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A Multi-Criteria Decision Making TOPSIS Fusion Approach for Selection Best Strategy Charging for Electric Bus Systems

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Abstract

An essential part of electrifying bus networks is deciding on the appropriate charging strategy among the many available alternatives, such as opportunistic (rapid) charging techniques and overnight (slow) charging. The broad usage of electric buses in public transportation networks and the increasing demand for environmentally friendly transportation options have elevated the significance of this step. This research establishes a multi-criteria decision-making (MCDM) fusion method for choosing the optimal electric bus charging strategy by considering various variables, including operational, quality-of-service, social, environmental, and economic factors. To determine what matters most for making decisions in this field, we surveyed electric bus specialists and reviewed the literature extensively. We used the TOPSIS method as an MCDM fusion method to combine the criteria and alternatives. We compute the weights of criteria by the average method. Then, the TOPSIS fusion method selects and ranks the alternatives. We collected the 20 criteria and five alternatives in this study. We show that overnight is the best charging strategy in the electric bus system. We performed a sensitivity analysis to show the different cases in criteria weights, then ranked the alternatives under different weights to establish the stability of the results.

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1. Introduction

To combat climate change, it is crucial to reduce emissions of greenhouse gases (GHGs), of which the transport sector is a primary global source. About one-fifth of all greenhouse gas emissions come from the transport sector, says the Intergovernmental Panel on Climate Change (IPCC). In this industry, emissions from road transport are the highest, followed by air and sea transport emissions[1], [2].

One way to lessen the impact of climate change and reduce greenhouse gas emissions from transport is for more cities to switch to electric buses (EBs)[3]. EBs are a greener and more sustainable option than conventional diesel or gasoline-fueled buses as they don't release any pollutants into the atmosphere and can be fueled by clean energy. Moreover, EBs enhance air quality, decrease health risks related to air pollution, and reduce operating expenses[4], [5].

On the other hand, EB fleet transformation requires substantial investments in charging facilities and enabling legislative and regulatory actions. Among the many alternatives for assessing strategies, such as opportunistic (rapid) charging systems and overnight (slow) charging, choosing the optimal one is an essential first step in electrifying bus networks[6], [7]. This is a crucial step for public transportation agencies because of the rising demand for eco-friendly transportation and the widespread use of electronic buses in these systems[8]–[10]. Every possible course of action contains benefits and drawbacks, making it difficult to choose the optimal one. Effective policymaking requires handling a multi-criteria decision-making (MCDM) dilemma, which requires lawmakers to assess various aspects with distinct dimensions simultaneously. We used the MCDM method as the MCDM fusion method to select the best strategy for charging the electric bus. We used the TOPSIS fusion method to analyze the alternatives and choose the best one[11], [12].

To resolve ranking issues, Hwang and Yoon presented TOPSIS, an approach to Multiple Criteria decision-making systems. The reasoning behind this approach is quite similar to how humans make decisions, as the optimal choices are near the positive ideal solution (PIS) and far from the negative perfect solution (NIS). Decision-makers may quickly grasp this strategy since it is grounded on a reasonably basic working principle. According to Behzadian et al., TOPSIS is widely used in MCDA for this reason[13], [14].

Despite the method's straightforward rationale and widespread implementation, there have been several criticisms of various parts of the underlying algorithm. There are several issues with the current setup, including assessment normalization, criterion weighting, the norm for computing alternative distances from PIS and NIS, and the construction of the closeness index from these distances[15], [16]. The normalization problem will be the primary focus of this article. In addition, we will suggest a TOPSIS technique expansion that can handle hierarchically organized criteria and multiple weight vectors consistent with the data given by the Decision Maker (DM). We will go into further depth on these points immediately[17], [18].

The first step is normalizing the data so that all performances may be expressed on the same scale. Vector normalization, max-normalization, min-max normalization, and sum-normalization are among the most well-known normalization methods that have been employed. They all attain the end goal. But, in TOPSIS, the choice of normalization process is crucial as it can potentially change the outcomes drastically. Also, when applied to the same criterion stated in various units, the same normalization approach might provide different results. This is because some of these normalization procedures, like vector normalization, are very sensitive to the unit scale of the criteria[19], [20].

The main contributions of this are summarized as:

We used the MCDM fusion method to analyze the criteria of charging strategy in the electric field and select the best strategy.

We used the TOPSIS fusion method to combine the criteria and alternatives and select the best one.

