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APPLICATIONS OF THE MOORA AND TOPSIS METHODS FOR DECISION OF ELECTRIC VEHICLES IN PUBLIC TRANSPORTATION TECHNOLOGY

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Abstract. The technological development of buses among the new alternative concepts is evaluated in this paper. Bus transportation is an important system in the public transportation, which is cheap, flexible and, in many cases, in terms of capacity and speed. But increasing car traffic in the city centre and increasing the emission such as Carbon Dioxide (CO_2) in the air are some of the dangerous problems for urban life. Therefore, it is needed the public transportation to stop increasing car traffic and needed the cleaner technology for air and environmental quality. Electric Buses (EBs) can play an important role for resident's life quality with improving the urban air quality. However, planners and managers have difficulty in decision-making due to diversified EBs together with the developing technology. Multi-criteria decision-making (MCDM) methods that are analytic decision processes, prepare a good solution for this problem. In this study, 5 EBs are assessed under the special criteria with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Multi-Objective Optimization on the basis of the Ratio Analysis (MOORA) methods. These 2 methods are MCDM methods that are used to aim of ranking of alternatives in the complex decision problem. These methods are applied to select the best EB under the 6 criteria. Finally, E5-Bus is selected as the best option that rank of the 1st at all the 3 methods. Besides, MOORA and TOPSIS methods were compared. The results are shown alongside the best bus selection for public transportation that MOORA method is also a strong tool for solving vehicle selection problems in transportation. The proposed model has been validated using existing real applications. The proposed multi-criteria analysis can be used for advising decision-makers in their decision-making process for Electric Vehicles (EVs) in the area of clean transportation.

Keywords: electric bus, MOORA, TOPSIS, urban transportation, MCDM, selection process.

Notations

AHP – analytic hierarchy process;
ANP – analytic network process;
BRT – bus rapid transit;
BWM – best–worst method;
CO_2 – carbon dioxide;
EB – electric bus;
ELECTRE – elimination and choice translating reality (in French: *ÉLimination Et Choix Traduisant la REalité*);
EV – electric vehicle;
MCDM – multi-criteria decision-making;
MOORA – multi-objective optimization on the basis of the ratio analysis;
MULTIMOORA – multiplicative MOORA;
PROMETHEE – preference ranking organization method for enrichment evaluation;
TOPSIS – technique for order of preference by similarity to ideal solution;
VIKOR – multi-criteria optimization and compromise solution (in Serbian: *Višekriterijumska optimizacija I KOmpromisno Rešenje*).

Introduction

Transportation has significant economic, social and environmental impacts, and is an important factor in sustainability due to increasing number of the internal combustion engine vehicle and its environmental impacts. This problem is a major issue in all metropolitan regions in the world today. At the same time this problem and growth of urbanization increases various environmental problems in the future (Litman 2008).

Sustainable transportation solutions are the most important subject in this point. There are several aims about

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sustainable transportation. Some of them are to minimize consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, to reuses and recycles its components, to minimize the use of land and the production of noise, to ensure operates efficiently, to offer choice of transport mode, and to support a vibrant economy (Gilbert *et al.* 2003).

Bus transportation plays a major role in the public transportation, which is cheap, flexible and, in many cases, in terms of capacity and speed. But increasing car traffic in the city centre and increasing the emission such as CO_2 in the air are some of the dangerous problems for urban life. Therefore, it is needed the public transportation to stop increasing car traffic and needed the cleaner technology for air and environmental quality.

The alternative-fuel vehicles are a good solution for sustainability transportation. The EVs among their alternatives are considered the most promising alternative to internal combustion engine vehicles towards a cleaner transportation sector (Canals Casals *et al.* 2016). Besides, the EVs are considered as an eco-innovation that has the potential to reduce environmental problems caused by the transportation sector (Jochem *et al.* 2016; Rezvani *et al.* 2015; Lane, Potter 2007). Todays, the EV technology has been starting widely use due to rapid depletion of fossil fuels and in taking care of environment. Many manufacturers are investing a lot in EVs concepts (Das *et al.* 2019).

The release of large amounts of harmful gas to air and environment have been materialized due to fossil fuel consumption. So, while this situation is affecting negatively to global warming, also causing serious health and environmental problems. Besides, it affects in a negative way also people. So, scientists have thought that alternative transportation vehicles with the transportation technology cleaner fuels based can play an important role in mitigating the greenhouse effect and improving the level of the liveability of city (Lanjewar *et al.* 2015). Gas emission is one of the major environment problems in today' world. Minimizing these emissions and leaving a liveable world to the next generations have become a vital factor and directs the development of technology all over the world. The systems with electrical energy are taking firm steps toward being a frequently preferred system nowadays as it is both economic and environment friendly. At the same time, it is engines and transportation vehicles with renewable energy have being enhanced each passing day in terms of quality and amount.

