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Research Article

Multi-criteria Decision-Making Approach for choising e-Bus for Urban Public Transport in the City of Niš

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Abstract: Public urban passenger transport is a large consumer of fossil fuels, which contributes to the emission of harmful gases. Although alternative fuels are more environmentally friendly, their widespread use is still challenging even for developed countries, partly due to their higher cost. There is also some resistance to introducing sustainable transport systems due to the perception that it could significantly change the style and quality of life. Today, the bus subsystem of public passenger transport is the most widely used public transport technology. Many European public transport systems rely heavily on buses powered by conventional fossil fuel, are integral to their local fleets in most EU states. For public urban transport to increase its participation in the modal distribution of trips in cities, public transport vehicles must comply with established European standards that define different limits of exhaust gas emissions. Public transportation of passengers by bus plays a significant role in the transport system of the City of Niš as an accessible and acceptable means of transportation. Buses that use electricity as propulsion (e-Bus) are considered the cleanest technologies, producing zero local emissions and having the greatest impact on increasing local air quality. In the paper, a multi-criteria ranking of six electric buses was performed based on four criteria, available on the market of the Republic of Serbia, using the MABAC and MOORA methods, while the Entropy method was used to calculate the weight coefficients, to select an adequate bus manufacturer for the needs of public passenger transportation in the City of Niš.

Keywords: e-Bus; City of Niš; MABAC; MOORA; Entropy

I. INTRODUCTION

The EU's commitments to reduce GHG emissions are translated into concrete goals at the individual level of each member state and for individual economic sectors [1]. The White Paper [2] of the European Commission sets goals related to the reduction of GHG emissions by 60% in 2050 compared to 1990. Since around 70% of GHG emissions caused by traffic come from road traffic, the White Paper sets a target of reducing emissions by around 60%. In addition to the above, the White Paper also states the following goals: to reduce the use of "conventional fuels" in city traffic by 50% by 2030; and complete replacement of "conventional fuels" in cities by 2050 [2].

Every year, for urban areas, air quality continues to be a priority to global warming, which primarily means reducing pollutant emissions [1, 3]. European cities will face new challenges in making economically and environmentally acceptable decisions [4] as urban mobility is predicted to increase by 100% [5] and the EU targets to increase the share of public transport, as well as complying with new CO_2 emission regulations for vehicles. Achieving these goals will not only require technology that makes motorized vehicles more energy efficient but also the transition to low (or even lower) carbon dioxide emission modes of transport, such as public urban passenger transport, and motivating city dwellers to use certain modes of transport, replaced by walking and cycling.

The Low-emission Mobility Strategy adopted by the European Commission identifies key levers in the field of transport, including EU-level measures to increase the participation of low-emission and zero-emission vehicles, as well as vehicles with low-emission alternative fuels [6].

For public urban transport to increase its participation in the modal distribution of trips in cities, it is necessary to implement the improvement and development of a better network of lines to satisfy the daily need for user mobility. This would mean that the use of public urban transport should be seen as a competitor to cars. Public urban transport should be more frequent, cheaper, more reliable, safer, and accessible to all users to become more popular and provide the same or even better mobility characteristics than other forms of transport. However, it is also necessary for public transport vehicles to comply with established European standards that define different limits of exhaust gas emissions from road vehicle engines. Today, the most widely used public transportation technology is the bus subsystem of public passenger transportation. Given that buses powered by conventional fossil (diesel) fuel are large emitters of pollutants, the introduction of "cleaner" buses into daily use can contribute to reducing exhaust gas emissions and improving air quality.

In City of Niš, traffic represents one of the primary and fastest growing activities of human activities that release harmful substances or pollutants as a result of burning fossil fuels, and road traffic is the most responsible for the increase in exhaust gas emissions. The city is facing problems imposed by the large increase in the number of individual vehicles, which require more traffic areas than the city can provide and worsen living conditions and quality of life. The general importance of bus traffic for the city of Nis and its use is primarily related to the issue of urban mobility [7]. The increase in the number of vehicles and the volume of traffic threatens the quality of the environment the most, i.e., exposure of the population to poor air quality and the negative impact of noise.

