Assessing Feasibility of overnight-charging electric bus in a real-world BRT system in the context of a developing country

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Abstract

Air pollution, as a significant urban problem in metropolises, has harmful impacts on societies in many aspects. According to the worn-out fleet of diesel buses and fossil fuel dependencies in Tehran, alternative fuels have become more popular in sustainable public transportation. Although battery electric buses (BEBs) provide many benefits, their purchase price and required infrastructure are the main challenges for decision-makers. This paper provides a systematic approach to examining the environmental, traffic, and economic efficiency of overnight-charging electric buses (OCEBs) in Tehran, Iran. Environmental analysis shows that Carbon Oxide and Nitrogen Oxide will reduce to zero and eliminate dependence on fossil fuels. The payback period is predicted to be 7 years. Due to the better acceleration of OCEBs, the travel time, delay, and stop time reduce by about 4%, 10.67%, and 5.15% on average, respectively, which leads to a better experience for passengers and an increase in public transportation utility that cause more people attract to OCEBs. The present results indicate the feasibility of OCEBs implementation as a sustainable transportation mode and can be useful in policymakers' decision-making and planning for the future public transport system.

Keywords: Overnight-Charging Electric Bus, Microscopic Traffic Simulation, Benefit-Cost Analysis, GHG emission, Payback Period

1- Introduction

Air pollution is one of the most complex metropolitan problems, and it has adverse impacts on many aspects of the world [1]. According to World Health Organization, 4.2 million people worldwide and about 27 thousand in Iran die each year from air pollution [2]. Emissions in the transportation sector were responsible for 23% of global emissions in 2013, 75% of which were related to road transport, an increase of 68% compared to 1990 [3]. Diesel engines are the leading cause of carcinogenic gases that highlight the need for moving toward a sustainable and green public transportation system as an essential policy to reduce transport sector pollutants [4-6].

Governments all over the world have taken some steps toward switching diesel buses (DBs) with sustainable energy buses to minimize greenhouse gas (GHG) emissions [7-9]. Among different types of alternative fuels for buses, electric buses (EBs) are more suitable for emission production and energy consumption than conventional buses [10-11]. The innovation of lithium-ion battery (LIB) technology has turned electric vehicles into a renewable mobility alternative over the last decade that requires minimal maintenance. Some studies conclude that LIB technology is still developing, and the reliability, specific energy, and quality of such technology could be still enhanced over time. The number of urban EBs is currently growing, but the main concern of policymaking is the required infrastructures and high cost of investment [12-13]. The total operating cost of EBs is lower than internal combustion engine buses (ICEB) because of higher fuel efficiency, lower electricity price, and maintenance, but high initial investment including purchasing cost and charging facilities, make EBs pricey. The battery-electric buses (BEBs), also known as pure electric buses, are operated using an onboard battery package. According to the range and charge time of BEBs, they have two modes of operation: opportunity and overnight. The opportunity electric buses (OPEBs) have a smaller battery pack with a short range (20–30 miles) and take 5–10 minutes to get a full charge (80% – 100%), while the overnight-charging electric buses (OCEBs) equip with a relatively larger battery pack with a range of up to 200 miles and a much longer charging time (2–4 h) [14]. PROTERRA, one of the well-known manufacturers of EBs, claimed that E2max OCEBs’ charging time is about 5 hours and the range is 560 km, although these values might vary under different conditions. One of the main advantages of OCEBs is their flexibility in operating on different routes; also, unlike OPEBs, the charging infrastructure is concentrated at only one or two points, but on the other hand, due to their larger batteries, OCEBs are heavier than OPEBs [15]. Although OCEBs have a higher purchase cost than OPEBs, they have lower charging infrastructure costs than OPEBs. In terms of lifetime operation costs, OCEBs and OPEBs are almost the same (0.44 vs. 0.42 €/km), but in terms of the total cost of ownership per kilometer, OCEBs are 5% cheaper than OPEBs. OPEBs require charging stations along their routes and also need to be fully recharged overnight at the depot. OPEBs are restricted in providing service because their route is limited to an area where only the charging system is established, and the charging time must be considered in the bus
schedule, which may lead to service disruption [16]. From the perspective of the urban environment, health, and noise pollution, it is necessary to mention that OPEBs cause various problems such as additional space for infrastructure installation, power cables along with the route/pavement, noise pollution, destruction of the beautiful appearance of the urban environment at charging stations and safety issues in the neighborhood of charging infrastructure due to the implementation of charging stations along the route [17]. According to the aforementioned pros and cons of different types of BEBs, we consider OCEBs as the more appropriate option for public transportation in Tehran, Iran.