In addition to these major factors, EVs will be ensure benefit to air quality with decrease the dependence on fossil fuels in the transportation. Therefore, the interest in EVs have been stimulated an increasingly because of concerns about climate change and energy security, along with advances in battery technology (Hidrue *et al.* 2011). In this way, a decrease of local exhausted emissions can increase the air quality and decrease health and environment problems that are related to air pollution especially in urban areas. Recently, EBs transportation systems are among the urban plans made for mass transportation and are used in the urban areas. The EVs that is the new transportation technology with use of electric energy will be make significant improvements for the more liveable cities in the urban area. Due to developing technology day by day, selecting the most suitable bus technology is great importance for the metropolitan cities. The expectation of the passengers from public transportation is to ensure fast, comfort, safe and timely transportation. It is possible to provide an advantageous public transportation service thanks to bus in respect to specialist like urban transportation with zero emission, high reliability through electrically driven traction systems, electricity preference as a fuel instead of diesel and a low fuel cost, high efficiency in terms of the energy per passenger, silent and safe transportation, high transportation quality, low energy consumption cost. Because busses built that is new busses and new different characteristic such as environmentally friendly. EVs are diversified, and their performance is increased with the developing technology. Thus, planners and managers have difficulty in decision-making due to diversified EBs for urban transportation. Decision-making methods that are analytic decision processes, present a good solution for complex selection process. The selection of the EB technology based on sustainability is important for developing countries or cities because of their varying technological needs and priorities. MCDM methods are an effective tool to assess, benchmark and selection alternatives of sustainable transportation under the various factor.

MCDM processes help decision-makers to solve complex real-world decisions involving conflicting criteria in a systematic way under the presence of a plethora of factors and criteria. The application of MCDM in urban transportation has been day by day increasing in the past few decades. Hsiao *et al.* (2005) used AHP and TOPSIS hybrid analytic decision-making processes to improving air quality for selecting low pollutant emission bus systems. Vahdani *et al.* (2011) proposed 2 novel MCDM methods under the fuzzy environment for alternative-fuel buses selection. Onat *et al.* (2016) used the TOPSIS and intuitionistic fuzzy set in their approaches. The life cycle of alternative vehicle technologies was ranked in terms of sustainability performance. Büyüközkan *et al.* (2018) focused on selection process of bus technologies by using an intuitionistic fuzzy Choquet integral with group decision-making. In their study, evaluated urban transportation alternatives based on sustainability. Aydın and Kahraman (2014) made an application for vehicle selection in the public transportation using fuzzy-AHP and VIKOR. At the same time, there are some application and evaluation in the literature about alternative-fuel vehicle technology (Oztaysi *et al.* 2017; Mukherjee 2017; Vaughan *et al.* 2018; Sehatpour *et al.* 2017; Yavuz *et al.* 2015; Li *et al.* 2019). Besides, various applications and research interests in the EV field such as environmental impact assessment (Choma, Ugaya 2017; Ensslen *et al.* 2017; Nordelöf *et al.* 2014), environmental life cycle assessment (Ercan *et al.* 2015; Zhang *et al.* 2018, 2019), charging technologies and battery technologies (Shareef *et al.* 2016; Fotouhi *et al.* 2016; Song *et al.* 2018; Mahadik, Vadirajacharya 2019; Chiranjeevi *et al.* 2020), charging infrastructure and location planning of charging stations (Andrenacci *et al.* 2016; Xu *et al.* 2016; Kong *et al.* 2017; Guo, Zhao 2015; Awasthi *et al.* 2017; Lin *et al.* 2020) are found in the scientific literature.

There are also numerous papers also in recent years with application of MCDM methods for solving general transportation problems. Pedroso *et al.* (2018) evaluated performance of public transport options using multi-criteria analyses. Alkharabsheh *et al.* (2019) assessed passenger demand for urban transportation via AHP in their real-world application. Güner (2018) studied about measuring the quality of public transportation systems and ranking the bus transit routes with MCDM. Errampalli *et al.* (2020) made an application in Indian cities for evaluation of integration between public transportation modes. Erdoğan and Kaya (2016) offered a systematic approach based on maintenance decision support system to eliminate the risks arising from failures for BRT system and used MCDM in their evaluation process. Mohammadi *et al.* (2020) made a multi-criteria assessment for the passengers' level of comfort in urban railway rolling stock. Khayamim *et al.* (2020) used MCDM methods for selecting and timing the urban transportation infrastructure projects. Mahmoudi *et al.* (2019) studied about sustainability evaluation criteria of urban transportation network. Noureddine and Ristic (2019), showed application of TOPSIS method and linear programming approach for route selection. Also, Stanković *et al.* (2019) proposed rough and fuzzy-MCDM approach for determining criteria weights for traffic accessibility.

MCDM methods are widely used to selection of alternative-fuel vehicles as is seen in the literature. But, the main contribution of this paper to the literature is to present the best selection using MCDM under the specific criteria among EB technologies in urban transportation. The difference of this study from the similar ones is to select only among the EB technologies.

