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Analysis of the Strategic Value of Electric Vehicles Based on Mathematical Modeling Approach

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Abstract: *Protecting our shared planet, where we coexist, is an undeniable global consensus. Based on this consensus, various regions and countries are gradually replacing fuel-powered buses with environmentally friendly E-buses. This article analyzes the environmental impact of using fuel-powered vehicles and electric vehicles. Therefore, a model was established that relates factors such as PM2.5, AQI, the number of electric vehicles, the number of fuel-powered vehicles, the total length and number of bus routes, and daily passenger volume. However, considering the complexity of these factors and their interdependencies, the article first considers using Principal Component Analysis (PCA) to select a few key indicators from multiple variables. Then, based on the key indicator data and air quality data for each month, the article uses multiple regression analysis in MATLAB to determine the corresponding parameters. Finally, the article predicts and analyzes the air quality in the Houston area for the next 10 years based on the fitted equation. Based on the financial performance of the public transportation company in the Houston area obtained from research, and assuming that the company replaces 10% of its fuel-powered vehicles with electric vehicles every year, the article predicts the company's financial status for the next 10 years (2024-2033) using Monte Carlo simulation. The prediction includes investment costs for charging stations for electric vehicles, procurement costs for electric vehicles, and additional electricity costs. Based on the predicted results, the article uses the Net Present Value (NPV) indicator from economics to evaluate the investment in assets, aiming to ensure that the transition costs do not exceed 50%. The article adopts the same approach as in question two but modifies the replacement rate of fuel-powered vehicles. Instead of 10% per year, the replacement rate is set to 8% for the first five years and 12% for the next five years. The article then simulates and evaluates the different replacement strategies between question two and question three. Additionally, the conclusions from the first and second questions are applied to Beijing and New York to evaluate the ecological changes in different regions, demonstrating the reliability of the constructed models. The article discusses the benefits and advantages of adopting electric vehicles to government officials. The aim is to encourage government officials to consider increasing investment in replacing fuel-powered vehicles with electric vehicles.*

Keywords: *PCA, NPV indicator, Monte Carlo simulation, environmental protection*

1. Introduction

Protecting our shared planet, where we coexist, is an undeniable global consensus. Based on this consensus, various regions and countries are gradually replacing fuel-powered buses with environmentally friendly E-buses [1]. We are provided with the following basic information about electric buses, or e-buses:

1) E-buses are friendly to the environment as they run on electricity.

2) In the long term, e-buses are efficient in terms of cost because of the lower operation costs and the decreasing battery prices due to technological renovation.

3) Government programs aid the construction and adaptation of e-bus systems.

4) Several challenges obstruct the building of the infrastructure, including the high initial costs, the development of charging devices for the buses, the technology of charging time, and possible limitations in range.

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Based on the provided previous information, we are asked to solve the four questions:

The first problem requires us to devise a model to predict the ecological outcomes of the transition to a whole e-bus system and apply the model to a city with a substantial population but without such a structure.

For the second question, we develop a holistic financial model for converting the city to e-buses, including possible external funding to cover nearly half the costs and apply it to the city chosen in the previous question.

Continuing, the model from the first question is adjusted for the third question. The finishing date for the complete transition to e-buses is before 2033, so the previous model is accommodated for ten years to accomplish the goal [2].

Finally, we apply our statistics and obtained results in a letter to the transportation authority of one of the cities chosen for the model and advocate for using e-buses in that area, including the benefits and potential outcomes.

2. Establishment and solution of the model

2.1. Model of harmful gas changes after using electric vehicles

Modeling

For the first question which requires us to construt a model in any city to show the ecological impact of the electric cars, we consider several aspects that may affect the final result: the number of electric cars, the sum of length of all the routes, the average daily passenger volume, the pm2.5 concentrqtion, the AQI index number, the total number of bus lines in the city. As is shown in Fig. 1.