This paper aims to provide a systematic approach to examining the environmental, traffic, and economic efficiency of OCEBs under different operating conditions in Tehran. The main contributions of this paper are: 1) Most previous studies were conducted in developed, high-income countries. While in this paper, OCEBs' operation and their impacts have been studied in Tehran, Iran, as a developing country; 2) Less attention has been paid to the effects of OCEBs on mixed traffic flow, travel time reduction, and longitudinal slope, which we addressed these gaps in our study; 3) Most previous studies used economic approaches such as life cycle assessment (LCA), but we used microscopic simulation and economic analysis simultaneously to evaluate traffic, environment and economic impacts of OCEBs.

Many researchers studied BEBs in different countries. In most cases, they concluded that BEBs are zero tailpipe emission, reduce fossil fuel dependency, and are economically justified in life cycle (12 years) costs [7, 18-24].

Xylaia et al. investigated the impacts of electrifying Stockholm's bus fleet to reduce Carbon Oxide (CO). They used an optimization model to locate chargers and estimate emissions using LCA in different operation scenarios. Their results showed the reduction of local pollutants in the city of Stockholm by using BEBs [19]. Song et al. compared BEBs and DBs based on LCA and GHG emissions. They concluded that BEBs have the potential to significantly reduce GHG emissions, especially in clean power mixes [20]. Mahmoud et al. evaluated different aspects of hybrid, fuel cell, and battery-electric buses. The examined buses were hybrids (series and parallel), fuel cells, BEBs (overnight and opportunity), and diesel. They concluded that fuel cell and BE buses had an efficient performance, and overnight BEB was chosen as the best solution [22]. Yu conducted a study on using EBs in the Hong Kong public transportation system to evaluate their public acceptance and environmental impacts. He concluded that BEBs have long-term payback periods and no exhaust emissions. Besides, the barriers to public acceptance of BEBs were lack of infrastructure support, battery capacity, and battery anxieties [24]. Lajunen and Lipman investigated LCA and CO emissions of BE, fuel cell, diesel, and natural gas buses. Life cycle costs include purchase, service, maintenance, and potential CO emission costs. According to the simulation results, alternative fuels significantly improve the efficiency of the buses. BEBs substantially reduce CO emissions and energy consumption by 75% [7]. The Global Green Growth Institute conducted a comprehensive study of India's public transportation system, outlined the benefits of EBs, and explored the implications of their operations. It was concluded that EBs do not have any exhaust emissions as the main cause of air pollution in urban areas [14]. Aber conducted a study on the implementation of EBs in the New York bus fleet and examined their economic, health, and environmental impacts. He found that replacing the current fleet with the EBs reduces the air pollution caused by DBs and the life cycle cost (12 years) of EBs is 12.5% lower than DBs [21].

According to the literature review, it can be concluded that OCEBs are an appropriate solution for clean transportation, and their high cost is related to battery, complexity of system design, and their new and emerging technology. The complexities of BEB operations make decision-making challenging, so it is essential to thoroughly examine the different technology options and operating models of BEBs.

The article is presented in the following way: data and methods are discussed in the 'Methodology' section, the results and discussion are presented in the 'Data Analysis' section, and the 'Conclusions' section provides the main conclusions, limitations, and recommendations for future studies.

2- Methodology

Microscopic simulation models are becoming increasingly popular tools for designation, optimization, and analysis of transportation networks and management policies [25-26]. We used Aimsun as a microscopic simulation tool to simulate the operation of OCEBs on bus rapid transit (BRT) line 7 in Tehran, Iran. Afterward, outputs are assessed based on different aspects such as economic feasibility as well as environmental and traffic performance. Figure 1 illustrates the flowchart for the proposed methodology.

It is north worthy that Aimsun equipped with pollutant emission model to calculate different emission rates in various traffic flow and geometric conditions [27]. Many studies used Aimsun pollutant emission model to analyze the environmental impacts of their proposed scenarios [28-30]. Aimsun calculates different pollutant emissions of vehicles based on vehicle and fuel types factors in three modes of acceleration, deceleration, and idling. Afterward, the emission rate of each vehicle will be calculated based on the slope of the streets and the speed of traffic flow. Finally, Equations 1 to 3 will be used to calculate the emission rate using Panis et al. model [27]. According to the studies, CO and NOx are
the most critical and hazardous pollutants that could be studied and analyzed in terms of their environmental impacts in Aimsun [31].

\[
ER_{seg} = \frac{E_{seg}}{L_{seg} \cdot t_{seg}} \quad (1),
\]

\[
E_{seg} = \sum_{i} ER_{i} \cdot VP_{i} \cdot L_{seg} \quad (2),
\]

\[
L_{seg} = V_{seg} \times 3600 \quad (3),
\]

where, \(ER_{seg}\) accounts for segment emission rate, \(ER_{i}\) is emission rate of vehicle \(i\), \(VP_{i}\) shows the number of vehicle \(i\), \(t_{seg}\) accounts for segment travel time, \(L_{seg}\) is the segment length and \(V_{seg}\) is the segment speed.

