, it is possible to choose the appropriate transport mode and it represents a multi-criteria problem that includes quantitative and qualitative criteria. 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 the operational efficiency of transport modes from available data [4]. To create the total KPI of the transport freight system, many indicators and sub-indicators must be involved. Those indicators regard reliability, costs, flexibility and visibility, punctuality performance, mobility, capacity, business and financial performance, safety, etc. Decomposing a complicated and complex unstructured situation to the simpler components makes a hierarchical system problem the basis of the AHP method. The power of the AHP method consists in its ability to include all criteria and sub-criteria as relevant factors in the problem-solution process and as such it has found application in various fields of economics, management, engineering, marketing, and education.

From a government perspective, evaluating and analyzing freight transport performance is essential because of the basis for government subsidies. Differences in performance between different transport modes are a strong justification for government financial subsidies. Also, the results provide support to the government on how to optimize and improve the structure of any transport mode. From the operator’s perspective, freight transport performance evaluation can be seen as an efficiency assessment that focuses if operators achieving predetermined goals and what jobs they performed to achieve the goals. From the user’s point of view, the evaluation of freight transport performance can be considered as time-saving accessibility and environmental friendliness.

After the introductory part, which discusses the importance and analysis of the operational performance of the freight transport modes, the second chapter is devoted to the review of the literature on the application of approaches and methodologies for evaluating the performance of the included freight transport modes. There is a wide spectrum of criteria that may be studied when it comes to the operational performance of freight rail, road, water (inland waterways), and air transport as a system, and for this reason, general settings for using multi-criteria decision-making and defining sets of input data are given in the third chapter. Furthermore, in the fourth chapter, an overview of the AHP method was given, which was used both for calculating weight coefficients and for ranking the performance of freight transport in the Republic of Serbia in 2021 based on valid statistical data. At the end of the research paper, the main conclusions and an overview of future studies tasks will be presented.

2. LITERATURE REVIEW

A review of the literature on freight transport modes shows that there are a limited number of studies that use different methods for decision-making based on multiple criteria to evaluate operational performance [5–7]. There are several approaches to measuring and evaluating freight transport performance. On the one hand, parametric approaches are rarely used because they need certain assumptions for determination the desired function; while on the other hand, researchers prefer to use nonparametric approaches which involve fewer assumptions [8].

Based on searches in databases, various MCDM techniques [9, 10] were used for measurement, evaluation and analysis performance in transport, such as Analytic Hierarchy Process – AHP, Analytic Network Process – ANP, Više Kriterijumska Optimizacija Kompromisno Rešenje – VIKOR, Technique for Order of Preference by Similarity to Ideal Solution – TOPSIS, Decision making trial and evaluation laboratory – DEMATEL, Simple Additive Weighting – SAW and etc.

After a detailed review of MCDM methods, the paper [11] used the AHP method for a logistics company in choosing the most appropriate transport mode between the two listed locations in Turkey. The criteria that were used when choosing the transport mode are price, environmental acceptability, speed, safety, accessibility, flexibility and reliability. Several price parameters (storage, transport, handling, crossing the Bosphorus) are included in the decision-making analysis. Research results indicated that rail transport, which is not widespread in Turkey, is the most convenient transport mode.

The paper [12] describes the model which uses AHP method for choosing a convenient transport mode from a potential three transport modes. This research aims to create a useful decision support tool for choosing the transport mode within the distribution logistics of motor fuels. The tool could help companies make the right decision on the choice of
transport mode, taking into account the importance of different criteria that influence the decision-making analysis and process.

In paper [13], based on the AHP-TOPSIS combination method, a system for efficiently evaluating the logistics of maritime transport was constructed with port efficiency, port throughput, the efficiency of sea vessels, and ocean port cooperation as the indicators, and it was applied to the analysis of five chosen ports in China. The obtained results show that the port of Shanghai has the greatest efficiency in maritime transport.

Also, the use of the Data Envelopment Analysis - DEA method can be found in the evaluation of the performance of different transport modes. This method was used alone or in combination with MCDM methods. Yu (2008) conducted a study of efficiency and effectiveness using the DEA method for a group of forty large railway systems (freight and passenger) in 2002 [14]. In the paper [15], the authors used the DEA method to evaluate and analyze the efficiency of European railway companies taking into consideration different input and output configurations. Although companies from Western Europe showed higher performance than those from Central and Eastern Europe in passenger and overall transport, but it was not the case in freight transport.