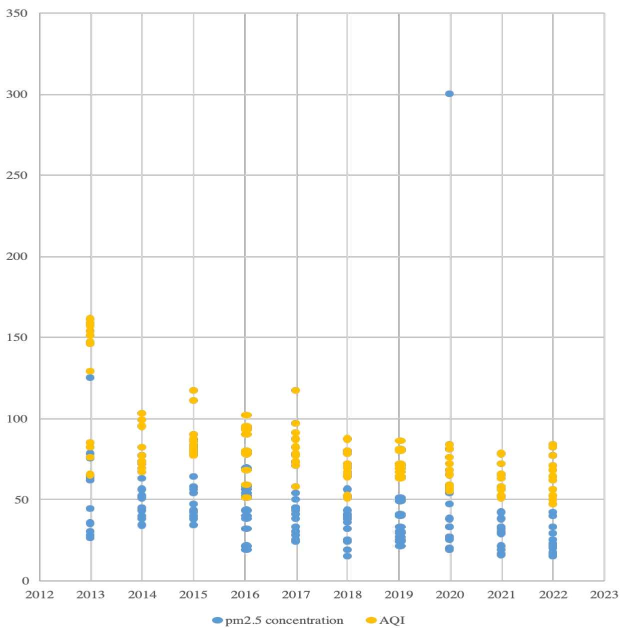

Figure 1: Air quality index of PM2.5 box AQI response

When consturcting the model based on the data from all these aspects, we use the linear mapping called the PCA (principal component analysis). By transforming all the data to a new coordinated system, we can get a new fittiing formula which considers all the aspects above. Then, the data of each aspect withthe fitting formula will form variance, ranking from the highest to the lowesr. We delete the aspects that have the variance which is too low to have significant relationship to the result [3].

Here we choose the city of Shanghai as an example. Shanghai started to introduce the first electric car in 2013 January [4], and the ratio of the electric buses in the city continously increase over time. As a result, we use the data of all the above five aspects, and the data of the air pollution index from 2013 January to 2020 December. As is shown in Fig.2 and 3.

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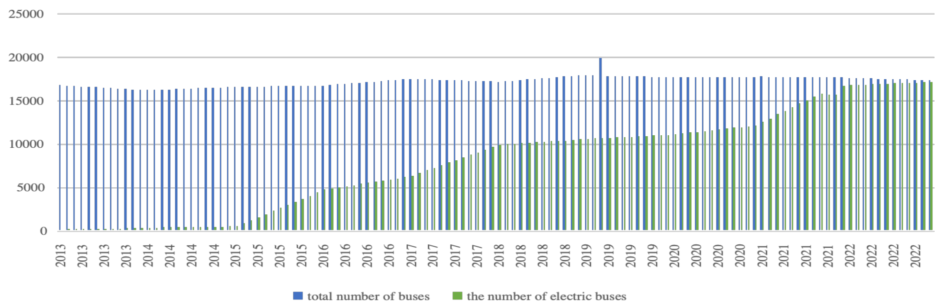

Figure 2: Monthly changes in the number of buses and trams in Shanghai from 2013 to 2022

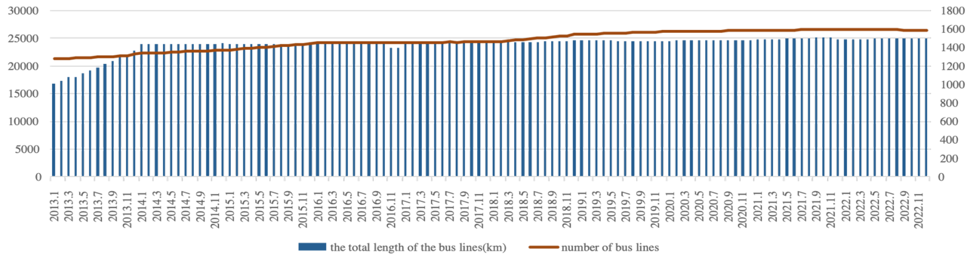

Figure 3: Monthly changes in the number of bus line venues and routes in Shanghai from 2013 to 2022

Model Solution

After collecting all the data, we start to use the matlab to form several curves. We firstly use the matlab with the method of PCA. In the experiment, we can directly see the percentage on how the five aspects are influencing the final result. According to the Matlab, we get the ratio for each:

0.6734 for the sum of the buses in the city,

0.1746 for the sum of electric buses,

0.1077 for the total length of all the bus lines,

0.0387 for the number of bus lines,

0.0057 for the amount of people who use the transportation per day.

The result shows that the sum of the buses, the sum of the electric buses, the total length of all the bus lines play a major role in determing the result of the air pollution.

As a result, we only use the three factors which occupy the most in the calculation of the air pollution index.

Then, by considering several factor related to the air pollution, including PM2.5 and the AQI(air quality index), we combine all the three factors in Matlab to form the function with the help of the ternary regression analysis method. Also, the purpose to choose the two index of air pollution is to determine the credibility of the function.