Moreover, traffic data and other related information have been collected from field surveys and organizations [32]. Firstly, we use input data to model the case study, including route geometry, stations, schedules, buses, and the infrastructure. A large amount of data is required for the microscopic simulation of BRT in Aimsun. Such data includes the digital map of the site for exact drawing, route information including path length, longitudinal slope, number of lanes, and lane width. It also requires intersection information, including traffic flow of each approach legs, control type, traffic signs and signals, surface marking, turnings, traffic signals timing, and precise detector location. Public transportation system information such as buses' physical and technical characteristics, headways, timetables, station locations, infrastructure information, station stopping times, the distance between stations, etc., is also required. After collecting the data needed, the 7th line of BRT in Tehran was simulated with default parameters. To achieve more reliable outputs, calibration and validation of the simulation model were conducted through the comparison of field and simulated data to increase model accuracy and confidence. The calibration and validation processes will be discussed in section 3.1. Afterward, we simulated OCEBs as a sustainable transportation mode in Aimsun and derived the important outputs such as travel time, speed, delay, flow, emissions, and fuel consumption.

2.1 The environment under analysis: the city of Tehran

As the capital of Iran, Tehran is the most congested and populated city in Western Asia, with a population of around 8.8 million people. It has suffered from congestion and air pollution due to the growth in urban population and car ownership. Local authorities are trying to reduce severe air pollution by introducing sustainable and green transportation [31]. The seventh line of Tehran’s BRT is one of the most extended lines (18 km) of public transit, which transfers a large number of passengers from the northernmost point of Tehran to the southern point. All along the bus route, there is a dedicated and exclusive lane. Based on Tehran public transportation administration reports, this line transfer 220,000 passenger daily, and the average travel time at peak hour is about 80 minutes. Figure 2 illustrates the 7th line of BRT in Tehran scheme [32]. More than 70% of Tehran's pollutants are emitted by clunker buses because 97% of buses are old, and more than 80% of urban air pollution is induced by low-quality fuel [33]. In this regard, we simulated the 7th line of Tehran's BRT operation, and after calibration and validation of the model, OCEBs as sustainable public transportation were analyzed. Traffic simulation and economic analysis are conducted to derive the required outputs in the next section.

3- Data analysis

3.1 Traffic simulation

To simulate the real operation of buses, calibration as the process of determining the model parameter’s values is crucial [34]. A well-calibrated model needs to assign a reasonable value to each vehicle to accurately simulate the dynamic interactions in the traffic flow in the sense of mixed-traffic operations, where numerous fast and slow-moving modes create a complex environment [35]. This paper selected traffic flow and travel time parameters for calibration. After calculating appropriate values, we compare the volume of vehicles at different intersections to complete the calibration process. Figure 3 compares the field and simulated volume data. Given the R square of 0.95 and root mean square (RMS) of 2.7, it was found that the calibration of the model is performed properly. In the case of travel time, simulated and field data were compared, and the calculated RMSE (Equation 4) was 1.23. Also, the emission rate of buses in the simulation model has been compared with the real data, and no significant differences have been observed at a 95% confidence interval (Figure 4).
\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2} \]  

Where, \( n \) is the number of iterations in the simulation model, \( y_i \) represents the observed value and \( \hat{y}_i \) is the predicted value in the model.

Validation is an essential phase in the model development process to assess the model's reliability. In addition, no model can be confirmed till the validation checks have been passed [36]. Validation is defined as the process of testing the model with data that are independent of the data used in the calibration to examine the model's appropriateness in reproducing the reality. In this regard, the validation of the simulated model was performed for another day, and the results indicated that the model works accurately.