After the introductory part that emphasizes the importance and analysis of the public transport system with electric drive, the second part of the paper presents an extensive review of the literature on the application of approaches and methodologies for the use of multi-criteria decision-making techniques in public passenger transport. The third part describes the general procedure of using multi-criteria methods and defining input data that are presented as alternatives and criteria, which ultimately leads to the formation of a decision matrix. The selection of appropriate alternatives and criteria was made based on a review of foreign scientific and technical literature and the available market in the Republic of Serbia. In the fourth part, the process of applying Entropy for determining weight coefficients, as well as the use of MABAC and MOORA methods for ranking electric buses in the City of Niš, is explained. The paper will conclude with the main findings and an overview of future research objectives.

II. Related papers

Buses are a key component of public transport, providing a cost-effective and flexible service with benefits in terms of capacity and speed. However, rising car traffic and increasing CO_2 emissions in urban areas pose significant risks to city life. To address these issues, there is a growing need for improved public transportation systems that reduce traffic congestion and utilize cleaner technologies to enhance air quality. Electric buses (EBs) are considered a crucial solution for improving urban air quality and enhancing residents' quality of life.

Public bus operators worldwide, from Shenzhen to Philadelphia and Izmir to Delhi, are increasingly adopting electric buses [8]. Their decision is driven not only by environmental concerns, such as reducing noise pollution and supporting the green transition but also by the economic advantages that emerge when evaluating the entire life cycle cost. The paper emphasizes that integrating electric vehicles requires a comprehensive approach and has the potential to revolutionize operations. Transport companies could evolve into community service providers, occasionally offering balancing energy to power supply systems through Vehicle-to-Grid (V2G) technology or acting as virtual power plants in collaboration with solar power operators. Volánbusz Zrt. has started building a data-driven ecosystem to support this model, enabling cost-optimized operations using data from its growing electric bus fleet and Industry 4.0 technologies [8].

Decision-makers face difficulties in choosing the most suitable EB due to the wide range of available options fueled by technological advancements. Multi-criteria decision-making (MCDM) methods offer a structured approach to solving this problem. In this study [9], five electric buses are assessed using six criteria through two MCDM methods: the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Multi-Objective Optimization based on Ratio Analysis (MOORA). These methods help rank alternatives in complex decision-making situations. The study concludes that the E_5-Bus is the best option according to both methods, with results from MOORA and TOPSIS being closely aligned. Additionally, the MOORA method is highlighted as an effective tool for solving vehicle selection problems in transportation. The proposed model has been validated with real-world applications and can support decision-makers in selecting electric vehicles for sustainable transportation [9].

Electric buses, for example, produce zero tailpipe emissions, contributing to cleaner air and making them especially desirable in densely populated areas to enhance air quality and urban livability. The paper [10] proposes a multicriteria decision-making process using the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to evaluate electric bus options for central Ankara. Six electric bus alternatives were assessed based on seven specific criteria. Additionally, sensitivity analysis confirmed the robustness of these results across different scenarios [10].

The energy consumption patterns of conventional fuel-powered and electric vehicles differ due to their unique driving characteristics, a topic widely studied but often in less common geographical settings. The paper [11] fills that gap by analyzing driving data from both electric and diesel buses on the same routes in Hong Kong during regular daily operations. This allowed for a fair comparison of driving behaviors between the two bus types under identical real-world conditions, highlighting the novelty and contribution of this research. The results showed that route-specific comparisons revealed significant differences in driving patterns between electric and diesel buses, which may have been overlooked in mixed-route analyses. These differences were more pronounced in terms of range, intensity, and direction when analyzed on a route-by-route basis, affecting energy consumption. The study suggests that government agencies and bus operators should consider these findings when planning the deployment of electric buses [11].

The paper [12] focuses on the Republic of Serbia, where EVs account for only a small fraction of registered vehicles (0.007%). It also analyzes the attitudes and preferences of the Serbian population regarding EVs through a survey, identifying the key reasons for purchasing EVs and the main obstacles to adoption. The study provides useful insights for policymakers in similar markets on how to boost EV adoption and helps manufacturers understand which features are most attractive to potential buyers in these regions [12].

