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Original Paper

Reasonable Planning of King County's E-bus Replacement Plan

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Abstract

With the increasingly intensified global warming severe air pollutions, governments all over the world have begun or is right now looking for ways to fix the problem. Among all the solutions, sustainable urban transportation system is what many governments pay attention to because of their apparent contribution to the reduction in greenhouse gases emissions and pollutants. In this passage, we focus on the exact ecology impacts the promotion of e-buses will cause. On the other hand, the potential financial burdens the transitioning processes will bring are perceived by us in order to make a decent plan for the government to implement.

For the first part of constructing the model to measure the ecology impact of transition in one area, we start with the identification of King County as a metropolitan area suitable for prediction. Then we collect information and data of its local bus fleet and e-bus transitioning plan, find out the exact number of each type of buses (diesel, hybrid and electric) around these years and the emissions of corresponding buses. We use both ARIMA and Least Squares Regression to predict the number these buses in the future until the year the local government aim to complete the plan but choose the result displayed by the better one. In this case, we obtain the data for emission of carbon dioxide, oxynitride and PM10 in each year and evaluate the ecological impact. At the same time, we predict the data for the emissions later if the bus fleet keep the same and observed over 90% of decline when we compare the value after transition to the control group.

Afterwards, to estimate the financial cost, we identify the main parts involved in the processes of transitioning, classify them with one group of cost for long-term and the other for short-term---that is, changed as the plan is gradually implemented. We build models for each factor we identified and use Riemann Sum to unify the long-term and short-term costs. Based on the data we predict in problem one and from the local government's website, we easily gain the financial implications of for about 50 million dollars in King County. Through the analysis of the government's grant in other area, we roughly verify that 50 million dollars would be an acceptable cost.

Finally, in our 10-year roadmap development, we explored further into the population distribution of

King County and the existing traits for public transportation. Our starting point in this article is to classify the urban pattern into four types of bus operation routes, and then define the passenger flow from high to low. At the same time, we define the total number of vehicles that need to be replaced for different types to develop transportation replacement plans. Based on our assumptions, calculate the carrying capacity of each type of bus in line with the passenger flow. Eventually, it can be proven that the total carrying capacity of the bus meets the transportation needs of all King counties. Then apply to other regions.

Keywords

Electric buses, Financial impact, Ecological consequences, City roadmap, Riemann integral, ARIMA, Linear regression

1. Introduction

1.1 Background

Nowadays, the environmental problem is becoming more and more intense, we need to think about how to reduce the pollution of the environment. And non-renewable energy - oil also poses great challenges to the economic and social environment.

Electric buses (e-buses), which can contribute to cities' sustainable development and reduction in air pollution, are steadily drawing attention from cities and governments worldwide. In 2022, e-buses have been accounted for 38% of all electric vehicles (https://kingcounty.gov/~/media/depts/metro/about/advertising/transit-advertising-policy), mainly served in public transportation system to replace traditional diesel buses, aiding the governments to achieve the 17 Sustainable Development Goals of the United Nations plan (https://kingcountymetro.blog/2018/04/18/metro-updates-transit-advertising-policy-regarding-campaign-speech/).

While the benefits related (like low operational expenses) steadily being revealed in some city area that dominate the use of e-buses, the public also started to consider more about the potential challenges behind the implementation such as constructions of infrastructure (charging place), lengthy charging times, range limitations, electricity use, battery disposal, etc. All of the aspects undoubtedly increase the uncertainty of e-buses promotion, especially for those cities seemed not available in budgets.

In this case, analyses toward the existing patterns of the most common used non-electric buses and e-buses are necessary. Specific comparative results will be gained as aid for the governments to have thorough understanding of e-buses.

1.2 Question Restatement

The main purpose of the section was to apply models that can help to predict the impacts transitioning in one certain metropolitan area will bring, further explore the model, then craft a 10-year roadmap for the urban transport (also should be tested in two more areas).

- Firstly, we should identify one metropolitan area which meet the requirements of enough population size and quantizable bus fleet without fully electrification. In the following work, we are required to probe into the influential factors of ecology among e-buses transitioning, create a model to clearly explain the relationship.

● Secondly, we need to focus on the financial cost, which means the involvements of money among processes other than transition in conversion have to be considered. The potential fundings we predict at all should reach at most 150% of e-buses transition cost. What we will showcase is a mathematics model include all possible factors and under the certain limitation, representing the total financial costs.