After simulating the operation of the 7th line of Tehran's BRT and calibration and validation of the model, travel time and environmental indicators were calculated. Given the stochastic nature of the simulation, it is necessary to run multiple replications and compute the average to derive the results [37]. Therefore, according to the proposed equations and studies, 10 replications are considered to calculate the average of required outputs. The simulation environment of the network is presented in Figure 5. Also, the exclusive BRT lane (Figure 5.a) and the impacts of different elements in signal timing, such as pedestrian volume is illustrated in Figure 5.b.

Regarding the old bus fleet of Tehran, OCEBs were simulated as a solution. Operational characteristics of BYD, 18m-Battery Electric Bus were used as input parameters in Aimsun and required outputs were derived [38], illustrated in Figure 6.

As DBs experienced long stops at intersections, they faced environmental problems such as increased fuel consumption and pollutant emissions. Besides, stop-go driving led to an increase in air pollution because of the longitudinal slope of the route. Hence, we have attempted to enhance the system's efficiency by replacing the existing fleet with OCEBs. Compared to conventional buses, OCEBs provide zero tailpipe emission, silent movement, improved acceleration, reducing fleet operating costs, and minimizing fossil-fuel dependence [17, 19-21]. Regarding better acceleration of OCEBs, the travel time was reduced by about 4%, and passengers faced lower delays, leading to an increase in public transportation utility. More people will attract to OCEBs. Regarding zero tailpipe emission and no diesel consumption of OCEBs [17, 19-21], CO and NOx emissions eliminated and reduced fossil fuel dependencies.

Regarding the importance of traffic performance assessment in projects, we investigated various indicators such as average speed, delay, flow, density, and stop time. Figure 7 illustrates the traffic performance indicators of OCEBs compared with DBs. As it could be seen, the delay and stop time of OCEBs are less than DBs. According to electric buses' better acceleration and power, OCEBs reduced delays and stop time by 10.67% and 5.15% on average, respectively. Moreover, flow, density, and average speed increased by 3%, 3.1%, and 2.93% on average, respectively. According to the aforementioned traffic performance indicators, it is founded that OCEBs are more appropriate than DBs. In this regard, they are a suitable solution for traffic and environmental problems in Tehran, but due to their high capital cost, an economic analysis should be conducted to justify their implementation.

### 3.2 Economic Analysis

Benefit-cost analysis (BCA) accounts for the costs and benefits variation attained by a potential enhancement to the existing facilities [39]. BCA can be used in decision making to help assess whether 1) A project should be implemented or not; 2) When a project should be implemented; BCA may show that a project does not pass the economic tests now, but 10 years later, it would be worthwhile; and 3) Which scenario should be funded regarding the limited resources, among several competing alternatives and plans. Considering the high capital cost of OCEBs, careful BCA should be conducted to assess the implementation feasibility and the potential benefits and costs to calculate the payback period.
3.2.1 Travel time saving value

In Aimsun, travel time accounts for the average time that it takes for each bus to travel on a specific route [40] and is calculated using Equation (5).

\[ TT_i = \frac{TEX_i - TEN_i}{D_i} \times 1000 \]  

(5)

Where the entry time of the \( i \)-th bus is recorded as \( TEN_i \) (sec), and its corresponding exit time is stated as \( TEX_i \) (sec). \( D_i \) accounts for the total distance traveled of vehicle \( (i) \) in meter, and the average travel time per km of vehicle \( (i) \) is presented by \( TT_i \) (sec). Value of time (VOT) is calculated according to Equation (6) to determine the financial value of passengers’ times [31-32].

\[ VOT_B = \frac{s}{T \times 12 \times D} \]  

(6)

where \( VOT_B \) is the VOT of passengers ($/hr), \( s \) is the average annual household income ($), \( T \) is the average monthly working hours (hr) and \( D \) accounts for the household size. Regarding passengers’ information and statistics published by the Central Bank of the Islamic Republic of Iran and the Bureau of Economic Statistics, the VOT is calculated as $1.5 per hour (1 US Dollar is equivalent to 42,105 Iranian Rials [41]).

Considering $1.5 per hour and transferring of 220,000 passengers on this line, the amount of time saved by travelers is calculated in relative terms. According to studies conducted by various scientists, the efficiency and superiority of OCEBs are long-term, and their benefits and costs should be considered during their life cycle costs (12 years) using time series data [19, 21]. It should be noted that we have used Holt-Winters method to forecast the required values using XLSTAT software. Holt-Winters method, also known as triple exponential smoothing, comprises three smoothing equations: 1) The first part is called the average or level, which shows the general behavior of the model; 2) The second part is the trend (line slope), which is constant in time but is considered as the parameter of variables; 3) The third section, which changes periodically, is also used to show seasonal changes [42].