The aim of this study is to make of the best selection of EB for urban public transportation. In this scope, the 5 alternative EBs are evaluated using by criteria of speed, passenger capacity, range, maximal power, battery capacity and charging time. TOPSIS and MOORA methods, which are giving the best ranking, are used respectively in decision-making process. Thereby, this selection process will be ensuring design of the more sustainable urban transportation. Besides, this study will be a good source for purchasing processes and will be help municipality executives and transportation planners in their decision-making process.

In this paper, TOPSIS and MOORA are proposed as MCDM technique for evaluating and selecting the suitable technology for transportation. Then the results of solutions are made comparison and evaluations. The following sections of the paper are formulated as the following: Section 1 explains methodology of MOORA and TOPSIS methods. Section 2 presents the case study with MOORA and TOPSIS decision model for the most suitable selection of EB alternative. The next Section 3 is applied to results discussion of the case study and validation of the results. Besides study's limitations and further research directions suggestions are given. The final section presents the major conclusions and concludes the research with some recommendations.

1. Methods

The present study aims at developing a multi-objective and multi-criteria evaluation model for assessment of alternative EV for public transportation by using TOPSIS and MOORA methods. Finally, the solutions of each method are compared among the themselves.

1.1. TOPSIS method for decision-making

TOPSIS ranking method developed by Hwang and Yoon (1981), is include of the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance of the negative ideal solution. There are several studies in literature review, which are about TOPSIS. Some of them are selection of monorail technology (Hamurcu, Eren 2017), optimization of the most critical electrical equipment (Özcan *et al.* 2019), evaluation of alternative monorail routes (Hamurcu, Eren 2019), maintenance strategy selection (Özcan *et al.* 2017), supplier selection (Özcan *et al.* 2018) and selection of 3PL company for online shopping sites (Eren, Gür 2017).

The TOPSIS method is described in the following steps (Hwang, Yoon 1981).

Step 1. The decision problem and normalization of the evaluation matrix:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{J} f_{ij}}}, \quad (1)$$

where: f_{ij} – the evaluation matrix; r_{ij} – the normalized evaluation matrix ($j = 1, 2, \ldots, J$; $i = 1, 2, \ldots, n$).

Step 2. The weighted normalized decision matrix is constructed. However, we did not use weighted normalized decision matrix, only, the criteria have equal priorities in this study.

Step 3. Determination of A^+ (ideal solution) and A^- (negative ideal solutions):

$$A^+ = \left(\left(\min_i v_{ij} \left| j \in J \right|\right), \left(\max_i v_{ij} \left| j \in J' \right|\right)\right); \quad (2)$$

$$A^- = \left(\left(\max_i v_{ij} \left| j \in J \right|\right), \left(\min_i v_{ij} \left| j \in J' \right|\right)\right). \quad (3)$$

Step 4. Calculate the separation measures under the criteria for each alternative: these values can be measured using the Euclidean distance in these calculation process:

$$d_{ij}^{*} = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_{i}^{j}\right)^{2}}; \quad (4)$$

$$d_{ij}^{-} = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_{i}^{-}\right)^{2}}. \quad (5)$$

Step 5. Calculation of CC_j^{*}, the relative closeness to the ideal solution – CC_j^{*} is defined as:

$$CC_j^{*} = \frac{d_j^{-}}{d_j^{-} + d_j^{+}},$$

or

$$CC_j^{*} = 1 - \left(\frac{d_j^{+}}{d_j^{+} + d_j^{-}}\right). \quad (6)$$

Step 6. Ranking the result values of CC_j – finally, alternatives can be preference ranked according to the descending order of CC_j. In this ranking, the highest CC_j value is our best choice.

1.2. MOORA method

The MOORA method is 1st introduced by Brauers in order to solve complex decision-making problems. 2 type of the MOORA method used widely: the ratio system and the reference point approach (Brauers, Zavadskas 2006). MOORA method helps for decision-makers the process of simultaneously optimizing 2 or more conflicting criteria or objectives subject to certain constraints. MOORA is a relatively new method among the MCDM, but it has been applied to different areas in the literature. This application is used for project selection (Jones *et al.* 2013), materials selection (Karande, Chakraborty 2012), strategy selection (Dey *et al.* 2012), efficiency analysis of banks (Özbek 2015) and selection of best manufacturing system (Mandal, Sarkar 2012).

The 1st approach is the ratio system that can be defined as presented below.

Step 1. Firstly, these process stars with the decision matrix **X**:

$$\mathbf{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \quad (7)$$

where: x_{ij} – performance measurement value of i alternative in respect of j objective (i – alternative; j – qualification or criteria) ($m \times n$ – matrix value of "total number of alternatives" × "total number of qualifications").

Step 2. 2nd process is normalization process. Decision matrix **X** constructed in ***Step 1*** is normalized with equation:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^{2}}}, \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n. \quad (8)$$

Step 3. If you used weight, the weighted normalized decision matrix is formed with the help of equation:

$$v_{ij} = w_j \cdot x_{ij}^{*}, \quad (9)$$

where: w_j – weight of the jth criterion. We do not use weight of criteria in this study or we use equal weight.

