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Evaluating the Annual Operational Efficiency of Passenger and Freight Road Transport in Serbia Through Entropy and TOPSIS Methods

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Abstract: Road transport emerges as a crucial segment of the transportation system, demanding comprehensive analyses of operational performance across passenger and freight domains. This investigation delineates a meticulous multi-criteria analysis of Serbian passenger and freight road transport, relying on data extracted from the Annual Statistical Reports promulgated by the Statistical Office of the Republic of Serbia during 2015-2021. Initially, a compendium of eight pertinent criteria, namely carrying capacity, total number of passenger and tonne-kilometres, employee count, generating power, fuel consumption, and foreign currency receipts, is identified, with a subsequent emphasis placed on six criteria necessitating multi-criteria analysis, applicable cohesively to both passenger and freight transport sectors. Weighting coefficients for each criterion are calculated employing the entropy method, while a multi-criteria ranking of the operational performance of road transport is devised through the application of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The quintessence of this research lies in the execution of a novel multi-criteria analysis with an aspiration to architect a hierarchy regarding the operational performance within the scrutinised timeframe of road transport in Serbia.

Keywords: Road transport; Operational performance; Entropy method; TOPSIS method

1 Introduction

Alterations within a nation's economic and production landscapes invariably reverberate through all facets of its development, delineating the pivotal role of adaptability and responsiveness in safeguarding against stagnation or impediments to economic growth. This principle is explicitly manifested in the fluctuations and developmental trajectories experienced by various modes of transport globally and particularly within the Republic of Serbia. Despite the advantageous geographical positioning of the Republic of Serbia as a transit nation, road transport has not only cemented its indispensability but also perpetuated a significant impact upon the continuous ascension of economic development. Current consumers of road transport services harbour expectations encompassing enhanced service quality, diminished traffic obstructions and congestions, and reduced delays at border crossings, among others. Nonetheless, it must be acknowledged that the evolution of road transport perpetuates deleterious consequences, notably impacting road safety, environmental integrity, and public health [1].

An analysis reveals that road transport within the Republic of Serbia encapsulates a dynamic and predominant modality, exhibiting a robust presence with road transport entities transitioning from social ownership to privatization. A staggering 80% and 74% of total freight and passenger transport volumes, respectively, are facilitated through road transport [2]. The infrastructure underpinning road traffic and transport is composed of elemental components, inclusive of varied road categories and types, construction facilities affiliated with roads (encompassing overpasses, underpasses, bridges, and tunnels), signalling (both vertical and horizontal), toll booths, parking facilities, and additional amenities and apparatuses enabling more facile vehicle navigation across the road network. Roads, as public assets under state ownership, are devised with traffic surfaces that are availed to all or specified traffic participants in a legislatively regulated manner. The road network within the Republic of Serbia spans approximately 40,485 km, with road categorization conducted by authoritative state entities yielding 5,434 km of first-class roads, 10,979 km of second-class roads, and 1,155 km of highways [3].

The demarcation of passenger and freight road transport vehicles is potentially executed based upon a plethora of administrative and normative factors, encompassing laws, regulations, standards, etc. Such segregations, considering variables such as vehicle purpose, exploitation conditions, record-keeping, and vehicular construction, are inherently complex [4]. Concurrently, the Republic of Serbia, amidst its journey towards European Union (EU) integration, is compelled to reconcile its legislations with those instituted within the EU. Consequently, regulations and additional documents (laws) proffer vehicular and trailer divisions, applicable technical conditions, and regulations and laws pertaining to traffic safety, among others [5].

Organisation within road transport can be bifurcated into two pivotal aspects: the structuration of the company and its operational and developmental organisation. The former encapsulates the methodology of structuring enterprises for the conveyance of passengers and cargo, facilitated through the establishment and operation of business units. The latter emphasises customer service and the judicious utilisation of transport means. The paramount factors influencing the organisation of road transport include human and material resources, with technical means for conducting transport constituting the latter. A successful road transport organisation is epitomised by its ability to utilise these foundational factors in service of maximising transported passengers and cargo while minimising the expenditure of labour, resources, and time—thereby achieving maximisation of outcomes through cost minimisation.

Road transport organisations establish relationships between assets and work, ensuring transport services are as rational, economical, and secure as feasible. This encompasses its own distinctive techniques and technologies, where "techniques" refer to its means, and "technologies" pertain to expertise and knowledge in delivering transport services [6].