In this study, we collected 20 criteria and five alternatives from the previous studies.

We conducted the sensitivity analysis to show the stability of the results. We suggest 20 cases in weights of criteria.

2. TOPSIS Fusion Method

In this section, we introduce the TOPSIS MCDM method as an MCDM fusion method to combine the various criteria and alternatives to select the best strategy for changing the electric bus. The criteria are handled using the MCDM fusion method[21]–[23]. Figure 1 shows the steps of the TOPSIS fusion method. The following are the steps of the TOPSIS fusion method as:

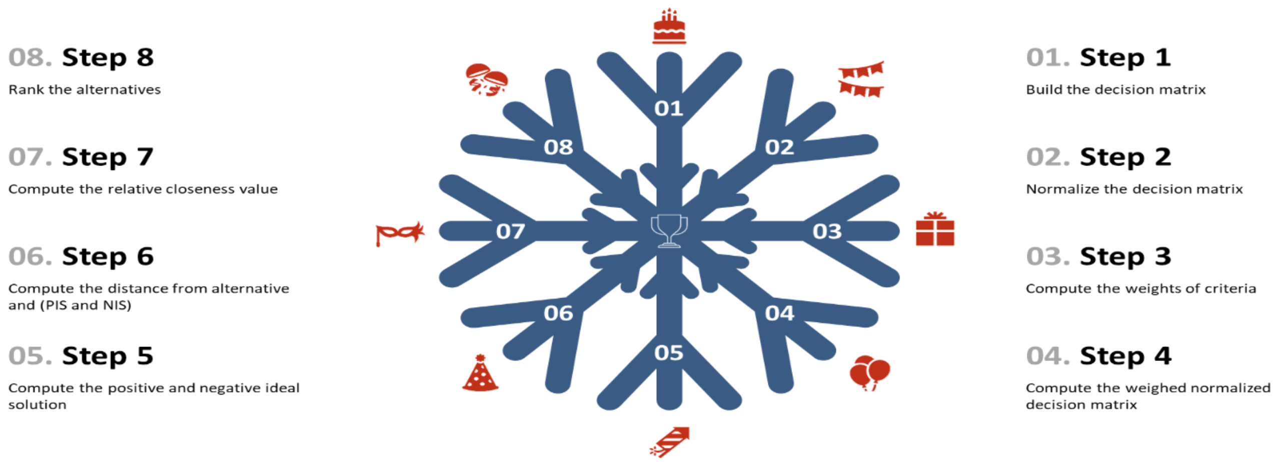

Figure 1: The steps of the TOPSIS fusion method.

Step 1. Build the decision matrix.

The decision matrix is built by using the criteria and alternatives of the selection problem. Experts used a scale from 1 to 9 to evaluate the criteria and alternatives.

Step 2. Normalize the decision matrix

The decision matrix is normalized using Eq. (1) as:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (1)$$

Step 3. Compute the weights of the criteria

The weights of criteria are computed using the average method and all criteria are ranked according to their importance.

Step 4. Compute the weighted normalized decision matrix

The weights of criteria are multiplied by the normalization matrix to compute the weighted normalized decision matrix as:

$$r_{ij} = w_j y_{ij} \quad (2)$$

Step 5. Compute the positive and negative ideal solution.

The positive and negative ideal solutions (PIS and NIS) are computed based on the cost and positive criteria. So we determined the positive and cost criteria in this study.

$$r_j^+ = \begin{cases} \max\limits_{i=1,2.,,,n} r_{ij} & for\ positive\ criteria \\ \min\limits_{i=1,2.,,,n} r_{ij} & for\ negative\ criteria \end{cases} \quad (3)$$

$$r_j^- = \begin{cases} \min\limits_{i=1,2.,,,n} r_{ij} & for\ positive\ criteria \\ \max\limits_{i=1,2.,,,n} r_{ij} & for\ negative\ criteria \end{cases} \quad (4)$$

Step 6. Compute the distance from alternative and (PIS and NIS)

$$t^+(x_i) = \sqrt{\sum_{j=1}^{m} (r_{ij} - r_j^+)} \quad (5)$$

$$t^{-}(x_i) = \sqrt{\sum_{j=1}^{m}\left(r_{ij} - r_j^{-}\right)} \quad (6)$$

Step 7. Compute the relative closeness value

$$U_i = \frac{t^{-}(x_i)}{t^{-}(x_i)+t^{+}(x_i)} \quad (7)$$

3. Results

In this section, we introduce the results of the TOPSIS fusion method. We select the best strategy for charging the electric bus. We collect the 20 criteria and 5 alternatives from the previous studies as:

- EBC1. Integration with Renewable Energy
- EBC2. Regularity Considerations
- EBC3. Integration charging infrastructure
- EBC4. Energy Demand and Battery Capacity
- EBC5. Rout compatibility
- EBC6. Grid Capacity and Power Demand
- EBC7. Power Supply
- EBC8. Job Opportunity
- EBC9. Depot Availability
- EBC10. Charging Infrastructure
- EBC11. Fire Risk
- EBC12. Investment Cost
- EBC13. Operational Schedule
- EBC14. Accessibility to Charge
- EBC15. Operational Experience
- EBC16. Environmental Considerations
- EBC17. Operational Cost
- EBC18. Charging Seed and Infrastructure
- EBC19. Potential Return Investment
- EBC20. Bus Route Access

The alternatives used in this study are:

- ECS1. Overnight Depot Charging: The depot or bus station is where buses are charged overnight.
- ECS2. Battery Swapping: At designated stops, passengers may swiftly swap out the bus's detachable battery packs for fully charged ones.
- ECS3. Opportunity Charging: Short pauses or layovers are charged at particular places along the itineraries of buses.
- ECS4. Mixed Charging Strategy: The unique requirements of the bus system dictate the use of a mix of several charging schemes.
- ECS5. In Route Charging: The charging infrastructure is seamlessly incorporated into the highway or bus lanes, enabling the bus to be charged continuously even while in motion.

Step 1. We build the decision matrix between 20 criteria and 5 alternatives. The experts evaluate the criteria and alternatives by using a scale from 1 to 9. 1 indicates the low value and 9 indicates the largest value.

Step 2. Eq. (1) is used to normalize the decision matrix between criteria and alternatives as shown in Table 1.

Table 1: The normalization decision matrix by the TOPSIS fusion method.

	ECS_1	ECS_2	ECS_3	ECS_4	ECS_5
EBC_1	0.11547	0.34641	0.69282	0.57735	0.23094
EBC_2	0.280056	0.70014	0.280056	0.420084	0.420084
EBC_3	0.431934	0.518321	0.518321	0.086387	0.518321
EBC_4	0.474342	0.474342	0.474342	0.316228	0.474342
EBC_5	0.558744	0.558744	0.139686	0.209529	0.558744

EBC$_6$	0.618718	0.441942	0.441942	0.176777	0.441942
EBC$_7$	0.727607	0.16169	0.485071	0.323381	0.323381
EBC$_8$	0.508913	0.254457	0.254457	0.593732	0.508913
EBC$_9$	0.30429	0.365148	0.486864	0.486864	0.547723
EBC$_{10}$	0.156652	0.156652	0.548282	0.704934	0.39163
EBC$_{11}$	0.323498	0.431331	0.431331	0.646997	0.323498
EBC$_{12}$	0.421076	0.084215	0.757937	0.421076	0.252646
EBC$_{13}$	0.707107	0.392837	0.471405	0.31427	0.157135
EBC$_{14}$	0.604743	0.453557	0.377964	0.52915	0.075593
EBC$_{15}$	0.392232	0.196116	0.196116	0.784465	0.392232
EBC$_{16}$	0.078326	0.234978	0.469956	0.704934	0.469956
EBC$_{17}$	0.160644	0.722897	0.240966	0.481932	0.40161
EBC$_{18}$	0.328266	0.393919	0.590879	0.19696	0.590879
EBC$_{19}$	0.707107	0.235702	0.157135	0.157135	0.628539
EBC$_{20}$	0.313112	0.375735	0.563602	0.500979	0.438357

Step 3. Then we compute the weights of the criteria. Let three experts evaluate the criteria on a scale from 1 to 9. Then by the average method, we compute the weights of criteria as shown in Figure 2. The results show that criterion 4 is the best and criterion 15 is the worst in all criteria.