● Thirdly, an even more complete plan should be provided for local governments to reach the goal of transitioning in a decade. Based on the models built in previous two question, the roadmap must be reasonably displayed and may fit two additional areas.

1.3 Our Work

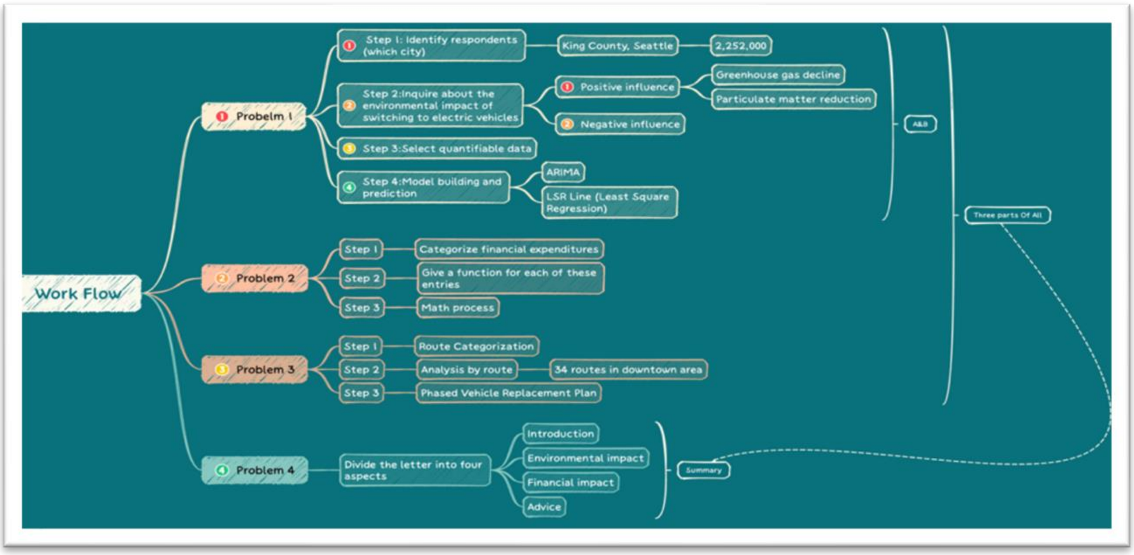


Figure 1. Our Team Workflow

● **Problem 1**

First, we identify our target location: King County, Seattle, with a population of 2,252,000. Next, we investigate the environmental impact of transitioning to electric vehicles, considering both positive effects such as reduced greenhouse gas emissions and lower particulate matter, and negative aspects like production-related environmental impacts and increased strain on the power grid. In step 3, we carefully select quantifiable data points, including electric vehicle sales, emissions data, and electricity consumption. Finally, we employ statistical methods like ARIMA for time series analysis and LSR Regression to build predictive models. These models help us understand and anticipate the environmental implications of electric vehicle adoption in the region.

● **Problem 2**

First, we involve categorizing financial expenditures, grouping them into different expense types.

Second, we assign a specific function or purpose to each of these categorized entries, defining their roles within the financial framework. Finally, mathematical processes, such as differentiation, are applied to analyze and understand the changes or trends in these expenditure categories. This systematic approach helps in gaining insights into financial management and optimization by breaking down and examining individual components of expenses.

- **Problem 3**

Firstly, we initiate the process by categorizing routes based on various criteria. Then, we involve a comprehensive analysis of these routes, with a specific focus on the 34 routes within the downtown area. This analysis helps us understand the unique characteristics and demands of each route. Lastly, we develop a phased vehicle replacement plan. This plan aims to optimize the deployment of vehicles on these routes, ensuring efficient and sustainable transportation solutions for the future.

- **Problem 4**

We divide the letter into four distinct aspects. The 'Introduction' section serves as an opening to set the tone and context. Following that, we address the 'Environmental Impact,' examining the ecological consequences of a particular action or decision. In the 'Financial Impact' section, we delve into the monetary consequences, both costs and benefits. Lastly, the 'Advice' section offers recommendations and guidance based on the analysis of environmental and financial impacts, providing a comprehensive perspective on the subject matter.

2. Assumptions and Justifications

■ **Assumption 1:** The e-buses to be purchased in the conversion are all regarded the same types as nowadays most common used ones in King County. In this case, all the indicators of the vehicles should also be regarded the same.

Justification 1: The recent purchases of buses by the government are of the same types, indicating the government's recognition of these types of bus. Meanwhile, the unified models and standards of buses also make the prediction more practical and intuitional.