Step 4. Finding of y_i^{*} value:

$$y_i^{*} = \sum_{j=1}^{g} X_{ij} - \sum_{j=g+1}^{n} X_{ij}, \quad (10)$$

where: y_i – normalized value related with i alternative in respect of all criteria ($j = 1, 2, \ldots, g$ – indicates the criteria to be maximized; $j = g+1, g+2, \ldots, n$ – criteria to be minimized).

Step 5. The best ranking with MOORA method are obtained by ranking founded y_i^{*} values result of evaluation in descending order.

The 1st 3 steps in the reference point approach and ratio method of MOORA are the same. The other analytic process includes briefly following steps (Brauers *et al.* 2008).

Step 1 (Equation (7)), ***Step 2*** (Equation (8)) and ***Step 3*** (Equation (9)) are the same with 1st method in this method.

Step 4. r_j values are determined for each reference points. While determining r_j values, it is making 2 oriented evaluation. Firstly, highest values are chosen for maximization criteria (if the purpose is maximization); secondly, minimum values are chosen for the minimization criteria (if the purpose is minimization).

Step 5. The distance with the reference points are calculated in finally step by using the Min–Max metric of Tchebycheff given in Equation (11) or (12):

$$P_i = \min_i\left(\max_j\left(\left|w_{ij} \cdot r_{ij} - v_{ij}\right|\right)\right),$$

if you do not use weight of criteria $w_{ij} = 1$); (11)

$$P_i = \min_i\left(\max_j\left(\left|r_{ij} \cdot X_{ij}\right|\right)\right). \quad (12)$$

The best alternative would be that which has the minimum total deviation according to all the criteria or reference points. In other words, it means that the best selection would have the minimum P_i numeric value. Final ranking consists of by ranking the P_i values in increasing order.

1.3. Decision-making with TOPSIS and MOORA

MCDM is an important tool, which is used by public enterprises or private sector to transportation project selection, evaluation of investment in transportation system infrastructure, appraise the efficiency of a policy for decision-making in transportation systems, selection of technologies and selection of transportation alternatives, etc. Hence, transportation plan and projects effect various area especially natural environment, social structure and economy. Therefore, decision-making in the transportation subject is need to considering multiple factor. Therefore, MCDM techniques are good methods due to help a number of alternatives are evaluated with respect to a number of criteria (quantitative or qualitative).

Here we name just a few: AHP (Saaty 1977), ANP (Saaty 1999), TOPSIS (Hwang, Yoon 1981); ELECTRE (Roy 1990); PROMETHEE (Brans, Vincke 1985), VIKOR (Opricovic, Tzeng 2007) and BWM (Rezaei 2015). These methods play an important role in the decision-making process for both small and large decision problems and transportation problems.

TOPSIS and MOORA are most similar methods among the other decision-making methods. Each 2 methods utilize vector normalization procedure to normalize the decision matrix (Kecek, Demirağ 2016; Wang *et al.* 2019a, 2019b). TOPSIS method has been used for transportation area as only TOPSIS, hybrid with other MCDM methods and fuzzy-TOPSIS. Some of them; evaluating of quality for public transport services by using fuzzy-TOPSIS (De Aquino *et al.* 2019; Awasthi *et al.* 2011a, 2011b); evaluating alternative-fuel busses for public transportation and transportation service quality with hybrid TOPSIS method (Erdoğan, Kaya 2016; Awasthi *et al.* 2011a, 2011b), maritime transportation using by AHP and TOPSIS methods (Celik, Akyuz 2018). Evaluation of transportation with TOPSIS (Celik, Akyuz 2018), assessment on sustainable development of highway transportation capacity with TOPSIS (Li *et al.* 2014). TOPSIS method is used widely for 3 reasons (Wang, Chang 2007): (1) this method logic is rational and understandable; (2) the computation processes are straight forward; (3) decision process permits the pursuit of best alternatives for each criterion depicted in a simple mathematical form.

MOORA method, multi-objective optimization approach, is used for ranking discrete alternatives. The MOORA method have basic 4 factor: (1) the options for each objective; (2) normalization; (3) optimization; (4) the importance of each alternative (Majumder, Maity 2017). This method makes the decision-making process a reliable one. MOORA method is a new method and have some advantages regarding other MCDM methods such as AHP, TOPSIS, VIKOR, ELECTRE, PROMETHEE. For example: computational time is very less; very simple; minimum mathematical calculations; a good stability (Hafezalkotob *et al.* 2019; Brauers, Zavadskas 2012). Besides, another advantage of the MOORA method according to others, is that it refers to a responses' matrix of alternatives to determine which alternative is the best regarding the ratios (Brauers, Zavadskas 2009). MOORA method has been used supply selection (Şimşek *et al.* 2015), material selection (Gadakh *et al.* 2018), the assessment of occupational safety and health (Dizdar, Ünver 2020), machine selection (Sarkar *et al.* 2015), laptop selection (Adalı, Işık 2017), road design (Brauers *et al.* 2008) and projects selection for urban transportation (Hamurcu, Eren 2018) in the last literature. So, the literature limits about transportation planning process using MOORA method. Besides, there is not a study about TOPSIS and MOORA methods together used as comparative analyse. But there are a few study using by MULTIMOORA about fuel selection (Erdogan, Sayin 2018), battery recycling mode selection (Ding, Zhong 2018), assessing the efficiency of transport sector (Baležentis, A., Baležentis, T. 2011) and evaluation of excavator technologies (Altuntas *et al.* 2015).