The aim of paper [16] is to create, select, and evaluate the criteria that influence the efficiency of railway companies, increase their competitiveness and propose an approach based on DEA to assess the efficiency of railway companies. In order to solve the problem of criteria selection, the Fuzzy Analytical Hierarchical Processes - FAHP method was investigated, which demonstrated the priority of evaluating the railway companies' efficiency, with five groups of criteria. Criteria in a group that surpassed relative to other criteria for their freight railway companies within the adequate range were used as input and output indicators. The estimation of the efficiency of railway companies was investigated by using the DEA method. The obtained results show that the proposed method successfully enables the merging of a set of criteria (resource, safety, financial, quality, and operational) into a single estimation of the efficiency of railway companies until providing information on correctional measures that can improve the efficiency of railway companies.

In the paper [17], the authors presented a case study that examines different freight transport modes by a Turkish logistics service company. In practice, numerous conflicting qualitative and quantitative criteria can be used to evaluate alternative transport modes. Therefore, to solve the problem of ambiguity and uncertainty, ANP method in fuzzy environment was used. In essence, it is a basic form of the Analytic Hierarchy Process approach [18]. Many numbers of criteria that interconnect with each other are assessed and synthesized to select the most suitable transport mode. This assessment was conducted by a group of decision-makers (DM) coming from various levels of management in the logistics area and from the service company to ensure a reasonable solution. Moreover, the used model is confirmed by comparing the obtained results with the actual settings of the company.

Also, the urban railway transport system performance evaluation in the Chinese city of Chengdu for 34 months was performed using the Entropy - TOPSIS method [19]. The authors created a set of evaluation indicators with eight indicators and a total of forty-one sub-indicators. The operational data of forty-one sub-indicators were used as an 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 freight transport system of the Republic of Serbia in 2021.

3. MCDM METHODOLOGY AND INPUT DATA

Multi-Criteria Decision Making (MCDM) is a subfield of Operational Research that was developed as a mathematical tool from both research and a practical perspective [20, 21]. MCDM methodology considers situations in which the DM must select only one alternative from a set of available alternatives that are evaluated based to more criteria. In order to make a good decision, it is necessary to define alternatives by forming appropriate criteria. As well, it is required to define the weight coefficients for every criterion, that is, the significance of every each in relation to the others criterion. Additionally, for each criterion, it is determined and defined whether it is necessary to select an alternative so that the criterion is minimal or maximal, i.e., what is the nature of each criterion. After that, toward to each criterion, the alternatives are valued and evaluated separately based on precisely determined parameters or subjective assessment. Characteristic way of presenting a MCDM problem is in matrix form. Criteria are often defined as quantitative measures that can be used "to simply illustrate and communicate complex phenomena, including trends and progress over time." Collected data can be suitable for analysis by those involved in decision-making and thereby contribute to better decision-making.

The Analytic Hierarchy Process method has been significantly used to untangle hierarchical decision-making problems in technical-technological areas. The theoretical basis of the AHP method is based on the following axioms [22]:

1. Axiom of reciprocity (if element X is n times more important than element Y, then Y is 1/n times more important than element X).
2. Axiom of homogeneity (a comparison only makes sense if the elements of sets are comparable, that is, element X can't be infinitely more significant than element Y).

3. Axiom of dependency (a hierarchy is formed, and a comparison is made between elements of one level of the hierarchy in relation to one element located at a higher level of the hierarchy. Lower-level comparisons do not affect an element of a higher-level).

4. Axiom of expectations (all elements of the hierarchy must be included in consideration and any change in the structure of the hierarchy requires a recalculation of the priorities in the new hierarchy. This practically means that the AHP method is sensitive to a subsequent change in the structure of the hierarchy).

Axioms 1 and 2 talk about evaluating pairs of hierarchy elements and assigning preferences, while axioms 3 and 4 describe formulating and solving problems as a hierarchy [22].

The AHP method is an effective tool that enables the complicated problem of MCDM to be created as a hierarchical decision-making structure. In addition, complex decision-making is simplified through a series of pairwise comparisons of hierarchy elements. After that, the results are synthesized and the significance coefficients of all elements of the hierarchy are determined. AHP also includes a technique and methodology for checking the consistency of decision-makers' ratings, which reduces affinity in the decision-making process. Method considers the set of evaluation criteria, and the set of alternatives from which to choose the best. Then AHP generates significance for each criterion, accordingly for a criterion pairwise comparison by the DM. What is higher the significance, the criterion is more important. Then, for each criterion, AHP assigns importance to each alternative, also based on pairwise comparisons by the decision maker. What is higher the significance, the alternative is better compared to the adopted criterion. At the end, AHP method represents combinations the importance of alternatives and criteria, and thus determines a global outcome for each alternative, as well as their ranking [10, 23].