■ **Assumption 2:** We assume that the annual repair cost of each kind of bus remains the same in the future under all circumstances in these set of questions. (The buses would not meet severe accidents that require much more many to mend.)

Justification 2: Since standard of one year is consistent with many other variables we used in the equations, data collected in annual cost is not only rational, but also simplify the model by unifying units. At the same time, although the costs of repairing the buses or buy new ones after severe problems may be relatively high, the probability of accidents occurring is still very low, while the time and frequency of their occurrence are always uncertain factors that cannot be precisely measured.

■ **Assumption 3:** The price for the e-buses ticket equals to traditional diesel or other types of buses and will stay the same in the future.

Justification 3: Because in the perfectly competitive market of buses, the profit of constant fares is the highest, so the government is most likely not to change the fares.

■ **Assumption 4:** The batteries of e-buses are all assumed to be properly recycled by the government and therefore the pollution of waste batteries will not be considered. (On the other hand, the financial cost to recycle the batteries will be estimated in the second problem.)

Justification 4: The bus fleet is ruled by the government, which means the processing of wasted batteries will be carried out under specific standard and procedures normally. It is fine to ignore the pollution caused by accidental disposal without treatment.

3. Symbol Notations

Symbol	Definition	Unit
$\boldsymbol{F_t}$	The Function of Consumption and Time	\
BAd	Advertising Revenue	$/dollar
$BTic$	Ticket Revenue	$/dollar
$CFuel$	Fuel Expenditure	g/Gallon
NBs	Number of Buses	\
DBs	Annual Distance Traveled by Each Bus	Km/Kilometers
W_c	Fuel Quantity Per Kilometers	g/km
R_t	The Function of Number of Passengers and Time	\
$R2018$	Number of Passengers In 2018	\
$Perc_{Chl}$	Child Ride Rate	\
$PercAdult$	Adult Ride Rate	\
$Perc_{old}$	Old Ride Rate	\
ACC	The Average Carrying Capacity of One Bus	\
Ret	The Function of The Number of Passengers in Bus and Time	\

4. Problem 1: Ecological Consequences of E-bus Transition

4.1 Identification of the Metropolitan Area

King County, located in Washington USA, hold a population size of over two million people according to its census in 2022 (https://chargedevs.com/newswire/washingtons-king-county-metro-to-purchase-up-to-120-new-flyer-electric-buses/). In its urban transportation system, buses play important role and had been always drawing the local government’s attention. Till now, the bus fleet is mainly consisted of hybrid buses, partially with e-buses and is going to introduce more e-buses into their fleet (https://www.newflyer.com/bus/xcelsior-charge-ng/).

4.2 Modeling Building

4.2.1 Data Grouping, Comparative Analysis

According to the data we checked, King County will achieve vehicle electrification by 2035, that is, by 2035, all the buses in operation will be electric. To understand the ecological consequences of transitioning to a fully electric bus fleet, we envision building two models to predict greenhouse gas and air pollutant emissions.

In order to analyze the ecological consequences of replacing the bus fleet with trams more intuitively, we managed to divide the data into two groups: Group A &Group B. Group A is sustainable development, which is implemented in accordance with the plan to fully replace the tram by 2035; Group B is for the existing development, unsustainable development, maintain the existing fleet plan to implement. The specific differences are detailed in the table below:

Data Group	Group Type	Detailed description
A	Sustainable development	According to the comprehensive replacement plan of 2035, the number of hybrid and diesel vehicles will decrease from 2020, and the number of pure electric vehicles will gradually increase
B	Unsustainable development	In line with the existing fleet, the number of oil vehicles and their hybrid and diesel vehicles will remain unchanged from 2020.

Chart 1. Explanation of Sustainable Development Group (A) and Unsustainable (B) Development Group

4.2.2 Model Selection

According to what we have said above, we divide the way to determine the ideal model into the following steps, as shown in the figure:

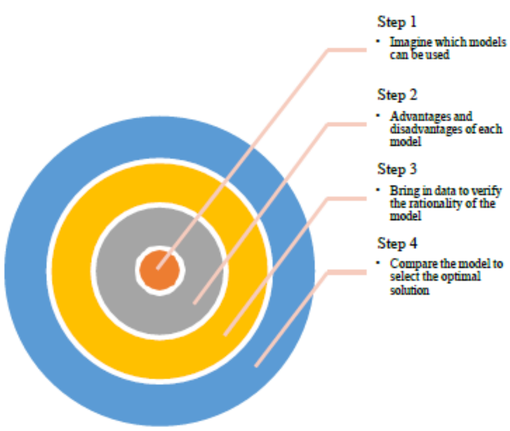


Chart 2. Model Selection Step Diagram

- **Step 1:**

In the initial phase of our analysis, we identified two potential models suitable for addressing our problem: the ARIMA model and the minimum quadratic regression model. These models were chosen based on their compatibility with the dataset and the specific challenges at hand.