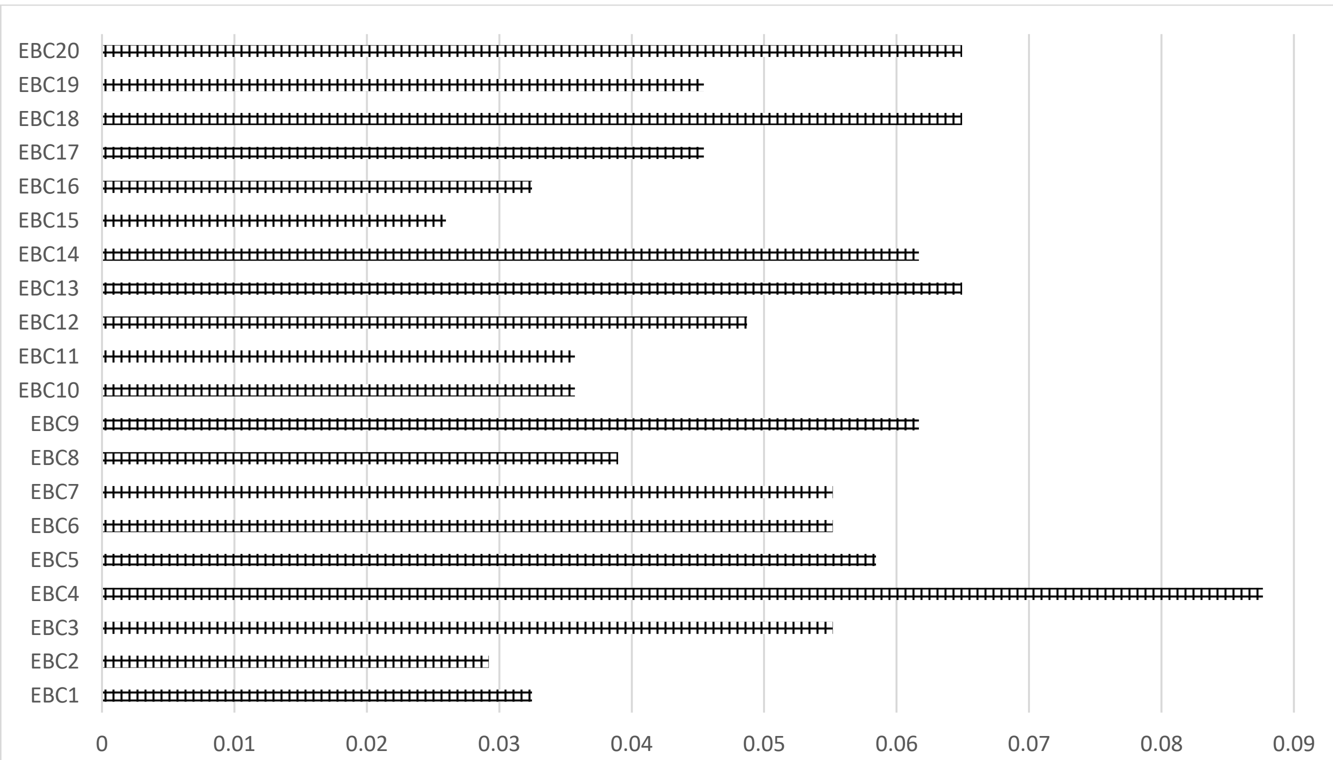

Figure 2. The weights of 20 criteria in the electric bus charging method.

Step 4. Eq. (2) is used to compute the weighted normalized decision matrix as shown in Table 2.

Table 2. The weighted normalization decision matrix by the TOPSIS fusion method.

	ECS$_1$	*ECS*$_2$	*ECS*$_3$	*ECS*$_4$	*ECS*$_5$
EBC$_1$	0.003749	0.011247	0.022494	0.018745	0.007498
EBC$_2$	0.008183	0.020459	0.008183	0.012275	0.012275
EBC$_3$	0.023841	0.028609	0.028609	0.004768	0.028609
EBC$_4$	0.041582	0.041582	0.041582	0.027721	0.041582