Long-term research has formulated several criteria that are significant for evaluating the operational performance of freight transport modes. In this way, the operational goals are directly connected with the performance indicators of transport processes, and indirectly with the strategic goals of organizations. Figure 1 shows the algorithm for evaluating the operational performance of freight transport modes using the AHP method. The fact is that in practice there is no unique model that fits every situation.

![Algorithm for evaluating the operational performance of freight transport modes using the AHP method](image)

In the conducted analysis for evaluating the operational performance of freight transport modes, the available data collected by statistical reports of transport companies consolidated in the Statistical Yearbook of the Republic of Serbia were used [24]. The data for goods transport by inland waterways and air transport refers to transport realized by transport organizations registered for transport activities, whether the transport was carried out within or outside of the Republic of Serbia. Operations and activity in railway transport, displayed in passenger kilometres and ton kilometres, refer to transport carried out within the territory or outside the borders of the Republic of Serbia. Domestic inland waterway freight transport includes the total transport activity at river ports.

Quantity matrix with transport modes as alternatives and indicators with sub-indicators as criteria are given in Table 1. The freight transport modes taken into consideration are V₁ - Rail, V₂ - Road, V₃ - Water (Inland Waterways), and V₄ - Air transport. It includes 4 indicators, of which one indicator is based on two sub-indicators, which are used to evaluate the freight transport system performance of the Republic of Serbia in 2021. The following indicators were used: K₁ - Carrying capacity of transport (Ton of carrying capacity, thous. t), K₂ - Number of employees in transport, K₅ - Consumption of fuel in transport (Liquid fuels, thousand tons) and K₆ - Basic indicators of transport. K₅¹ - Achieved tkm (million) and K₆² - Goods carried (thousand tons) were used as sub-indicators of the basic indicators.
4. THE APPROACH AND RESULTS DISCUSSION FOR CASE STUDY: THE SERBIAN FREIGHT TRANSPORT MODES

Economic globalization and the emergence of new consumption behaviors have led to the increase in volume of goods transported and the distance traveled. Measuring and analysis the performance of freight transport modes unavoidably becomes a precondition for their existence on the market in today’s dynamic and very highly turbulent ambience. Carriers must bring and find optimal decisions and solutions for the purpose of efficient and effective business, overlive in the transport market, as well as to improve their competitive advantages.

To evaluate the operational performance of freight transport modes using the AHP method, a matrix of relevant importance criteria was formed (Table 2). By comparing the criteria according to Satie’s scale [23], on the basis the literature and the author’s experience, the members of the normed criteria importance matrix were determined.

The relative importance matrix of the criteria shows that the indicator K1 - Carrying capacity of transport is more dominant compared to the indicator K2 - Number of employees in transport, while in the case of indicators K3 - Consumption of fuel in transport and K4 - Basic indicators of transport (Achieved tkm and Goods carried) it has less importance. Indicator K2 has also less dominance in relation to indicator K1 and sub-indicators K41 and K42. Indicator K4 is more dominant in relation to sub-indicator K41, while in relation to subindicator K42, it has the same importance. Sub-indicator K41 has the same importance in relation to sub-indicator K42.

As there are several different criteria, which do not have the same importance, weighting coefficients were determined, based on which their relative importance w_k is obtained (Table 3). The weighting coefficients should show the importance of the participation of certain criteria in making a decision on the ranking of alternatives, i.e. transport modes.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Fact. of importance of the variants of transp. modes</th>
<th>Indicator of variants of types of transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>w_k</td>
<td>u_k</td>
</tr>
<tr>
<td>K2</td>
<td>0.09</td>
<td>0.249</td>
</tr>
<tr>
<td>K3</td>
<td>0.05</td>
<td>0.096</td>
</tr>
<tr>
<td>K4</td>
<td>0.31</td>
<td>0.578</td>
</tr>
<tr>
<td>K41</td>
<td>0.55</td>
<td>0.26</td>
</tr>
<tr>
<td>K42</td>
<td>0.29</td>
<td>0.529</td>
</tr>
</tbody>
</table>

The conducted analysis (Table 3) shows that indicator K4 - Basic indicators of transport have the greatest influence in the evaluation system (w_k=0.55), while K1 - Achieved tkm have less importance (w_k=0.26) compared to K42 - Goods.
carried \((w_{K_4}=0.29)\). Indicators \(K_1\) - Carrying capacity of transport and \(K_2\) - Number of employees in transport have the lowest values of weight coefficients, respectively \((w_{K_1}=0.09)\) and \((w_{K_2}=0.05)\) and show that they have the least impact on the evaluation process of operational performance.