- **Step 2:**

Subsequently, we conducted a thorough evaluation of the data to gauge the strength of its linear relationship. Our exploration revealed that when we applied the ARIMA model, its performance was suboptimal due to the data exhibiting a remarkably strong linear relationship. Consequently, we made the decision to exclude the ARIMA model from consideration.

- **Step 3:**

In the final step of our approach, we adopted the minimum quadratic regression model for our predictive analysis. This decision was guided by its ability to effectively capture the underlying nonlinear patterns in the data, ultimately leading to more accurate predictions. By selecting the least squares regression approach, we aimed to enhance the quality of our analysis and ensure that our model was well-equipped to handle the intricacies of the dataset.

4.2.3 Why Least Square Regression (LSR) Line

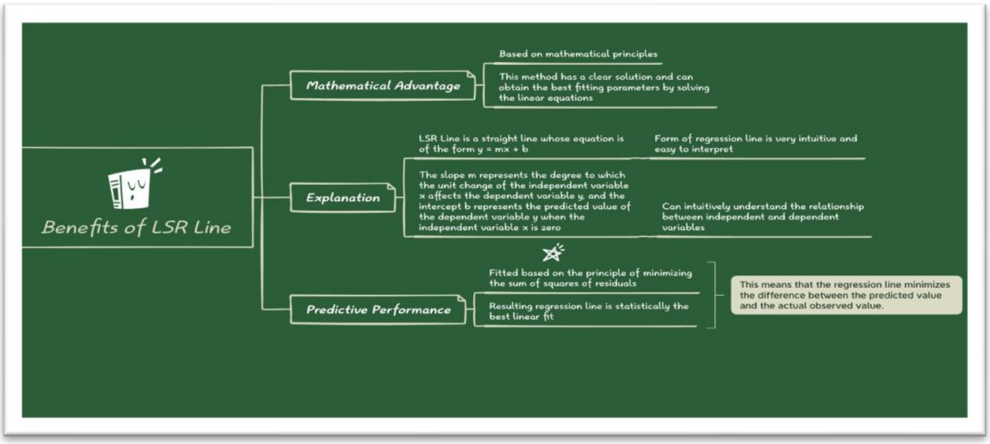


Figure 2. Benefits of LSR Line

The Least Squares Regression model offers several advantages. It is a user-friendly and versatile statistical tool, applicable to various data types, providing a clear understanding of the relationships between variables. Its coefficients enable better comprehension of the impact of different factors on outcomes. The model also demonstrates strong predictive performance when the linearity assumption is met. Furthermore, it aids in variable selection, identifying significant contributors to outcomes, streamlining the model, and enhancing its interpretability. In summary, the Least Squares Regression model is a powerful tool for data analysis, decision support, and applications across diverse fields, from economics to natural sciences.

4.2.4 Find the Best Goodness of Fit

◆ Define the best goodness of fit (***R*²**score & RMSE)

Two Parameters	Explain
***R*2**	Multiple measurement coefficients, the closer the value is to 1, indicating that the variable of the equation has a better ability to explain y
RMSE	The root means square error, the closer the value is to 0, the smaller the error and the better the prediction

We use functions in Python that evaluate the following two variables, comparing them from 1 to 9 to find the optimal value:

Polynomial Approximation Degree	***R*2**	***RMSE***
1	14.09657292850211	196.07228677428813
2	3.0717395194955195	181.40751054341976
3	0.6290097619767383	158.38703322555642
4	3.0434182734023265	181.1763351361471
5	0.433972181790093	158.48103201870438
6	0.3866806155613809	158.70378371145878
7	0.07912612764508509	2241.895771286939
8	0.08591151251518259	167.96346441948114
9	0.0009658658595391724	34559.15038335714

According to the evaluation index R ²; polynomial approximation degree =8 performs best.