In order to achieve greater objectivity in decision-making over the last years, numerous multi-criteria models have been developed. TOPSIS and MOORA methods also ensure objectivity for decision problem in considering only their analytic process (without important weight of evaluation criteria). Therefore, we used the criteria weights as equal important.

2. An application

The various cities in the world have been used EBs for public transportation. Besides, the governments stimulate development in use of alternative-fuel buses over the past few years. As across the world, several studies have been carried out by municipalities to sustainable public transport following increased public awareness in Turkey. For example; the EBs have been serviced in the Konya, Eskişehir, İzmir metropolitan municipality and Elazığ municipality. Besides, Malatya and Şanlıurfa metropolitan municipality have been used the electrical transportation systems for a long time. İstanbul metropolitan municipality also is planned to buy EB. Hence, many cities will be used EVs or cleaner technology instead of the internal combustion engine vehicle in next years. Figure shows flow chart for decision problem.

This selection process is applied for public transportation in the municipality. EBs are proposed for urban transportation and the best selection is made among the alternatives. 5 alternatives EBs are determinate by academic experts and the important specifications also are determinate by these expert team. Alternatives and their specification are shown in Table 1. This research study involved 4 experts as 2 academics and 2 transportation planners with a minimum of 10 years of experience in managing the department of urban transportation planner in Ankara

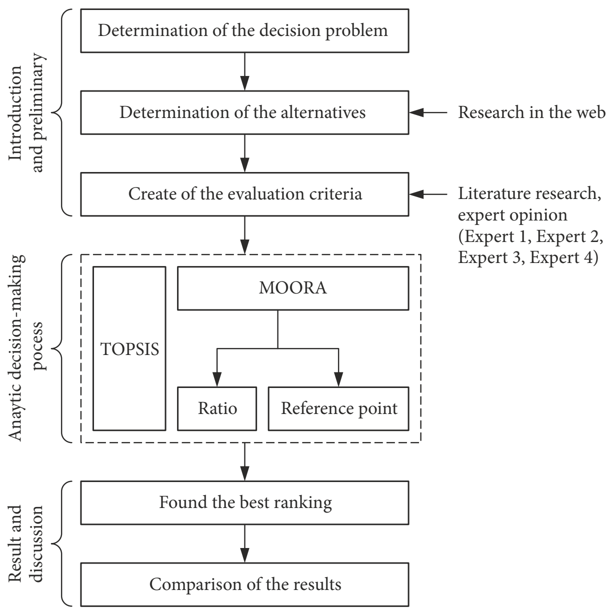

Figure. The flowchart for proposed model

Metropolitan Municipality. We used crisp data to eliminate expert opinion in the evaluation process. Criteria of technical/operational, economic, environmental, social, safety, and policy are used widespread as main criteria for analysis in the transportation sector (Zubaryeva *et al.* 2012; Jones *et al.* 2013; Shiau, Liu 2013; De Luca 2014; Nosal, Solecka 2014; Buwana *et al.* 2016; Curiel-Esparza *et al.* 2016). There are used lots of criterion in the literature that are economic, technical, social, environmental and technology as main criteria. These criteria are used to select alternative-fuel vehicle selection or alternative-fuel selection to reduce emission for environment. Energy availability, energy efficiency, acquisition cost, fuel cost, range, vehicle life, initial cost, maintenance cost, purchase cost, operating cost are under the economic criterion; vehicle capacity, road capacity, traffic flow conformance are under the technical; passenger comfort stands, energy efficient, fuel availability, air pollution, noise, pollution, reduce emission, dematerialization are under the social; air pollution and noise pollution are under the environment and performance safety, sense of comfort, vehicle capacity, user acceptance are under the technology main criterion. But we use only specific 6 main criteria according to expert opinion for vehicle selection in this evaluation. In this manner, the criteria involved are described as follows:

- speed (Crt-1): high values are ideal (max: +);
- passenger capacity (Crt-2): high values are ideal (max: +);
- range (Crt-3): high values are ideal (max: +);
- maximal power (Crt-4): high appraisals are preferred (max: +);
- battery capacity (Crt-5): high values are ideal (max: +);
- charging time (Crt-6): low values are ideal (min: –).