Given that the primary activity of road transport is the conveyance of goods and passengers, specialised road-transport companies are formed, each registered to execute this mode of transport as a core activity. A notable observation is that road-transport companies' schematics for transporting passengers and cargo remain almost identical, albeit with distinctions in the exploitation service for freight transport, which can be segmented into local, internal, and international transport [6].

Separation of passenger and cargo transport into distinct enterprises is correlated with a diminution in operational costs, culminating in an augmentation in revenue. Significantly, a company's operations are profoundly influenced by the vehicular workload intensity, which precipitates augmented transport work, thereby fostering enhanced income management and cost regulation.

A road-transport company is conceptualised as an organised system of personnel, transport means, load-handling machinery, and vehicle maintenance and accommodation space, all contrived for the execution of transport work. The overarching objective of such a company is the relocation of passengers or goods from one locale to another. Within this system, the passenger or goods represent the subject, the driver is the transport worker, and the vehicle functions as the working means.

The exploitation and technical characteristics of road transport present marked disparities when juxtaposed with other modes of transport, such as rail or water transport, especially in realms such as movement resistance or the connection of rolling units. Fundamental operational and technical features include the mutual independence of rolling units and elevated frictional resistances.

As economies, industries, living standards, and consequently, travel motivations develop, the demands for dispersive transport augment their proportion in total transport, catalysing the expedited development of road transport. This is optimally exemplified through data pertaining to the number of registered road motor vehicles. Given the substantial growth tendency of dispersive transport, particularly in passenger conveyance, road transport harbours a promising future.

Despite its applicability for concentrated transport, road transport also finds utilisation for such purposes because its modern distribution work in total transport enables effortless adaptation of its capacities, organisation, and technologies to contemporary demands.

Evaluation of operational performance, when perceived from a national perspective, is vital as it forms the foundation for state subsidies and proffers pivotal data to the state regarding enhancements in road transport performance. From an operator's perspective, evaluation is discerned as a measure of their efficiency, i.e., the degree to which they attain their established objectives and the efficacy of the methodologies employed towards their attainment. From the viewpoint of passengers, road transport performance evaluation is perceived in terms of time conservation, fulfilment of travel necessities, and service quality.

In the ensuing section, which will delve into a review of literature concerning the implementation of approaches and methodologies for assessing railway performance, a broad spectrum of criteria, which may be scrutinised concerning the efficiency of road transport as a system, will be explored. Consequently, a general procedure utilising a multicriteria approach will be articulated in the third section to define input data sets, presented in the form of criteria for passenger and freight road transport. The fourth section will elucidate the results derived from the entropy method, employed for weight calculation, and the TOPSIS method, utilised for ranking the operational performance of road transport in the Republic of Serbia for the period spanning 2015 to 2021, predicated on valid statistics for the

Republic of Serbia's road transport system. The culmination of the paper will present the primary conclusions and proffer an overview of impending research tasks.

2 Literature Review

Various methodologies and techniques have been applied in diverse analytical processes within transportation research, leveraging multi-criteria decision-making (MCDM) methods due to their proficiency in navigating decisions amidst multiple, often conflicting criteria [7–12]. Throughout an extensive database exploration, numerous studies have been identified, employing a myriad of MCDM techniques such as Analytic Network Process (ANP), VIKOR (Multi-Criteria Optimization Compromise Solution), Analytic Hierarchy Process (AHP), Decision Making Trial and Evaluation Laboratory (DEMATEL), TOPSIS, and Simple Additive Weighting (SAW), among others. The application of these methods spans numerous areas, with several studies demonstrating the combined utility of different MCDM methods.

In a study by Fierek and Zak [13], MCDM methods were utilized to elucidate the planning processes of an integrated urban transport system for a medium-sized city area, demonstrating that the proposed approach possessed a universal character. The application was observed to be potentially beneficial for urban planners, traffic engineers, and municipal authorities in strategic planning within urban transport systems and devising advanced transport solutions. Another research endeavour, documented in Mavi et al. [14], applied Step-wise Weight Assessment Ratio Analysis (SWARA) and COmplex PRoportional Assessment (COPRAS) methods to articulate the suitability of the bus rapid transit system for extended distances, evaluating the performance of potential alternatives to enhance transportation performance, with an underlying objective to satisfy user needs.