EBC_5	0.032654	0.032654	0.008163	0.012245	0.032654
EBC_6	0.03415	0.024393	0.024393	0.009757	0.024393
EBC_7	0.04016	0.008924	0.026773	0.017849	0.017849
EBC_8	0.019828	0.009914	0.009914	0.023132	0.019828
EBC_9	0.018771	0.022525	0.030034	0.030034	0.033788
EBC_{10}	0.005595	0.005595	0.019582	0.025176	0.013987
EBC_{11}	0.011554	0.015405	0.015405	0.023107	0.011554
EBC_{12}	0.020507	0.004101	0.036913	0.020507	0.012304
EBC_{13}	0.045916	0.025509	0.030611	0.020407	0.010204
EBC_{14}	0.037306	0.027979	0.023316	0.032642	0.004663
EBC_{15}	0.010188	0.005094	0.005094	0.020376	0.010188
EBC_{16}	0.002543	0.007629	0.015258	0.022887	0.015258
EBC_{17}	0.007302	0.032859	0.010953	0.021906	0.018255
EBC_{18}	0.021316	0.025579	0.038369	0.01279	0.038369
EBC_{19}	0.032141	0.010714	0.007142	0.007142	0.02857
EBC_{20}	0.020332	0.024398	0.036598	0.032531	0.028465

Step 5. Eqs. (3 and 4) are used to compute the positive and negative ideal solutions. All criteria are positive except the cost criteria are negative criteria.

Step 6. Eqs. (5 and 6) are used to compute the distance from alternative (PIS and NIS)

Step 7. Eq. (7) is used to compute the relative closeness value as shown in Figure 3. The results show that overnight charging is the best strategy for the electric bus.

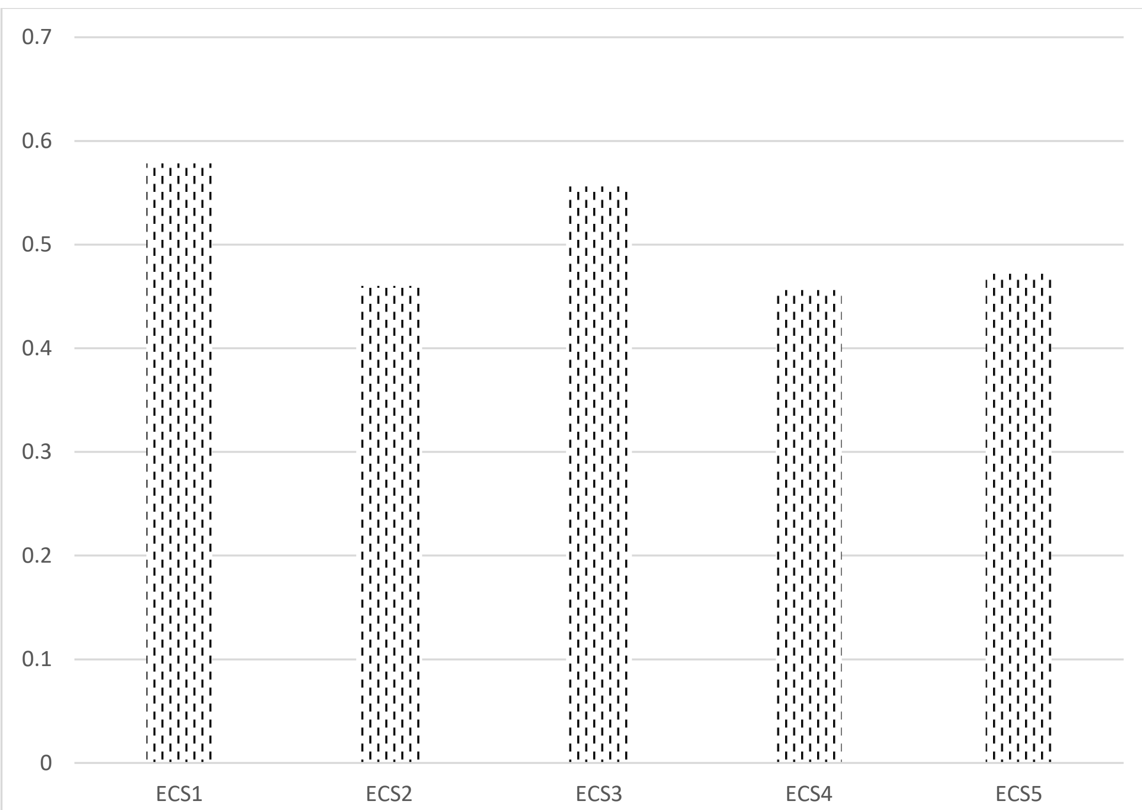

Figure 3: The values of closeness by the TOPSIS fusion method.

We applied the sensitivity analysis in this study to ensure the stability of the results. We obtain the 20 cases in weights of criteria as shown in Figure 4. In the first case, we put the first criterion with 0.055 weight, and other criteria are equal in weight.