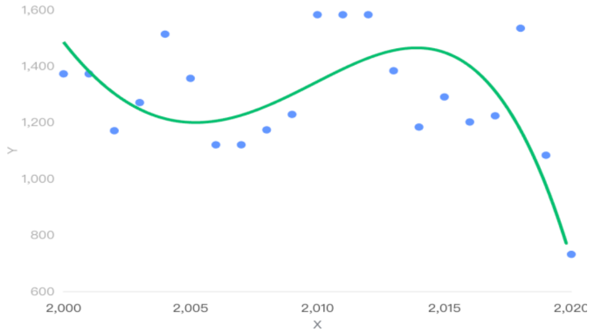


Figure 3. Actual Value & Actual Value Curve (Green Curve: Fitting Curve; Blue Dots: Actual Value)

4.2.5 LSR Line - Analysis Step

- **Step 1:**

In the first step of our analysis, we employ statistical tools to gauge the significance of the relationship between variables. We start by calculating the F-value, which is the ratio of two mean squares. This analysis helps us determine whether we can confidently reject the null hypothesis that the population regression coefficient is zero ($P < 0.05$). A significant F-value suggests the presence of a linear relationship between the variables, prompting the need for further examination of the strength of this relationship.

- **Step 2:**

Moving forward, we delve into the assessment of our model's fitting quality. We rely on the R^2value, which measures the proportion of variance explained by the model. Simultaneously, we scrutinize the VIF value (Variance Inflation Factor) to detect collinearity among predictor variables. If collinearity is observed (with VIF values exceeding 10 or 5, depending on the strictness of our criteria), we recommend considering techniques such as ridge regression or stepwise regression to mitigate this issue and enhance model stability.

- **Step 3:**

In the third step, we turn our attention to the individual significance of the predictor variables (X). By analyzing their significance levels ($P < 0.05$), we can determine which variables have a meaningful impact on the response variable (Y). This analysis allows us to identify key factors that warrant further exploration in our model.

- **Step 4:**

With the significance of individual predictor variables established, we proceed to assess and compare the influence of these variables on the response variable (Y). This evaluation is based on the regression coefficient (B value), allowing us to quantify and rank the degrees of impact that different variables have on our target outcome.

- **Step 5:**

In the final step, we derive the definitive model formula. Before applying linear regression, it's essential to ensure the data's quality by conducting statistical tests such as normality tests. Additionally, data preprocessing techniques, including outlier detection and removal, can be employed to refine the dataset, ensuring that it meets the assumptions and requirements of linear regression analysis. Once the data is properly prepared, we can confidently determine the model formula that best represents the relationships among the variables, facilitating meaningful predictions and insights.

4.2.6 LSR Line - Detailed Conclusions

	Nonnormalized Coefficient		Standardization Coefficient	t	P	VI F	R^2	Adjust R^2	F
	B	Standard Error	Beta						
Constant	18039.823	14931.441	-	1.208	0.242	-			F=1.259
Year	-8.334	7.429	-0.249	1.122	0.276	1	0.062	0.013	P=0.276
Dependent Variable: Total fleet (diesel, hybrid, pure electric)									

Chart 3. Linear Regression Analysis Results n=21

Note. ***, ** and * represent significance levels of 1%, 5% and 10% respectively.

The above table shows the analysis results of this model, including the standardized coefficient of the model, T-value, VIF value, R^2, adjustment R^2, etc., for the test of the model and the analysis of the formula of the model.

- The linear regression model requires that the overall regression coefficient is not 0, that is, there is a regression relationship between variables. The model is tested according to the result of F test.
- R^2represents the degree of fitting of curve regression, and the closer to 1, the better the effect.
- VIF value represents the severity of multicollinearity, used to test whether the model presents collinearity, that is, there is a highly correlated relationship between explanatory variables (VIF should be less than 10 or 5, strictly 5) If VIF appears inf, it indicates that the VIF value is infinite, it is recommended to check collinearity, or use ridge regression.
- B is the coefficient with constant.
- Standard error =B/t value.
- The standardization coefficient is the coefficient obtained after standardizing the data.

◆ Overall result presentation

- According to the analysis of the results of F-test, the significance P-value is 0.276, which does not show significance at the level, and the null hypothesis that the regression coefficient is 0 cannot be rejected, and the model is invalid.
- For the collinearity of variables, VIF is all less than 10, so the model has no multicollinearity problem, and the model is well constructed.