A study conducted by Petrović et al. [15] deployed Multiple Criteria Decision-Making techniques to scrutinise the operational performance of freight and passenger rail systems. In this context, an evaluation indicator system was developed, utilizing official data and incorporating five primary indicators alongside 18 sub-indicators for both freight and passenger transport. This operational data served as input for the MCDM approach, utilizing the entropy weight method to calculate the weight of each sub-indicator, while employing the TOPSIS method to calculate comprehensive evaluation values and rankings of performance annually. The Serbian railway was selected for a case study, applying seven years of data to validate the MCDM approach and to proffer related recommendations for both freight and passenger rail transport.

The focal point of research presented in Wang et al. [16] lay in the evaluation and comparison of the sustainable development of existing road transportation systems to discern the potential for effective development within the Organization for Economic Cooperation and Development (OECD) countries. An integrated entropy–CoCoSo approach was introduced for evaluating the sustainability of road transportation systems, and a framework process was proposed. Herein, the entropy method determined the weight of the decision criteria based on real data, providing a means to minimise the subjective impact of decision-makers and bolster objectivity. The CoCoSo method was then applied to rank the road transportation sustainability performance of OECD countries.

Lastly, a framework for a cross-country comparative assessment of transport sustainability within central and eastern European countries was developed in Bojković et al. [17]. This study aimed to evaluate the relative positioning of national transportation systems according to sustainability criteria, employing an AHP to evaluate current status and trends in transport performance. Resultantly, countries were positioned in a static-dynamic space in relation to sustainability sub-themes. The method's significance was underscored by its capability to monitor and analyze the functionality of transport systems concerning sustainability, thereby enhancing the awareness of policy-makers regarding these critical issues.

3 MCDM Methodology and Input Data

A diversity of business dilemmas in contemporary society necessitates decisions in problem-solving that transcend reliance on a singular criterion. Decision-making based on a lone criterion diminishes the veracity of the analysed issue. Consequently, the employment of MCDM emerges as requisite when an array of conflicting criteria is present [18]. Despite its numerous applications and substantial development both in research and practice over recent decades, a notable limitation of the multi-criteria approach is the incorporation of complex mathematical formulations for resolving multi-criteria issues. MCDM, a subset of operational research, converges with various natural and social sciences, situating itself within decision-making theory, particularly in contexts where the decision-maker selects an alternative from a set and assesses them based on chosen criteria. Before the advent of multi-criteria analysis, the problems of selection and ranking decisions were simplified to optimizing a singular criterion.

The predominant sources of data for evaluation are typically derived from statistical data and corporate annual reports. However, a key issue that has surfaced in recent years is the data availability from privatized and compartmentalized companies within the road transport sector. The reluctance of numerous operators from privatized sectors to disclose specific business details further compounds this issue. The presence of a substantial number of entities crucial to road transport not only complicates the task of data collection for evaluation but should ideally enhance the quality and breadth of the assessment, despite the considerable volume of available data. The evaluation phase also encounters certain predicaments, chiefly pertaining to assorted legal and security requisites, governmental influence on commerce, measurement inaccuracies, data time series, varied treatments of added value, and subcontractor activities.

For judicious decision-making, it is imperative to delineate the alternatives by defining pertinent criteria. Subsequent to this, their weight coefficients (i.e., the significance of each criterion relative to others) are established, followed by the determination of the nature of said criteria, and a selection is made regarding whether the criterion should be maximal or minimal. Each alternative is then independently evaluated according to each criterion, based on meticulously identified parameters or subjective assessments.

Table 1. Indicators and sub-indicators of road transport

Indicator	Sub-Indicator	Specification of Each Sub-Indicator	Unit of Each Sub-Indicator
Carrying capacity of road transport	f_1	Passenger capacity	thous.
	f_2	Ton of carrying capacity	thous. t
Basic indicators of road transport	f_3	Passenger-kilometers	mill.
	f_4	Ton-kilometers	mill.
Employees in road transport	f_5	-	number
Generating power of road transport	f_6	Internal-combustion engines	kW, thous.
Consumption of fuel in road transport	f_7	Liquid fuels	thous. t
Foreign currency receipts from road transport	f_8	-	USD, thous.