Then we apply the TOPSIS fusion method to the 20 cases in weights of criteria. We obtain the 20 ranks by the TOPSIS MCDM methodology as shown in Figure 5. The results are stable and the proposed model is efficient.

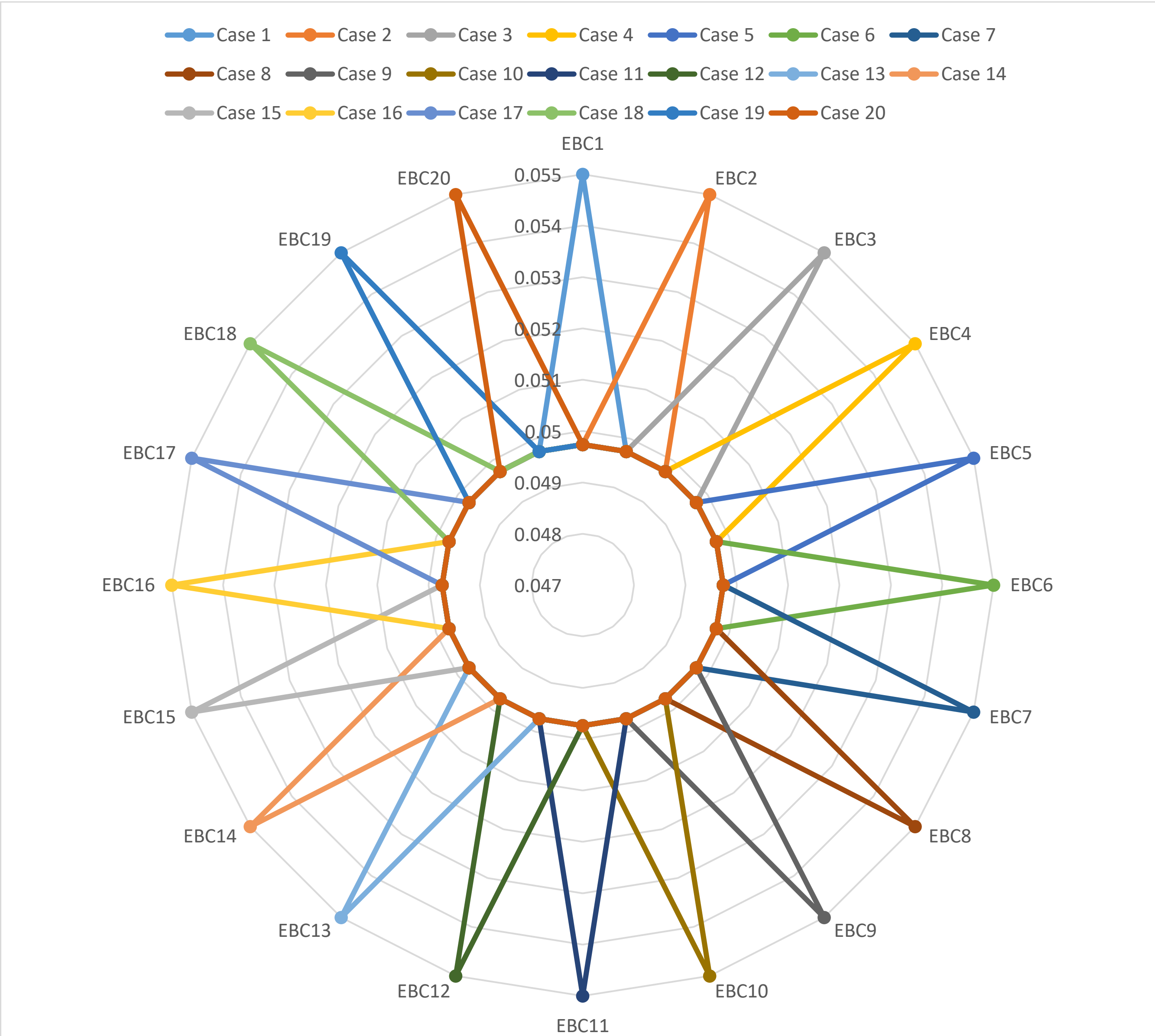

Figure 4: The 20 cases are in weights of criteria.