Results

By the method of PCA and the ternary regression analysis method, the function for the PM2.5 is y=20.81+0.0025x1-0.00187x2-0.0002707x3

2.2. Cost and Revenue Risk Assessment Model for Replacing Trams

Modeling

During the past few years, the globe's temperature has tremendously increased, some of the main factors would include manufacturing goods, generating power, and lastly transportation. To reduce the growth, many countries such as China have been promoting and transiting towards an all-sustainable urban transport community. Yet, money matters in this instance, therefore we here are trying to construct a financial model that depicts the conversion from gasoline-based to electric-buses to determine whether this decision should be made [5].

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To construct a financial model, we started by choosing a city that is making concerted efforts to incorporate e-buses into its fleets, Houston, Texas. One of the major public companies in Houston is METRO, which stands for Metropolitan Transit Authority of Harris County. They are committed to helping the United States achieve a 50% reduction in greenhouse gas emissions by producing only zero-emission buses by 2030, promoting energy management and waste reduction opportunities… This is also why we chose this company for our analysis of the financial aspect of this question.

To evaluate the financial status of the METRO company in the future, we used the published monthly reports in their library, which provides a list of income, expenses, and investments. Therefore, provides us with both the actual data of revenue and cost from the year 2018 to 2023. As is shown in Table.1 and 2.

Table 1: Revenue 2018-2023

Year	2018	2019	2020	2021	2022	2,023
Ticket (Fare)	68,700,000	67,500,000	38,500,000	25,800,000	28,900,000	42,000,000
- Assumption Ticket	5%					
Service-related grant	76,100,000	75,100,000	90,000,000	233,500,000	265,400,000	83,800,000
- Assumption Service grant	1.11					
COVID related grant						137,400,000
- Assumption COVID grant						
Capital Grant	52,200,000	94,400,000	72,100,000	62,000,000	53,300,000	100,500,000
General Mobility Transfers	179,100,000	181,700,000	181,300,000	187,400,000	205,100,000	204,300,000
Interest and Miscellaneous	19,200,000	17,500,000	13,800,000	16,700,000	12,700,000	44,300,000
Adv	96,180,000	94,500,000	53,900,000	36,120,000	40,460,000	58,800,000
Construction funds	77,110,688	48,526,279	121,944,965	105,616,879	88,643,760	93,235,578
Others	15,869,312	22,423,721	402,555,035	1,132,083,121	331,696,240	544,171,089
- Assumption Others		1.41				
Total	**584,460,000**	**601,650,000**	**974,100,000**	**1,799,220,000**	**1,026,200,000**	**1,266,506,667**

Table 2: Cost 2018-2023

Year	2018	2019	2020	2021	2022	2,023
Payroll	167,404,762	176,139,181	181,304,645	176,358,790	201,677,675	267,301,764
Materials and supplies	76,585,620	86,980,415	89,223,635	91,064,210	128,128,616	153,913,674
Fuel and Utilities	33,953,400	37,179,974	36,531,719	31,784,401	38,317,440	57,487,721
Repair + Replacement	7,745,153	11,283,997	995,249	9,214,678	7,261,248	5,823,725
Administration	113,016,047	120,741,450	127,755,355	107,076,546	166,446,056	149,149,156
Insurance	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000
Benefit	33,480,952	35,227,836	36,260,929	35,271,758	40,335,535	53,460,352.80
Other	212,403,065	222,876,147	424,637,468	841,308,618	546,034,430	341,694,174
Total	**653,220,000**	**699,060,000**	**905,340,000**	**1,300,710,000**	**1,136,832,000**	**1,037,461,567**

Then, to predict the future data, we decided to use the method of polynomial curve fitting, where we used Matlab to plot the points of data, get the polynomial function, and substitute the year we want to predict as x. For example, to calculate the general mobility transfer of the year 2024, I stated the X as the year 2018 to 2023 and Y as the actual transfer numbers for the associated years. Next, using the Curve Fitting Toolbox to get the equation y=(3.7829*106)*x-7.4596*109, lastly substituting the year number as x, resulting in the predicted value of 196989600.

Even though all values should be under a certain pattern, however, due to some abnormal data points caused by the COVID-19 era we would need to resolve this problem by ignoring the values of data and assume that the company went back to normal, which is the value of 2018. As we indicate that the value of fare in 2024 is the same as the value in 2018, and the relationship of fare revenue is that it increases by 3 % every year, we can result in a formula of Value = Value of last year) (1+0.03). For instance, in the case of the year 2025, the amount of fare revenue = (68700000) (1+0.03), where 68700000 is the fare in the year 2024. As is shown in Table 3.