◆ Model Formula

$Total\ Fleet = 18039.823 - 8.334 \times year$

4.3 Use Models to Make Predictions

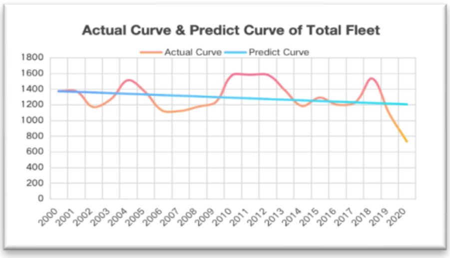


Figure 4. Actual Curve & Predict Curve of Total Fleet

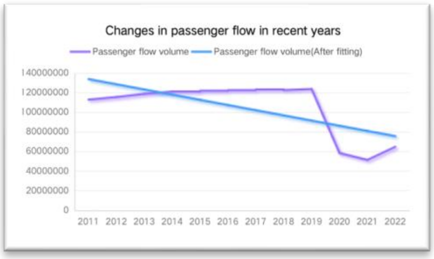


Figure 5. Changes in Passenger Flow in Recent Years

- Why is the forecast curve trending downward?

According to the passenger flow in recent years, please look at the graph below, the passenger flow shows a downward trend, indicating that people have better means of transportation. The decline in passenger traffic has led to a decline in vehicle fleets. Because there are already some people who do not travel by bus.

Above are images of actual and predicted values. We have predicted the number of vehicles based on the above model and multiplied the emissions of greenhouse gases and air pollutants according to the groups mentioned above. Please refer to the following table for specific calculation methods:

Emissions Calculation for Buses' Different Types (CO2, NOx, PM10)			
Bus Type	CO2	NOx	PM10
Hybrid	2259	1.25	0.0003
Diesel	2444	16.64	0.14
E-bus	331	0.9	0

Chart 5. Emissions Calculation for Buses' Different Types (CO2, NOx, PM10)

Note. Unit kg CO2/MWh; kg NOx/MWh; kg PM10/MWh etc.… The above data are the corresponding emission factors.

◆ Corresponding emission formula

- CO2:

$CO2 = Q_H \times 2259 + Q_D \times 2444 + Q_e bus \times 331$

- NOx:

$NOx = Q_H \times 1.25 + Q_D \times 16.64 + Q_{e_{bus}} \times 0.9$

- PM10:

$PM10 = Q_H \times 0.0003 + Q_D \times 0.14$

The following is the corresponding image of Group A and Group B: To explain the ecological consequences of switching to electric cars altogether, it is clear that Group A has significantly fewer greenhouse gases and air pollutants than Group B

◆ Group A:

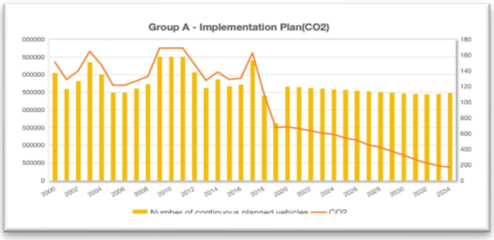


Figure 6. Implementation Plan for Group A (CO2)

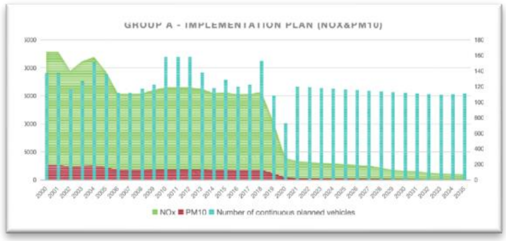


Figure 7. Implementation Plan for Group A (NOx&PM10)

◆ Group B:

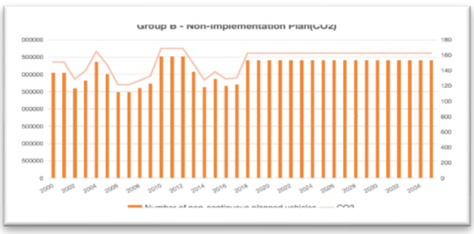


Figure 8. Implementation Plan for Group B (CO2)

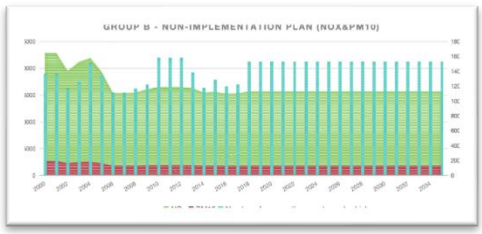


Figure 9. Implementation Plan for Group B (NOx&PM10)