In the pursuit of sustainable urban development, implementing cleaner propulsion systems in public transportation is essential for reducing urban pollution and emissions. The study [7] examines the City of Niš, where traditional buses significantly contribute to environmental degradation. The necessity for alternative propulsion systems is clear, but the transition presents various challenges and uncertainties. To navigate this complexity, the research employs the CRiteria Importance Through Intercriteria Correlation (CRITIC) method to establish weight coefficients and the Evaluation based on Distance from Average Solution (EDAS) method to determine optimal propulsion systems. These methodologies enable a comprehensive evaluation of options, including buses, electric trolleybuses, and trams, for both urban and suburban transport. The study offers a systematic analysis of each alternative based on established criteria, aiding in the identification of the most effective propulsion systems. This approach not only facilitates informed decision-making aligned with sustainability objectives but also significantly mitigates the environmental impact of urban transportation. The findings provide a foundational framework for decision-makers to strategically adopt eco-friendly transport solutions in urban contexts [7].

III. MCDM METHODOLOGY, INPUT AND OUTPUT DATA

A decision is the result of a process of evaluation and choice between alternatives, with the aim to achieve a certain result. It can be strategic, tactical, or operational, and is classified by the nature of the data and the way it is delivered (intuitive, programmed, or analytical). Decisions are made under conditions of certainty, risk, or uncertainty, and can be individual, group, or collective. The quality of the decision depends on the sufficiency of information, time, complexity, and costs. In addition, the context in which the decision is made, as well as its importance, plays a key role in the decision-making process [13, 14].

The nature of each criterion is established, specifying whether it should be minimized or maximized in the process of selecting an alternative [3]. Afterward, the alternatives are assessed for each criterion based on clearly defined parameters or subjective evaluations.

Electric buses represent a relatively new technology that is constantly being improved, especially in the area of energy storage systems (batteries), vehicle charging, traction control, optimization of energy consumption, and reduction of empty vehicle mass. Today, almost all the world's bus manufacturers offer electric buses of various sizes, including midi (8-9 meters), standard (11-13 meters), articulated (18-19 meters) and double-articulated (24-27 meters). Also, e-Buses have become part of the standard offer on the market. According to the ZEUS report [15], 32 manufacturers of electric buses and 8 manufacturers of charging systems are registered on the European market. The most represented manufacturers on the European market include BYD, VDL, Solaris, Volvo, Kamaz, GAZ, Yutong, Ebusco, Optare, Caetano, Skoda, Irizar and Van Hool.

When ranking electric buses for public passenger transport in the City of Niš, six alternatives (electric bus manufacturers) are being explored from A_1 to A_6, taking into account the latest technological advancements that are available on the market in the Republic of Serbia. The evaluation is based on several criteria:

C_1 - Price (in thousands of $) - The price of city electric buses depends on various factors such as bus size, battery capacity, manufacturer, and additional technology used. Although electric buses are more expensive to purchase, maintenance and fuel costs are significantly lower than conventional buses, which can lead to savings over a longer time.

C_2 - Charging time (in hours) - Represents the time required to charge the battery from the designed minimum to the maximum value of the battery capacity. Batteries are the most expensive components on an electric bus. Reducing the costs of these systems and improving their operating characteristics are of key importance for even greater applications in electric buses.

C_3 - Total number of seats (standing and seated) The total number of seats in the bus depends on the manufacturer, and model of the bus, its purpose and design, as well as the regulations of the country in which it is used.

C_4 - Range (in km maximum) - The range of city electric buses varies depending on the model, battery capacity, and the conditions in which they are used. Factors such as terrain, traffic density, air conditioning, and bus load can affect the actual range. Many electric buses use energy regeneration systems, which can extend the range during city driving.

A decision matrix (**Table 1**) has been created using the selected alternatives and criteria. This matrix helps determine the weight coefficients assigned to each criterion, which affect the selection of alternatives. Following this, a multi-criteria decision-making process is carried out, utilizing the determined weight coefficients to evaluate and rank the alternatives efficiently.

Table 1. *The initial decision matrix*

	C_1	C_2	C_3	C_4
	min	*min*	*max*	*max*
A_1	1120	1.4	83	180
A_2	750	3.1	79	300
A_3	1000	3.2	95	320
A_4	592.6	2.5	62	253
A_5	720	3.6	90	350
A_6	842	4	70	400

IV. Implementation of the Approach and Discussion of the Results

MCDM tools are commonly applied to address complex decision problems, particularly in transportation. One important decision area involves selecting clean technology vehicles, such as electric buses, which offer distinct advantages over traditional internal combustion engine vehicles.