Lastly, to calculate the cost of the year 2024-2030, we assumed that we are switching 10% of the gasoline bus every year to e-bus, using the same method for revenue will result a value in most of the factors of cost. Yet, as the two types of buses consume different fuel, we need to add two additional items in the cost, Charging station and electricity. To get the mile a bus run each year we used the fuel cost divided by the average dollars per gallon of oil that year and multiplied it by the average amount of distance a public bus run per year. For the cost of electricity, we used the equation: (total km per

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year)/(proportion of electricity buses in the total of 1233 buses)*(electric cost per km). As is shown in Table 4 and 5.

Table 3: Revenue for year 2024-2033

Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Ticket (Fare)	68,700,000	70,907,563	73,186,062	75,537,778	77,965,061	80,470,342	83,056,126	85,724,999	88,479,633	91,322,782
- Assumption Ticket (assume economy back to normal (yr 2018) after COVID from 2024)		3%	3%	3%	3%	3%	3%	3%	3%	3%
Service-related grant	76,100,000	78,545,350	81,069,277	83,674,307	86,363,045	89,138,181	92,002,491	94,958,842	98,010,190	101,159,589
- Assumption Service grant		1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
COVID related grant										
- Assumption COVID grant(assume economy back to normal, no COVID grant)										
Capital Grant	83,326,400	86,415,000	89,503,600	92,592,200	95,680,800	98,769,400	101,858,000	104,946,600	108,035,200	111,123,800
General Mobility Transfers	196,989,600	200,772,500	204,555,400	208,338,300	212,121,200	215,904,100	219,687,000	223,469,900	227,252,800	231,035,700
Interest and Miscellaneous	31,970,400	35,227,500	38,484,600	41,741,700	44,998,800	48,255,900	51,513,000	54,770,100	58,027,200	61,284,300
Adv	96,180,000	99,270,588	102,460,487	105,752,889	109,151,086	112,658,479	116,278,576	120,014,999	123,871,486	127,851,895
Contruction funds	108,016,800	113,292,500	118,568,200	123,843,900	129,119,600	134,395,300	139,671,000	144,946,700	150,222,400	155,498,100
Others	15,869,312	22,423,721	31,685,259	44,772,036	63,263,968	89,393,514	126,315,194	178,486,419	252,205,619	356,372,629
- Assumption Others(assume economy back to normal (yr 2018) after COVIDfrom 2024)		1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
Total	**677,152,512**	**706,854,722**	**739,512,886**	**776,253,109**	**818,663,560**	**868,985,216**	**930,381,387**	**1,007,318,560**	**1,106,104,529**	**1,235,648,795**

Table 4: Cost of the year 2024-2033

Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Payroll	252,656,000	268,975,000	285,294,000	301,613,000	317,932,000	334,251,000	350,570,000	366,889,000	383,208,000	399,527,000
Materials and supplies	155,024,000	169,650,000	184,276,000	198,902,000	213,528,000	228,154,000	242,780,000	257,406,000	272,032,000	286,658,000
Charging station	739,800	739,800	739,800	739,800	739,800	739,800	739,800	739,800	739,800	739,800
Electricity	654,360	1,308,720	1,963,079	2,617,439	3,271,799	3,926,159	4,580,519	5,234,878	5,889,238	6,543,598
Fuel and Utilities	34,485,696	30,653,952	26,822,208	22,990,464	19,158,720	15,326,976	11,495,232	7,663,488	3,831,744	-
Repair+Replacement	7,701,793.72	7,949,278.35	8,204,715.50	2,883,460	2,295,440	1,707,420	1,119,400	531,380	(56,640)	(644,660)
Administration	160926400	169415000	177903600	186392200	194880800	203369400	211858000	220346600	228835200	237323800
Insurance	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000	8,631,000
Benefit	50,531,200.00	53,795,000.00	57,058,800.00	60,322,600.00	63,586,400.00	66,850,200.00	70,114,000.00	73,377,800.00	76,641,600.00	79,905,400.00
Other	212,403,065	222,876,147	424637468	286,638,893.33	311,384,169.44	340,886,843.59	312,969,968.79	321,746,993.94	325,201,268.78	319,972,743.84
Total	**883,753,315**	**933,993,897**	**1,175,530,671**	**1,071,730,857**	**1,135,408,128**	**1,203,842,798**	**1,214,857,919**	**1,262,566,940**	**1,304,953,211**	**1,338,656,682**