Determinated, that these criteria are more significant and specific than any other criteria for EBs.

2.1. Application of TOPSIS

Normalized matrix, ideal solutions for TOPSIS method are given at the Table 2. As given in Table 2, the quantitative data for the EB selection problem are 1st normalized by using Equation (1). Shown at the same table, A^+ and A^-, which are purpose value are determinate as max or min by using Equation (2) and Equation (3).

Equations (4) and (5) are used for dd_j^+ and dd_j^- values. These values in the result of calculations are given in Table 3. And finally, using Equation (6), are made result ranking with CC_j^* values.

2.2. MOORA implementation

The 1st step for the application of MOORA method is establishing decision matrix. After this step, MOORA-Ratio and MOORA reference point methods apply mentioned in the process respectively. Using Equation (8) Equation (9), and Equation (10), respectively, ratio method for MOORA approach and its ranking are given in Table 4. Final rank according to ratio method are E5-Bus, E1-Bus, E4-Bus, E3-Bus and E2-Bus.

Reference point for ranking are applied by using Equation (11) in addition to Equation (8) and Equation (9). Reference point approach and its ranking are given in Table 5.

Table 3. Rank for each alternative with TOPSIS method

Alternative	j^+	j^-	j^*	Ranking
E1-Bus	0.5072	0.7631	0.6007	2
E2-Bus	0.8474	0.4397	0.3416	5
E3-Bus	0.7425	0.4770	0.3912	4
E4-Bus	0.4725	0.5832	0.5524	3
E5-Bus	0.4881	0.7634	0.6100	1

Table 1. Alternative EBs

Alternative	Criteria for evaluation					
	Crt-1 [km/h]	Crt-2 [passenger]	Crt-3 [miles]	Crt-4 [kW]	Crt-5 [kW·h]	Crt-6 [h]
E1-Bus	72	50	200	360	360	2
E2-Bus	90	50	280	103	170	7
E3-Bus	80	57	50	200	200	2
E4-Bus	75	90	280	250	230	5
E5-Bus	75	136	300	250	346	7

Table 2. TOPSIS matrix

Alternative	Crt-1	Crt-2	Crt-3	Crt-4	Crt-5	Crt-6
E1-Bus	0.409	0.268	0.372	0.652	0.591	0.175
E2-Bus	0.512	0.268	0.521	0.186	0.279	0.612
E3-Bus	0.455	0.305	0.093	0.362	0.328	0.175
E4-Bus	0.426	0.482	0.521	0.453	0.378	0.437
E5-Bus	0.426	0.729	0.558	0.453	0.568	0.612
A^+	0.512	0.729	0.558	0.652	0.591	0.175
A^-	0.409	0.268	0.093	0.186	0.279	0.612

Table 4. Ratio system approach and ranking

Normalized	Crt-1	Crt-2	Crt-3	Crt-4	Crt-5	Crt-6	y_i	Rank
	(+)	(+)	(+)	(+)	(+)	(–)		
E1-Bus	0.409	0.268	0.372	0.652	0.591	0.175	2.117	2
E2-Bus	0.512	0.268	0.521	0.186	0.279	0.612	1.154	5
E3-Bus	0.455	0.305	0.093	0.362	0.328	0.175	1.369	4
E4-Bus	0.426	0.482	0.521	0.453	0.378	0.437	1.822	3
E5-Bus	0.426	0.729	0.558	0.453	0.568	0.612	2.122	1

Table 5. Reference point approach and ranking

Normalized	Crt-1	Crt-2	Crt-3	Crt-4	Crt-5	Crt-6	Max	Rank
	(+)	(+)	(+)	(+)	(+)	(–)		
E1-Bus	0.102	0.461	0.186	0.000	0.000	0.000	0.46071	3
E2-Bus	0.000	0.461	0.037	0.465	0.312	0.437	0.46519	5
E3-Bus	0.057	0.423	0.465	0.290	0.263	0.000	0.46480	4
E4-Bus	0.085	0.246	0.037	0.199	0.213	0.262	0.26211	1
E5-Bus	0.085	0.000	0.000	0.199	0.023	0.437	0.43685	2

Table 6. Comparison of results

Alternative	MOORA				TOPSIS	
	ratio method		reference point			
	y_i	rank	P_i	rank	CC_i	rank
E1-Bus	2.117	2	0.46071	3	0.6007	2
E2-Bus	1.154	5	0.46519	5	0.3416	5
E3-Bus	1.369	4	0.46480	4	0.3912	4
E4-Bus	1.822	3	0.26211	1	0.5524	3
E5-Bus	2.122	1	0.43685	2	0.6100	1

Reference points for MOORA: Crt-1, 0.512 (+); Crt-2, 0.729 (+); Crt-3, 0.558 (+); Crt-4, 0.652 (+); Crt-5, 0.591 (+); Crt-6, 0.175 (–). MOORA ratio system, reference point approach and TOPSIS results are shown respectively at the Table 6. The result of the best selection of methods are given and compared at the same table.