1. Entropy method

Determining the objective weights of the criteria using the entropy method is based on the measurement of the degree of uncertainty of the information contained in the decision matrix. This approach directly generates criteria weight values based on the contrast between the values of the alternatives for each criterion, considering all criteria simultaneously. It is considered an objective method because the weights derive from the criteria values themselves, eliminating the subjectivity, incompetence, or absence of the decision maker

[16]. The nature and type of criteria are not of decisive importance for the application of this method. In the context of multi-criteria decision-making, entropy is used to determine how significant the difference is between the values of

alternatives concerning to each criterion. If the values within one criterion are very similar, then the information provided by that criterion is low, and vice versa. Algorithm steps are [17, 18]:

In the first step, a decision matrix is formed:

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

In the second step, all members of the matrix x_{ij} are normalized using the form:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{2}$$

In the following third step, the amount of information contained in the normalized decision matrix and emitted by each criterion f_j can be measured as the entropy value e_j:

$$e_j = -k \sum_{i=1}^{m} r_{ij} \ln r_{ij} \qquad j = 1,2,...,n \tag{3}$$

By introducing the constant k=1/ln m, it is ensured that all e_j values are in the interval [0, 1].

In the next step, the degree of divergence d_j is determined in relation to the average amount of information contained in each criterion. Since the value d_j represents a specific measure of the contrast intensity of the criterion f_j, the final relative weight of the criterion can be obtained by simple additive normalization (**Table 2**):

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{4}$$

Table 2. *Obtained weighting coefficients of criteria*

	C_1	C_2	C_3	C_4
w_j	0.2101	0.4221	0.0959	0.2718

The Entropy method is useful because it removes the subjectivity in determining the weights and allows the decision-maker to rely on the mathematical characteristics of the data itself.

The calculation results of weighting coefficients, obtained through software MS Excel based on Eq (1-4), that the C_2-Charging time (0.4221) is the most important criterion in the evaluation system. After that comes a criterion C_4-Range (0.2718) and C_1-Price (0.2101). Criterion C_3-Total number of seats (standing and seated) has the smallest weighting coefficient (0.0959) showing that this indicator has a minor impact on the evaluation process.

2. MABAC (Multi-Attributive Border Approximation Area Comparison) method

It is one of the newer methods for solving multi-criteria decision-making (MCDM) problems. Its main feature is the introduction of the concept of a marginal approximation region for each alternative, where the performance of the alternatives is compared to the threshold values of the criteria. The MABAC method combines the advantages of other methods, such as simplicity of application and providing precise results. The steps of applying the MABAC method are [19]:

1. Formation of the decision matrix:

A decision matrix is set up in which the rows are alternatives and the columns are criteria. The values within the matrix represent the performance of each alternative against each criterion.

2. Normalization of values

The values in the matrix are normalized to bring them to the same scale. The following formula is used for the criteria to be maximized:

$$r_{ij} = \frac{x_{ij} - min\left(x_j\right)}{max\left(x_{ij}\right) - min\left(x_{ij}\right)} \tag{5}$$

The criteria to be minimized:

$$r_{ij} = \frac{max\left(x_{ij}\right) - x_{ij}}{max\left(x_j\right) - min\left(x_j\right)} \tag{6}$$

Here, r_{ij} is the normalized value of alternative *i* for criterion *j*.

3. Calculation of the boundary value matrix (BV):

The threshold values for each criterion represent the average of the normalized performance values for that criterion according to the following formula:

$$GB_j = \frac{1}{m}\sum_{i=1}^{m} r_{ij} \tag{7}$$

where BV_j is the threshold value for criterion j, and m is the number of alternatives.

4. Calculation of the distance matrix of the alternative from the threshold values according to the formula:

$$q_{ij} = r_{ij} - BV_j \tag{8}$$

where q_{ij} is the distance of the normalized value of alternative i for criterion j from the threshold value BV_j.

5. Calculating the approximation function G:

For each alternative, the approximation function is calculated as the sum of weight-corrected values q_{ij}:

$$G_i = \sum_{j=1}^{n} w_j \cdot q_{ij} \tag{9}$$

where G_i is the approximation function value for alternatives i, w_j is the weight of criterion j, and q_{ij} is the distance value for alternatives i.