Note: Alternatives symbolise the years under observation, while the criteria denote the operational performance of road passenger (Table 2) and freight (Table 3) transport within the Republic of Serbia.

Table 2. The initial matrix utilized for determining the performances of passenger road transport: f_1, f_3, f_5, f_6, f_7 and f_8

	f_1	f_3	f_5	f_6	f_7	f_8
2015	119	4601	14671	1230	138	625411
2016	120	4282	16266	1458	154	436584
2017	130	4255	16307	1468	161	312357
2018	139	4950	20648	1954	196	284323
2019	138	4662	21296	2225	214	288155
2020	180	3086	23707	3664	255	301754
2021	164	3586	23679	3771	264	575406

Table 3. The initial matrix utilized for determining the performances of freight road transport: f_2, f_4, f_5, f_6, f_7 and f_8

	f_2	f_4	f_5	f_6	f_7	f_8
2015	110	2973	14671	1230	138	625411
2016	120	4299	16266	1458	154	436584
2017	133	4980	16307	1468	161	312357
2018	167	6443	20648	1954	196	284323
2019	189	8175	21296	2225	214	288155
2020	252	7741	23707	3664	255	301754
2021	248	10108	23679	3771	264	575406

Within multi-criteria analysis models, the determination of the criteria's weights emerges as a problematic element, further complicating decision-making in a specific context. The weight of the criteria markedly influences the outcome of the decision-making process; therefore, the objectivity of the criteria's weight warrants considerable attention. It may be concluded that the true import of the criteria is vitally significant when deciding upon the method to be implemented in a given scenario.

An examination of existing literature yields the observation that no universal division of methods for determining weight coefficients is present; rather, such divisions are seemingly contingent upon the author's understanding and specific problem-solving needs. Notably, the most prevalent bifurcation of methods for determining weight coefficients has been discerned to fall into two principal categories: subjective and objective methods [19]. While subjective methods preserve the intuition and subjective opinions of decision-makers or experts, thereby directly influencing the results of the decision-making process, their objective counterparts, conversely, eschew the perspectives of decision-makers or experts. Instead, objective methods necessitate determining the information encapsulated within the decision-making matrix through the utilisation of specific mathematical models.

In the context of conducting operational performance analysis in the road passenger and freight transport sectors of the Republic of Serbia during the period spanning 2015 to 2021, input data—or criteria—were gleaned from data collated through regular monthly, quarterly, and annual statistical reports, as depicted in Table 1, Table 2 and Table 3 [2]. Said data are articulated in the form of indicators (criteria), including carrying capacity, total passenger and tonne-kilometres achieved, employee numbers, generating power, fuel consumption, and foreign currency receipts.

Weight coefficients, values that can be acquired through various methods such as the eigenvector method, least squares weight method, or entropy method, embody significant elements within this analysis. The entropy method, introduced by Claude Shannon (1984), is deployed for determining the weighting coefficients of MCDM. Its application encompasses the normalization of the values of alternatives per criterion, the calculation of the entropy of all alternatives in terms of the criteria, determining the degree of divergence of each criterion's average internal information, and acquiring the final relative weights of the criteria through additive normalization [19].

Objective weights of the criteria, as per the entropy method, are predicated on the measurement of the uncertainty of the information contained within the decision matrix, thereby directly generating a set of weight values for the criteria based on the mutual contrast of the individual criterion values of the alternatives for each criterion and subsequently for all criteria.

The TOPSIS method, inaugurated by Hwang and Yoon (1981), predicates itself upon the conceptualization that the optimal alternative should be proximally Euclidean to the ideal solution (positive ideal solution – PIS) and simultaneously distant from the anti-ideal solution (negative ideal solution – NIS). This compensatory aggregation method, which necessitates the identification of weights for each criterion [20], facilitates the comparison of a set of alternatives by constructing a decision matrix, normalizing and weighting it, identifying the positive and NISs, calculating the distance from the ideal and anti-ideal solutions for each alternative utilizing the two Euclidean distances, and computing the relative closeness of every alternative to the PIS, wherein higher values suggest superior ranking.

Following the formulation of the initial matrix (Table 2 and Table 3), the entropy method will be employed for determining weighting factors, and the TOPSIS method will be utilized for ranking the observed years.