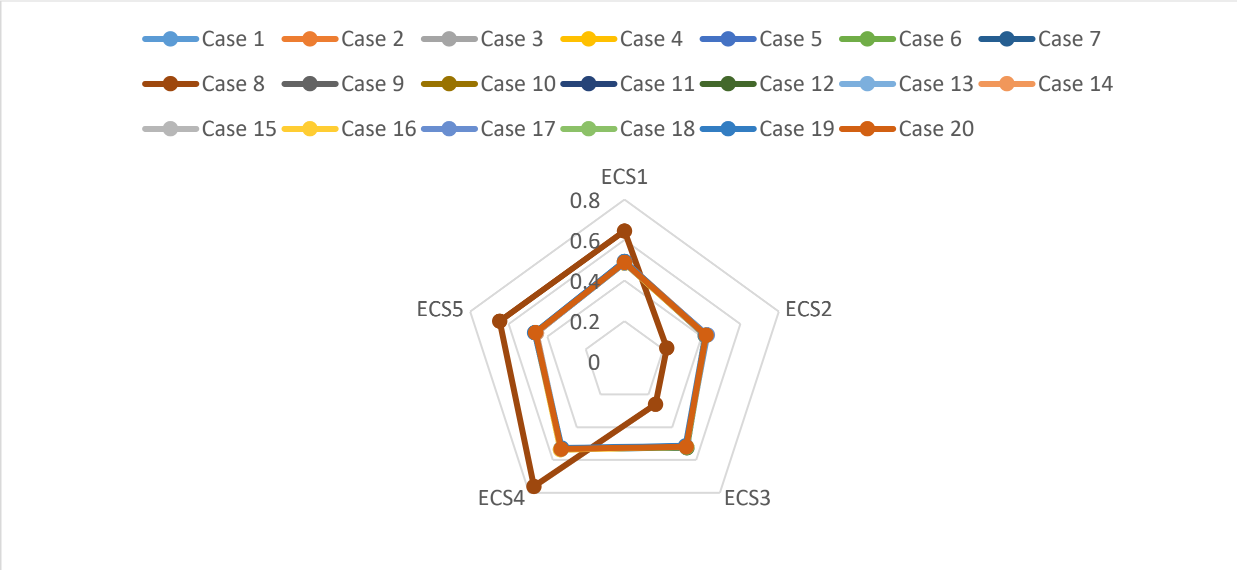

Figure 5: The closeness values under different weights of criteria.

4. Conclusions

Choosing a charging plan for electric bus systems is an important choice that affects the transportation operation's efficiency, efficacy, and overall success. The bus system's particular needs and limitations and the operators' objectives must be carefully considered to arrive at a well-informed decision.

Considerations such as energy demand, operational schedules, downtime, charging speeds, infrastructure availability, grid capacity, cost, scalability, integration with renewable energy, regulatory compliance, and industry best practices should all be part of a comprehensive evaluation before settling on a charging strategy. Transportation authorities and fleet operators may choose the best pricing approach for them by considering these factors.

Electric bus systems may use various charge techniques, such as overnight depot charging, in-route charging, battery swapping, opportunity or top-up charging, or a mix of these methods. Bus system specifics like route lengths, timetables, and charging infrastructure availability should be considered when choosing from many strategies, each with its own set of benefits and drawbacks.

Time to charge, required range, cost-effectiveness, and infrastructure availability must all be carefully considered. The optimal charging approach will minimize downtime and maximize the usage of charging infrastructure while ensuring that buses have enough energy to run safely and effectively.

It is also essential to think about how the approach will scale and adapt to new technologies in the future as part of the selection process. As new charging methods like wireless and ultra-fast charging gain traction, evaluating their viability for integration may be necessary.

Selecting an appropriate charging method that caters to the specific requirements of the transportation operation is crucial to effectively installing an electric bus system. Maximizing the advantages of electric buses, reducing emissions, improving air quality, and contributing to a sustainable and efficient public transportation system may be achieved by transportation authorities and fleet operators by adopting a well-suited charging plan.

We used an MCDM fusion method to analyze the criteria and select the best alternative. We used 20 criteria and five alternatives in this study. These criteria and alternatives are collected from previous studies. We used the TOPSIS method as an MCDM fusion method to combine the criteria and alternatives to select the best electric bus charging strategy. We compute the weights of criteria by the average method. We show that criterion 4 is the best and criterion 15 is the worst. We used these weights as input to the TOPSIS fusion method. The alternative overnighting strategy is the best method for charging electric buses. We conducted the sensitivity analysis to show the stability of the results.

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