Table 6 shows that E5-Bus is the best option according to each 3 methods results. Result of TOPSIS method and MOORA ratio method are the same. MOORA reference point method is different. Result of TOPSIS method and MOORA ratio method ranked as E5-Bus, E1-Bus, E4-Bus, E3-Bus, E2-Bus. When we generalize, reference method gives our the better than ratio method for MOORA. Because it gives the same result with TOPSIS and we used actual data for evaluation.

3. Discussion

The result of the proposed methods was compared on the examples of the public transportation bus preference of Europe and Turkey cities. Overall, the real applications also confirm the results presented in Table 6. The most preference buses are 1st 3 alternative (E5-Bus, E4-Bus and E1-Bus) that are found in result of this study.

We use a 3rd method for validation of the results of this study VIKOR method is used to validation of TOPSIS and MOORA methods' results. MOORA, TOPSIS and VIKOR, which are based on an aggregating function representing closeness to a reference point, have been implemented as MCDM methods for ranking alternatives in various studies (Çalışkan *et al.* 2013; Dey *et al.* 2016). MOORA, TOPSIS and VIKOR method have the important advantages with their simplicity and indisputable ranking order in alternative selection.

The VIKOR method that is the compromise solution method, is introduced by Opricovic and Tzeng (2007). See for main procedure and process steps of the VIKOR method: Wang *et al.* (2019a, 2019b); Awasthi *et al.* (2018); Gupta (2018); Kumar *et al.* (2020). To show the compatibility of application, the results of the study are also ratified with VIKOR method in this study. Table 7 shows the comparisons of method results with VIKOR methods for EB selection problem. It can be seen from the Table 7 that the ranks are small difference among the methods. Therefore, we use spearman rank correlation coefficient for similarity in rankings calculated by these methods. Spearman's rank correlation coefficient r_s for methods are shown in Table 8.

Table 7. Ranking of the alternatives for each method

Alternative	MOORA		TOPSIS	VIKOR			
	ratio method	reference point		$v = 0.25$	$v = 0.50$	$v = 0.75$	$v = 1$
E1-Bus	2	3	2	3	3	2	2
E2-Bus	5	5	5	5	5	5	5
E3-Bus	4	4	4	4	4	4	4
E4-Bus	3	1	3	1	1	3	3
E5-Bus	1	2	1	2	2	1	1

Table 8. Spearman's rank correlation coefficient for methods

Method		MOORA		TOPSIS	VIKOR			
		ratio method	reference point		$v = 0.25$	$v = 0.50$	$v = 0.75$	$v = 1$
MOORA	ratio method	–	×	1	×	×	1	1
	reference point	–	–	×	1	1	×	×
TOPSIS		–	–	–	×	×	1	1

Notes: Spearman' correlation test results show that the differences between rankings are not statistically significant (the calculated Z values ≥1.645: these situations are shown with "×" symbols. Besides, $Z = 1$ (the same rankings) also values at the same table show that the rankings are statistically significant ($Z \leq 1.645$).

In our study, the critical Z value at the level of significance of $a = 0.05$ is selected 1.645. According to Table 7 and Table 8, MOORA ratio method TOPSIS and VIKOR ($v = 0.75$ and $v = 1$) gave exactly the same ranking. And these 3 method's values $r_s = 1$ ($1 \leq 1.645$). Besides, from Table 7 it is clear that MOORA reference point method and VIKOR ($v = 0.25$ and $v = 0.50$) results are exactly the same and $r_s = 1$. Results exhibit an acceptable range for correlations acquired in MOORA ratio method TOPSIS and VIKOR ($v = 0.75$ and $v = 1$) and MOORA reference point method and VIKOR ($v = 0.25$ and $v = 0.50$). Thus, we can say that that MCDM methods like MOORA ratio method is effective in solving vehicle selection problem. Because, TOPSIS and VIKOR methods have supported this method result. Besides more study and different analyses should made for efficiency of MOORA reference point method. Because only 2 method have supported the each other.

Finally, MOORA (Reference method)-TOPSIS and VIKOR ($v = 0.75$ and $v = 1$) methods were compared with each other (also $r_s = 1$) and the results showed a good correlation between the methods (the same rank), that is the MCDM approach is a strong tool for solving complicated vehicle selection problems in various aims.

3.1. Implications of decision-making process on other areas

TOPSIS method are widely used for ranking/selection of alternatives in the transportation problems as it seen the literature. However, use of MOORA methods limited for transportation problems and there are only a few studies. Hence, it has been seen that MOORA method also is suitable technique for transportation problems, due to support to each other's of this study results. MOORA method can be used for many problems such as route selection, project selection, vehicle selection, personnel selection, etc., as long as there is clear data of the transportation. In addition, the use of MOORA method with fuzzy sets under fuzzy environment in future studies can be discussed.