4 Approach Deployment and Discussion of Resultant Findings

It is imperative to note that solutions derived from MCDM methods are not axiomatically optimal or the sole viable resolution. Instead, the methodology serves to elucidate the problem at hand, thereby enabling decision-makers to formulate a high-quality and feasible solution. Such a methodological protocol cultivates the requisite consensus by circumventing superfluous conflicts amongst the perspectives of decision-makers, the public, and various interest groups.

Alternatives, embodied by observational years, and relevant criteria for ranking are encapsulated within the initial matrix. The objective, defined contingent on the impact of the observed criterion, focuses on the operational performance of road transport in the Republic of Serbia. Through the assimilation of the decision-making matrix for freight (Table 2) and passenger road transport (Table 3), the deployment of the entropy method is facilitated.

Evaluation of operational performance in Serbian road transport for both passenger and freight segments was executed utilizing the entropy method to determine weight coefficients, based upon the accepted indicators (Table 4 and Table 5).

The computational results of the weighting coefficients indicate that generating power of road transport, represented by 0.4329 and 0.2988 for passenger and freight road transport respectively, emerges as the paramount indicator (sub-indicator) within the evaluation system (Figure 1). Conversely, passenger capacity (0.0522) and passenger-kilometres (0.0522) possess the most diminutive weighting coefficient for passenger road transport, indicating that these indicators hold minimal significance in the process of operational performance evaluation.

When utilizing the TOPSIS method to rank based on the adopted indicators for passenger and freight road transport within the 2015-2021 timeframe, it is discernible that the zenith of operational performances was attained in 2021, whilst 2017 witnessed the most suboptimal scenario (Table 4 and Table 5). Consequently, it may be inferred that the situation within road transport, encompassing both passenger and freight domains, has experienced a yearly enhancement since 2017 (Figure 2).

Positioned as one of Europe's intermediately developed countries with respect to road transport development, the Republic of Serbia necessitates the enactment of specific measures to foster its further advancement. Such measures encompass the construction of designated corridors and bypasses within the framework of highways and primary roads, all designed to elevate the quality and safety of traffic flow. Additional imperative actions include roadway restoration, rehabilitation of existing structures, and modernisation of local roads through the construction of contemporary roadways, ultimately aiming to render them suitable for motor traffic. This is aimed at enhancing road quality within the Republic of Serbia, ensuring a satisfactory service provision level and fulfilling service user needs.

Table 4. Weighting coefficients and operational performance ranking of passenger road transport: f_1, f_3, f_5, f_6, f_7 and f_8

Orientation Weight Coefficient	f_1 Max 0.0522	f_3 Max 0.0522	f_5 Min 0.0769	f_6 Max 0.4329	f_7 Min 0.1305	f_8 Max 0.2552	Ranking
2015	119	4601	14671	1230	138	625411	**4**
2016	120	4282	16266	1458	154	436584	**6**
2017	130	4255	16307	1468	161	312357	**7**
2018	139	4950	20648	1954	196	284323	**5**
2019	138	4662	21296	2225	214	288155	**3**
2020	180	3086	23707	3664	255	301754	**2**
2021	164	3586	23679	3771	264	575406	**1**

Table 5. Weighting coefficients and operational performance ranking of freight road transport: f_2, f_4, f_5, f_6, f_7 and f_8

Orientation Weight Coefficient	f_2 Max 0.1595	f_4 Max 0.2224	f_5 Min 0.0531	f_6 Max 0.2988	f_7 Min 0.0900	f_8 Max 0.1762	Ranking
2015	110	2973	14671	1230	138	625411	**5**
2016	120	4299	16266	1458	154	436584	**6**
2017	133	4980	16307	1468	161	312357	**7**
2018	167	6443	20648	1954	196	284323	**4**
2019	189	8175	21296	2225	214	288155	**3**
2020	252	7741	23707	3664	255	301754	**2**
2021	248	10108	23679	3771	264	575406	**1**

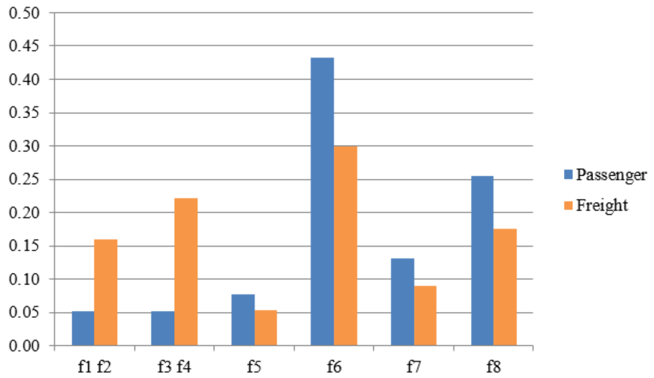

Figure 1. Graphical depiction of the computed weighting coefficients
Note: This figure was prepared by the authors.