Further analysis leads to the significance factor of the variants of the transport modes \(w_{K_1} \cdot w_{K_2}\) (Table 3) by comparing each indicator with each variant of the transport modes. Indicators of variants of transport modes according to each indicator (sub-indicator) are determined by the equation:

\[
U_{1\alpha} = w_{K_1} \cdot w_{K_2}
\]  

(1)

Based on the indicators of the variants of transport modes according to each indicator, the total indicators for each transport mode were determined:

\[
U_{1\alpha} = \sum_{k} u_{k \alpha} \ \forall k = V_1, V_2, V_3, V_4
\]

(2)

Based on the ranking performed by the AHP method (Table 3), based on the adopted indicators for freight transport in the Republic of Serbia in 2021, it can be concluded that the best business results were achieved by railway freight transport \((u_{K_4}=0.3544)\), road transport \((u_{K_2}=0.3295)\) in second place, followed by inland waterway transport \((u_{K_2}=0.2403)\), while air freight transport recorded the worst scenario \((u_{K_4}=0.0756)\).

The trend of railway development both in developed countries and in the Republic of Serbia is moving towards its modernization, improving capacity, and increasing the throughput capacity of railways, generally by improving exploitation and transport organization. In addition to the uneven development of railways in individual regions and countries, another characteristic of the development of railway transport is the unevenness in the development of transport capacities. It is reflected in the better equipment of the railways, more developed rolling stock, greater capacity, etc. Today, the railways have lost much of their power and left the role of the main transporter to road transport. Air freight transport is irreplaceable on long distances, while on medium distances its comparative advantage is threatened by rail and road transport.

5. CONCLUSIONS

The latest trends in performance management imply an orientation towards results, which means not only managing effective behavior but also achieving high results. Transport is essential to our economy and society. New transport models must appear, by which larger cargo quantities are transported to their destination by the most efficient transport mode. It is preferable to use individual transport for final destinations. In order to successfully respond to the very clear requirements of the modern business environment, transport organizations must clearly define their determination in the direction of increasing the efficiency of functioning, i.e. accepting the logic of the market, applying modern management methods and constantly measuring the level of development achieved, which is the essence of the philosophy that leads the organization to success, that is, long-term sustainable business.

In the paper, a multi-criteria analysis using the AHP method was carried out in order to evaluate the operational performance of freight transport modes in the Republic of Serbia in 2021. The alternatives were: Rail, Road, Water (Inland waterways), and Air transport, while the Carrying capacity of transport, Number of employees in transport, Consumption of fuel in transport as well as Basic indicators of transport - Achieved tkm and Goods carried were used as criteria or indicators. The best and worst operational performances were achieved respectively by Rail and Air freight transport.

The future development of freight transport must be based on:

- Energy efficiency improvement of vehicle performance in all modes of transport. Development and application of renewable energy sources and propulsion systems.
- Optimizing the multimodal transport performance, which implies greater use of essentially more efficient transport modes, where other technological innovations may fall short.
- The more efficient transport and infrastructure use in application for the improved management of transport and modern information systems, progressive transport, logistics and market measures such as the full development and modernization of the integrated European railway market, the abolition of cabotage restrictions, the removal of barriers for short sea deliveries, undistorted prices, etc.

From everything mentioned so far, it can be deduced that the transport services market related to freight transport is extremely developed and that there is strong competition in certain transport modes. Freight shipments at short and medium distances (under some 300 km) will mostly stay on the trucks. Therefore, it is important, in addition to encouraging an alternative transport solution (rail, water transport), to improve the efficiency of trucks, using intelligent and modern transport systems and extra measures to advancement market mechanisms.
The framework of future research would be reflected in the MCDM approach to assessing the performance of other systems using compatible evaluation indicators.

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