6. Alternative ranking. The alternatives are ranked based on the calculated G_i values. An alternative with a higher G_i value is considered better and is ranked higher.

The MABAC method allows the decision maker to see how each alternative is positioned to the "boundary" that represents the average performance values for each criterion, which makes this method very effective for solving multi-criteria decision-making problems.

3. MOORA method

It is simple to use and provides effective results in solving multi-criteria decision-making problems. The algorithm of applying the MOORA method is as follows [20]:

After the first step, that is, the formation of the decision-making matrix, the decision-making matrix is normalized as a second step, according to the formula:

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{10}$$

In the third step, the normalized performance is added in the case of maximization and subtracted in the case of minimization, so that the optimization problem is solved according to the formula:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^* \tag{11}$$

The resulting value of y_i can be positive or negative based on the total value of the maximization terms and the minimization terms. The best-ranked alternative has the highest y_i value, and the worst-ranked alternative has the lowest value.

According to the results (**Table 3**) derived from the Entropy method for evaluating weight coefficients and MABAC using Eq. (5-9), and MOORA using Eq. (10-11) methods for ranking e-Buses, in the MS Excel, the best alternative identified is A_4 manufacturer of an electric bus whose criteria are: C_1=592600 $ (price), C_2=2.5 h (charging time), C_3=62 (Total number of seats - standing and seated), and C_4=253 km (range). The worst alternative identified is A_6 whose criteria are: C_1=842000 $ (price), C_2=4 h (charging time), C_3=70 (Total number of seats - standing and seated), and C_4=400 km (range).

***Table 3.** Ranking of alternatives according to criteria*

	C_1	***C_2***	***C_3***	***C_4***	***Entropy - MABAC***		***Entropy - MOORA***	
	min	*min*	*max*	*max*				
w_j	0.2101	0.4221	0.0959	0.2718	**G_i**	**Ranking**	**xi**	**Ranking**
A_1	1120	1.4	83	180	1.47614	4	-0.08550	2
A_2	750	3.1	79	300	1.48421	3	-0.10223	3
A_3	1000	3.2	95	320	1.43956	5	-0.11792	5
A_4	592.6	2.5	62	253	1.53688	1	-0.07807	1
A_5	720	3.6	90	350	1.50873	2	-0.10385	4
A_6	842	4	70	400	1.39885	6	-0.13017	6

V. Conclusion

The ever-increasing competitiveness and complexity of the market, and the rapid development of technique and technology have made the decision-making process in many institutions, companies, and institutions of key, strategic importance, bearing in mind the fact that it represents one of the most important processes that takes place and has far-reaching consequences on its success and market position. The complexity of the nature of the process often imposes the need to make multi-criteria decisions. Knowing the basic theoretical concepts and the essence of multi-criteria analysis enables managers, engineers, planners and all other decision-makers to effectively apply the methods of multi-criteria analysis to solve numerous decision-making problems at different levels. With the use of computers and various software packages, multi-criteria analysis problems can be solved in a relatively short time.

Based on the shown trends of the increase in the number of electric-powered buses in operation worldwide, the large number of tender procedures around the world related to the purchase of electric-powered buses, the ever-increasing offer on the market by almost all bus manufacturers, positive experiences in exploitation and legal regulations that prescribe the increasing participation of "clean" buses in the transport systems of cities, which is best seen on the example of the member states of the European Union (Directive 94/2014/EC).

The aim and task of this work was to determine the best and most optimal solution when choosing an electric bus for the City of Niš, which can be found on the market of the Republic of Serbia, and all this by applying multi-criteria decision-making methods, specifically in this case the MABAC and MOORA methods while are the weight coefficients of the criteria calculated by the Entropy method. Based on the results obtained from the comparative analysis of the ranked alternatives based on the criteria, it can be concluded that the best-ranked alternative is A_4 and the worst alternative identified is A_6.

The findings provide valuable insights that can guide efforts to enhance air quality in the City of Niš. By utilizing these results, the City can focus on refining its traffic development strategies, both for the present and the future. These strategies can be adjusted to prioritize sustainable and efficient traffic solutions, ultimately contributing to cleaner air and a healthier urban environment.

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AUTHOR CONTRIBUTIONS

N. Petrović: Conceptualization and Supervising.

V. Jovanović: Conceptualization and Experiments.

S. Marković: Writing and Reviews.

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Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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