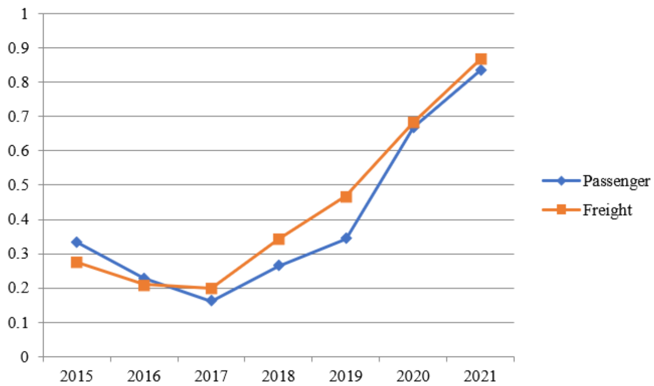

Figure 2. Ascending operational performance of road passenger and freight transport
Note: This figure was prepared by the authors.

5 Conclusions

The reflection of societal prosperity is invariably observed through the lens of its economic development and the quality of living standards. Inextricably interwoven with every facet of economic and social activity resides the indispensable requirement for proficiently organised transport, a necessity predicated upon its reliability. While initially emerging as an adjunct to trade activities, transport has evolved into an influential and vital sector within a country's economy, entwining intricately with technological advances and necessitating the employment of proficient personnel across diverse profiles.

Generally, transport, and specifically road transport, serves the fundamental purpose of facilitating the translocation of activities beyond local spheres, enabling expedited and simplified interactions amongst individuals and business systems and enhancing place accessibility. Such facilitation engenders the dilution of interstate borders and constraints, globalising transport and its flows, as the world amalgamates into a unified market.

Acknowledging the evolutionary journey of transport science, predicated upon experiential solutions, contemporary transport science is heavily anchored in knowledge derived from social, natural, and technical scientific domains. This underscores the notion that the modern transport system encapsulates not only technical and technological elements, such as infrastructure and vehicles, but is also firmly rooted in institutional and human resources.

Road transport, renowned for its flexibility, seamlessly accommodates varying transport demands and, while aptly suitable for the dispersive transport of cargo and passengers—specifically, the transport of smaller cargo and passenger quantities across divergent routes and times—encounters substantial competition from railway transport, particularly during long-distance transit involving substantial goods quantities.

Road transport is not confined merely to its network of roads but extends to encompass road transport companies, their vehicular fleets, and employees. It is imperative to interpret companies engaged in the road transport of goods and passengers as a municipal system, due to their significant impact upon the economy and citizenry.

In light of the substantial geographical advantage possessed by the Republic of Serbia in comparison to several other European Union countries, the development and application of strategies aimed at the enhancement of road transport becomes paramount, all whilst aligning with the transport policy of the European Union, and adhering to its needs and global transport development trends. This strategic development is anticipated to influence the organizational structures and modern operational practices of road transport companies. Transformations within these companies, dictated by scientific and technological advancements, particularly within the realms of information and communication technologies, necessitate the incorporation of modern management practices and the development of organizational company culture, culminating in company development, enhanced operations, and prudent resource utilisation.

An analysis of the operational performance of passenger and freight road transport within the Republic of Serbia, employing the multi-criteria ranking method, is presented herein. Eight criteria in total were utilised, with individual criteria for passenger and cargo equating to six, forming the basis upon which the initial input matrices were constructed. The significance of each criterion was computed using the entropy method, and annual ranking or evaluation of road transport performance was conducted utilising the TOPSIS method. Rankings, computed for the time period spanning 2015 to 2021, revealed peak performance in 2021, while 2017 was identified as the year of least optimal operational performance.

The deployment of multi-criteria methods furnishes a pivotal framework for burgeoning research, not solely for the evaluation of performance across other transport systems employing their compatible assessment indicators but also for addressing an abundance of issues and tasks across all societal domains.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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