In the near future, it is clear that EBs will continue further development and will become more widespread through the improvement of battery technology, increasing their life and capacity, optimizing electric drive components, and improve the system for recharging the battery. Therefore, evaluation criteria relationships can be analysed in future studies and can be researched to what extent they contribute to decision-making in selection processes.

Various applications such as selection of electric commercial vehicle, selection of public service vehicle and choice of armoured military vehicle can be done with this decision process. Especially, automobile manufacturer firms extend automobile portfolio towards EVs. Even, firms start production completely of electric automobile / EV. This conversion has been substantiated quite rapidly and new EV models and technologies have been developed. They have been competed each other for higher range and short charging time. So, it also can be used for selection of electric automobile / EV by improving this decision process proposed by us and hybrid MCDM methods.

3.2. Limitations and further research directions

There are lots of evaluation criteria and factors about vehicle selection and vehicle preference of customers. We used only 6 special criteria according to expert opinion for selection of EBs. Therefore, the special 6 criteria are major limitation in this study. The weights of criteria play a key role in MCDM problems. Therefore, each criterion may not contribute equally to choose the best alternative. This situation may 2nd one limitation for this study.

We use equal weight at each 2 ranking methods (TOPSIS and MOORA). To ensure objectivity in decision process with MOORA and TOPSIS, was used equal weight. So, we did not benefit from expert experience or opinions and did not use weighting methods like AHP, ANP, etc., in this study. We applied to expert opinion only to determinate alternatives and evaluation criteria. But evaluation criteria might not be equal weight. Maybe it might be difference levels according to each other's among the criteria. So, the importance level of the criteria or their weights may be found using AHP or ANP in the future studies. These methods, TOPSIS and MOORA could been used hybrid with AHP–ANP and fuzzy numbers. Besides, the other MCDM methods such as ANP, VIKOR, PROMETHEE and their hybrid applications can be used and compared in this study results. The criterion relationships can be considered and their relationships with each other can be taken in consideration using ANP. And this model can be also used in the other urban planning processes related to decision-making. We used only technical performance units. Therefore, it can be used different criteria to development this decision process in next study.

It can be made choices for decision-making processes like battery electric and electric hybrid for propulsion; ultracapacitor, battery and fuel cell for energy storage; conductive (plug-in) and inductive (wireless) for charging technology; slow charging or fast charging for charging strategy under the specific criteria.

The MCDM combine models such as AHP–TOPSIS, ANP–TOPSIS or AHP–MOORA or ANP–MOORA may contribute to satisfying the demands for transparency in public institutes by strengthening the underlying rationale behind bus purchasing decisions. The model can also be used with slight modifications in other decision-making problems in public institutes. In addition, mathematical models can be combined with this model for various aims. Moreover, aesthetic, maximal gradeability, maximal torque, charging capacity and dimensions of vehicles as a criterion can be used for evaluation process.

Conclusions

The air pollution is one of the most important problem for today's country and cities. Transportation and usage special vehicle are one of the effected essential cause to this problem. The existing solutions in transportation are moving towards alternative energies and EVs. So, utilizing EV is one of the ways to reduce CO_2 emission. According to literature researches, the preference and use of EVs depend on the developing of EV specifications. Specifications of EVs and buses vary across their alternatives in expanding vehicle market with the developing technology. In this point, it needs to analytic selection process to the best selection.

In this study, we use 3 analytic decision-making process. Result of applications show up 3 different ranking. There are some differences between methods results due to analytic procedure of methods. However, all 3 methods have support each other when looked in the results. E5-Bus is selected as the best option that rank of the 1st at all the 3 methods.

E5-Bus, E1-Bus and E4-Bus dominate 1st 3 rows all the 3 methods. So, it can say that E5- Bus is the best EV of bus ranking among our alternatives for public transportation. Public transportation is important subject for urban area. It is needed to the better plan and alternatives for the liveable cities. EBs and vehicles are a good solution for air quality and environment.

The following items are the benefits of this study. EBs that are the important subject environmental are evaluated/selected within the 6 specific criteria. It is ensured objectivity with TOPSIS and MOORA methods for decision process. This approach ensures benefit their decision-making process for municipality managers and transportation planners and helps to give effective decision in their planning process. It seen that the MOORA method with short and simple computation process, is a good method for vehicle selection problems. Applicability of the proposed comparative approach is illustrated with a case study. As demonstrated in the literature review, this successfully addresses the gap of applying the MOORA method in the field of transportation planning.

Author contributions

Mustafa Hamurcu and *Tamer Eren* conceived the study and were responsible for the design and development of the data analysis.

Mustafa Hamurcu was responsible for data collection and analysis.

Mustafa Hamurcu and *Tamer Eren* were responsible for data interpretation.

Mustafa Hamurcu wrote the 1st draft of the paper and made its all arrangements.

The solutions of methods were made by *Mustafa Hamurcu*.

Tamer Eren was supervision of all the study.

Disclosure statement

The authors states that he does not have any competing financial, professional, or personal interests from other parties.

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