Model Solution

After collecting all data from 2018-2023 to predict the revenue and cost of the year 2024-2030, we can use this table to find whether the company can "Achieve break-even". First, we need to calculate the profit by using the equation: Profit = Revenue - Cost. Second, based on the profit of the year 2024 we can calculate the value of the profit of the year 2025-2030 through the equation of =profit / (1+annualized year interest rate)^(number of years after 2024). Lastly, Explain why we use NPV: The investment in fleet renewal will be assessed on the basis of the financial indicator NPV (1), which will be forecasted using the Monte Carlo simulations technique. As is shown in Table 6. According to this technique NPV = (profit of that year in the value of 2024) / the total revenue of 2024) [6].

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Table 5: Electric bus of the year 2024-2033

Electric bus	123.3	246.6	369.9	493.2	616.5	739.8	863.1	986.4	1109.7	1233
Electric cost per km	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Gasoline bus	1109.7	986.4	863.1	739.8	616.5	493.2	369.9	246.6	123.3	0
Gasoline cost per km	0.8198	0.8198	0.8198	0.8198	0.8198	0.8198	0.8198	0.8198	0.8198	0.8198
Number of charge station	123.3	246.6	369.9	493.2	616.5	739.8	863.1	986.4	1109.7	1233
KM per year	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36	46739985.36
Total	**1233**	**1233**	**1233**	**1233**	**1233**	**1233**	**1233**	**1233**	**1233**	**1233**

Table 6: NPV 2024-2033

Year	**2024**	**2025**	**2026**	**2,027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Assume Profit	-206,600,802	-227,139,175	-436,017,785	-295,477,747	-316,744,568	-334,857,582	-284,476,532	-255,248,380	-198,848,682	-103,007,88
Value today	-206,600,802	-206,490,159	-360,345,276	-221,996,805	-216,340,802.20	-207,920,213	-160,579,586	-130,982,778	-92,764,377.76	-43,685,399.31
NPV	-0.31	-0.30	-0.53	-0.33	-0.32	-0.31	-0.24	-0.19	-0.14	-0.06
rate	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Results

According to Table 6 row named after NPV, we can tell that the value in 6 out of the 7 years results in a number less than 0.5 which depicts that it is under the potential external funding covering up 50% of the transition cost. Moreover, the development towards the goal of zero-emission not only brings growth in their financial scale but also creates a great impact on the globe's climate change.

3. Conclusions

Advantages of the model

1) The model derived in this article has certain universality and representativeness, as it can be employed in the actual operation of the transition from disel buses to electric ones or can be used in theoretical research for the operation and scheduled optimization of the plan. The identical predicted values calculated by various methods added to the accuracy of the prediction value.

2) The established model has simplicity to calculate, high efficiency, and close fitted value. The visualization through strong algorithm also contains high rationality and enforceability because the parameters included in the model has been verified by the data in the past, proving the high precision.

3) It provided a feasible solution to the shift from diesel buses to e-buses based on the method, which has advantages of simplicity and efficiency, with relatively accurate fit values, which results in high feasibility and applicability of the calculated results.

Disadvantages of the model

1) The established model is complicated in quite simplistic relative to the other complex and mainstream methods. Therefore, it is not influenced by numerous aspects, which might be crucial in this situation.

2) Several data have contained some missing points, which prompts us to rely on predicted values within the range. These data points might have significantly impacted our trend, so we have to make the assumption that the missing data is close to the actual values.

3) The model doesn't incorporate the influence of the international relationship and economy, which decreases the precision of the trend. Factors such as potential war, trade, and a similar pandemic have not been included in this prediction. Additionally, the data impacted by COVID-19 and that of the years before the pandemic have been used together in the analysis despite the differences.

Extension of the model

In this paper, a model of environmental consequence of shifting to electric buses and a financial model of related costs for the transtition are established, and a solution method based on simulation-optimization and dynamic research is proposed to obtain the optimal e-bus transition plan under different conditions. The model takes in comprehensive consideration, both in possible emission outcomes and source of money for cost, from real data in the past. It is also useful for future predictions and has simple and easy operation. The stimulation-optimizzation is based on the full use of resources, and the conclusion proves that the transition from diesel buses to e-buses will bring better ecological consequences and with the

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proportion of investment approxiately 50 percent, the program is feasible. The research ideas, models, and methods have certain reference significance for the bus environment-friendly and cost-efficient operation.

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