The Holt-Winters time series model’s simple form (without trends and seasonal changes) is presented as Equation 7.

\[ S_t = \alpha \frac{y_t}{I_{t-L}} + (1 - \alpha)(S_{t-1} + b_{t-1}) \]  

(7)

where \( y_t \) is the observed value corresponding to time \( t \) and \( S_t \) is the smoothed value at time \( t \). Moreover, \( I \) is a seasonal index, and \( L \) is the length of the seasonal changes period. If the model has a trend, the model specification will be shown using Equation 8.

\[ b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma)b_{t-1} \]  

(8)

In case of seasonal changes, the Equation 9 should also be considered as the model specification.

\[ I_t = \beta \frac{y_t}{S_t} + (1 - \beta)I_{t-L} \]  

(9)

Using statistics and information available in the Iranian Statistical Organization, the VOT was calculated from 2002 to 2018 and predicted with a 95% of confidence interval for the next 12 years using times series method (Figure 8). According to the VOT and number of passengers, the financial value of reduced travel time is predicted to be about $209 million during the lifetime of OCEBs.

3.2.2 CO and NOx Elimination Costs

In the research conducted by Boardman et al. (2017), the estimated CO and NOx reduction costs were about $890 per ton and $4790 per ton in 2016, respectively. The costs account for some issues that affect direct and indirect aspects of human life. Regarding 12-year life cycle of OCEBs, CO and NOx costs are forecasted using times series data obtained from previous studies and illustrated in Figures 9 and 10, respectively [43].
The financial value of CO and NOx elimination is predicted to be about $1.62 and $1.25 million over the lifetime of OCEBs (12 years), respectively.

### 3.2.3 Diesel Consumption Elimination Costs

Regarding OCEBs not consuming diesel and reducing fossil fuel dependencies, the diesel cost elimination should be considered a benefit of these vehicles. Regarding 12-year life cycle of OCEBs, the cost of diesel is also predicted using time series method. For this purpose, using statistics and information available from the Iranian Census Bureau and Knoema [44], we extract the diesel price from 2002 to 2018 and predict the price with a 95% confidence level for the next 12 years using statistical methods is illustrated in Figure 11.

The financial value of diesel consumption elimination is predicted to be about $140 million over the lifetime of OCEBs (12 years).

### 3.2.4 Electricity Consumption Cost

It is important to note that, given previous research, a limited number of OCEBs are tested in developed countries, and their power consumption is measured in the field. BYD, the OCEB that we considered as the case of our research, is capable of travelling on routes with a maximum slope of 15% and its power consumption is estimated at 1.5 kW/km [38]. After simulating the BYD bus in Aimsun and considering the electricity consumption profile as a Normal distribution (N(1.5, 0.5)), we estimate the electricity price during the lifetime of OCEBs with a 95% confidence level, illustrated in Figure 12. The total kilometer traveled by the fleet is about 3560 km, and the total electricity consumed is estimated to be about 5380 kW.

The financial value of the power consumption of OCEBs is predicted to be about $1.05 million over the lifetime of OCEBs (12 years).

### 3.2.5 Purchase Price of OCEBs and charging infrastructures as a new transportation fleet

According to the information gathered from the Tehran Bus Organization, Line 7 has 200 DBs. In order to replace the current fleet with the BYD OCEBs, their purchase price should be considered in the economic analysis. Regarding the exhaustion of the existing fleet, the sale price of DBs has been neglected. According to [38], the cost of each OCEB is $950,000, and since there are 200 buses in the current fleet, the total cost of OCEBs would be $190 million. Regarding OCEBs equipped with an overnight charging method, the cost of the charging infrastructure should be taken into account at the depot location (Railway and Tajrish Square). In Aspen, US, it costs about $40,000 to set up a charging station, and regarding 200 new OCEBs in the new fleet, $8 million should be considered for this purpose in the BCA [45].

### 3.2.6 Return on investment

One of the investment evaluation methods is the payback period, which helps determine when an investment's initial cash outflow is supposed to be recovered from the cash inflows provided by the investment [46]. In this paper, the monetary aspects of travel time saving, elimination of pollutant emissions and fuel consumption reduction account for the benefits and the purchasing price of charging infrastructure, OCEBs and electricity consumption incorporate costs (Figure 13). Regarding the long term return of investment of OCEBs, the payback period of the investment was estimated about 7 years in Tehran; This value varied between 5 to 8 years in previous studies based on the level of countries' development and their public transportation system [18, 24, 47].