4.4 Result Statement

Based on the above graphs of CO2, NOx, and PM10 (Figure 6,7,8,9), we can see that the total amount of CO2, NOx, and PM10 can be significantly reduced, effectively reducing greenhouse gas emissions (https://www.electricitylocal.com/states/washington/) and the impact of air pollutants. To some extent, it reduces climate warming and acidifies lakes and streams (https://en.wikipedia.org/wiki/King_County_Metro). Changing the nutritional balance of coastal waters and large river basins, increasing nutrients in the soil, damaging sensitive forests and farmland by air pollutants, and affecting the nutritional balance of coastal waters and large rivers basins, as well as the impact of air pollutants on ecosystem diversity and acid rain effects (https://www.sustainable-bus.com/electric-bus/new-flyer-xcelsior-charge-ng/).

5. Problem 2: Financial Implications of Conversion

Consider that the plan to convert existing buses to pure electric has expenses and revenues in addition to the cost of purchasing the e-buses itself, we categorize the amount of expenditure and revenue that is in excess of the original bus fleet, so that we can then link these factors together to determine their ultimate impact on fiscal expenditure.

The factors of revenue we determine to model are listed below:

- Tickets: The basic income of public transportation.
- Advertising revenue: Every bus can undertake advertising to increase the government's revenues.

Then are the determinants of expenditure of transitioning itself and those cost besides it but necessary in the processes:

- Total cost of buying the vehicle: As the main part of cost, also being the criterion to judge the relevance of external funding.
- Maintaining the e-buses: The increase in the number of e-buses lead to a larger financial burden compared to previous situations.
- Fuel: Although avoid the use of diesel, the energy used to generate electricity comes at a premium.
- Disposing of batteries: Processes of disposal to make wasted batteries not harmful to environment is costly.
- Construction of charging stations: To make sure that each electric bus can work normally on its corresponding day of attendance, charging stations have to be as many as enough to meet the demand of electricity.

After identify the factors, we divide them into two groups: $F(0)$ represents long-term consumptions during the whole period of transitioning and F(t) represents short-term consumptions that are collected annually:

$$F(0) = -C_{Bs} - C_{Cs} - C_{B} \tag{1}$$

$$\frac{dF(t)}{dt} = B_{Ad} + B_{Tic} - C_{Fuel} - C_{Mtai} \tag{2}$$

The cost of transitioning during the whole period is the combination of F(t) for every year and F(0), which requires us to integrate all F(t):

$$F(t) = \int B_{Ad} + B_{Tic} - C_{Mtai} - C_{Fuel} dt - C_{Bs} - C_{Cs} - C_{B} \tag{3}$$

5.1 The Revenue for Ticket

To predict the revenue, it is important to identify the number of rides and corresponding tickets' prices.

5.1.1 Passengers' Population Size Prediction

It is undoubted that there is no way to ignore the impact of pandemic, the existing data has showed that from 2020 to 2021, the passenger population size had declined a lot in King County (https://cptdb.ca/wiki/index.php/New_Flyer_Industries_XE40), but as vaccines become more widely available and society recovers, the number of visits is expected to gradually increase (https://www.ncesc.com/how-much-does-a-battery-cost-for-an-electric-bus/). In fact, according to a report by McKinsey & Company estimates in 2022 (https://www.urban-transport-magazine.com/en/bus-electrification-a-comparison-of-capital-costs/): depending on the speed of economic recovery and the extent of behavioral change, U.S. public transit ridership could only return to 80-90% of pre-pandemic levels until 2023. We assume that by 2023, the population of passengers will reach 80% of its previous level, then grew roughly at a sustained equilibrium rate equals to the average annual number of rides from 2000 to 2018 (which are before the pandemic). The number of rides in 2000 and 2018 are 960,000,000 and 1,230,000,000. The values of each year used later can also be acquired from the same government's website (https://usa.streetsblog.org/2022/08/16/us-dot-seeks-to-double-the-nations-electric-bus-fleet-which-is-currently-tiny-and-will-still-be). To access the annual rides of the bus fleet, we plus eighty percent of the rides in 2018 and the increasing rides in the specific year. The number of rides in the specific year is acquired through multiplying the annual average growth rate by the year:

$$R_t = R_{2018} \times 80\% + \frac{R_{2018} - R_{2000}}{19} \times (t - 2023), t \geq 2023 \tag{4}$$

where t represents the year, R_{2018} and R_{2000} separately correspond to the rides for year 2018 and year 2000; R_t is the number of all rides in year t.