Furthermore, Net Present Value (NPV) and Internal Rate of Return (IRR) have been calculated to assess the economic aspects of OCEBs. NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time, and IRR is a discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis which is calculated using Equations 10 and 11, respectively.

\[
NPV = \sum \frac{C_t}{(1 + r)^t} - C_0 \tag{10}
\]

\[
\sum \frac{C_t}{(1 + IRR)^t} = C_0 \tag{11}
\]
Where $C_0$ is the initial investment, $C_t$ represents the cash flow, and $r$ is the discount rate (5%). According to the calculated costs and benefits of OCEBs during their life cycle, the NPV and IRR are $74.75 million and 12%, respectively, indicating the efficiency and profitability of these vehicles.

4. Conclusion

Despite many benefits of Overnight Charging Electric Buses (OCEBs), such as zero tailpipe emission, silent movement, improved acceleration, reducing fleet operating costs and minimizing fossil-fuel dependence, their purchase price and required infrastructure are the main challenges of decision-makers. Hence, it is crucial to thoroughly evaluate their performance before implementing them in a real-world network. This paper provides a systematic approach to examining the environmental, traffic and economic impacts of OCEBs under different operating conditions in the 7th line of Tehran's BRT.

Results show many environmental, economic, and social benefits of implementing OCEBs in the 7th line of Tehran's BRT. In terms of the environmental impacts of these vehicles, it was concluded that by converting diesel buses (DBs) to OCEBs, Carbon Oxide (CO) and Nitrogen Oxide (NOx) would be reduced to zero and eliminate dependence on fossil fuels. Also, implementing OCEBs is critical to improving urban health because of less noise and air pollution related to fossil fuels. In terms of economic analysis, the payback period, net present value, and internal rate of return of these vehicles have been calculated. The payback period of OCEBs is predicted to be about 7 years, and their benefits are expected to be $173 million until their lifetime length (i.e. 12 years). In terms of traffic performance of OCEBs, travel time was reduced by about 4%, delay and stop time were decreased by approximately 10.67% and 5.15% on average, respectively, due to better acceleration of OCEBs. Also, flow, density, and average speed increased by about 3%, 3.1%, and 2.93% on average, leading to a better experience for passengers and an increase in public transportation utility that caused more people to attract OCEBs.

The current study has some limitations. Firstly, the main outcomes can only be generalized to the Iranian city and similar Middle East urban environments. Nevertheless, they cannot be applied to other countries or cultures because of their different perspectives. However, the above raises some discussion points useful for the next comparative studies exploring the differences in the environment and public transportation systems in other countries. It is important to note that it is difficult and sometimes impossible to evaluate all the costs involved in transportation systems; in this regard, it is recommended to consider the impact of noise pollution and people shifting to OCEBs in economic analysis for further research. Also, it is recommended to conduct a comparative study between the OCEBs and electric opportunity bus to achieve more insightful findings in choosing the most appropriate form of EBs in Tehran.

Reference

Captions

Figure 1. Flowchart for proposed methodology
Figure 2. The 7th line of Tehran's BRT system scheme [31]
Figure 3. Comparison of traffic flows in the simulation model and real data
Figure 4. Comparison of emission rate of buses in the simulation model and real data
Figure 5. Simulation environment in Aimsun
Figure 6. Comparison of Travel time and Environmental indicators of DBs and OCEBs
Figure 7. Traffic indicator of OCEBs compare to DBs
Figure 8. Forecast of Tehran Residents’ VOT in the lifetime of OCEBs
Figure 9. Forecast of CO reduction cost during the lifetime of OCEBs
Figure 10. Forecast of NOx reduction cost during the lifetime of OCEBs
Figure 11. Forecast of Diesel cost during the lifetime of OCEBs [41]
Figure 12. Forecast of Electricity price during the lifetime of OCEBs
Figure 13. Costs and benefits of OCEBs' implementation during their lifetime

Biographies

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Field Data Collection → Modelling of Simulation Setup → Simulation with Default Values → Identification of Candidate Calibration Parameters → Parameters Calibration → Run Replications in Aimsun → Comparison of Field Data with Simulated Data

Model Validation

Yes → Simulation of BEBs → Economic, Environmental, and Traffic Analysis

No → Not Compatible

 compatible → Compatible

Figures

Figure 1

Figure 2

Figure 3
Figure 4

Figure 5
Figure 6

Flow

Average Speed

Stop Time

Delay

Density

Traffic indicator changes of OCEBs compare with DBs

Figure 7