Therefore, we obtain the annual number of rides of the whole bus fleet. To obtain the annual number of rides specific for e-buses, we calculate the average busload as the quotient of all rides and number of buses (that is 1540 in 2018), then multiply that by the number of electric buses that were introduced after 2023(based on our own prediction in problem 1) each year:

$$A_{CC} = \frac{R_t}{N_{ABs}} \tag{5}$$

$$R_{et} = A_{CC} \times N_{Bs} \tag{6}$$

where A_{CC} represents the average carrying capacity of one bus; R_t represents the number of rides in year t; N_{Abs} means the number of all buses in 2018; Ret is the number of rides for all the new e-buses annually; N_{Bs} is number of new e-buses each year.

5.1.2 Ticket Price

The next step is to identify the exact ticket price. Ticket prices in King County vary are based on the passengers' ages, the children and seniors with lower prices and adults with full prices:

$$R_{total} = R_{Child} + R_{Adult} + R_{Old} \tag{7}$$

where R_{total} represents the total number of rides; R_{Child}, R_{Adult}, R_{Old} each correspond to the number of rides children, adults and the old.

To make later calculation simpler, we tend to find the average ticket price for all. (Under this circumstance, we assume that the old and children each account for 10% rides while the adults take up 80% of rides.) One dollar for the ticket of the old, none for the children and 2.75 for adults (https://about.bnef.com/electric-vehicle-outlook/):

$$P_{Ticket} = Perc_{Chl} \times P_{Chl} + Perc_{Adult} \times P_{Adult} + Perc_{Old} \times P_{Old} \tag{8}$$

where P_{Ticket} is the average price for one ticket, P_{Chl}, P_{Adult} and P_{Old} represent the prices for children, adults and the old; $Perc_{Chl}$, $Perc_{Adult}$, $Perc_{Old}$ separately represent the percentage of children, adults and seniors rides of the whole.

5.1.3 Summary of the Revenue for Ticket

Finally, times ticket price with corresponding number of rides and receive the results:

$$B_{Tic} = b_{et} \cdot R_{et} \cdot P_{Tic} \tag{9}$$

where B_{Tic} is the total benefits of the tickets for e-buses in year t; b_{et} is the number of all e-buses introduced at year t.

5.2 Advertisement Revenue

The advertisement revenue is mainly composed of three parts: advertise on the buses' bodies, in-car advertising and station advertising. However, as we assumed, the number of bus stations won't increase as buses increase, so the advertisement in bus stations and its relevant income are considered to stay stable in the following years. We decide only use the in-car advertising and advertise on the buses' bodies as variables.

The equation below shows the annual revenue the advertisement will make, the exact coefficient---8000 dollar for bus per year, can be learned from the data (https://kingcountymetro.blog/2022/06/07/ridership-over-200000-weekday-bus-service-adjustments-begin-june-13/; https://kingcountymetro.blog/2020/04/30/covid-19-update-estimated-weekday-bus-ridership-for-april-20-24-as-metro-connects-people-to-work-and-necessities/):

$$B_{Ad} = b_{et} \cdot B_{Ado} \tag{10}$$

where B_{ad} is the benefits from advertisement for all the e-buses annually; B_{Ado} is the average benefits from one e-bus in one year.

5.3 Cost of Conversion

We identify the most common e-buses nowadays, which are also planned to be introduced more later in King County, find the procurement price (10.8 million dollars per bus) of them, at last predict a cost with the number of e-buses planned to buy till 2035, when the transitioning be completed (https://worldpopulationreview.com/us-counties/wa/king-county-population):

$$C_{Bs} = C_{ABs} \times N_{Bs} \tag{11}$$

where C_{Bs} is the cost of purchase for all the e-buses introduced after 2023; C_{ABs} is the money used to buy one e-bus; N_{Bs} is the number of all the e-buses introduced from 2023 to 2035.

5.4 Maintenance Fee

Advertising revenue is a factor that cannot be ignored (because the revenue of buses is mainly ticket price and advertising). However, due to its instability and indeterminacy, it is almost impossible to predict the future advertising revenue if the analysis is included. Therefore, in order to simplify the calculation of the model, the annual advertising revenue of each bus remains unchanged. As what we have assumed, the cost of maintaining the e-buses is constant, so we only need to add a coefficient representing the number of years on it. According to the government's statistic, the concrete money used is 54000 dollars per bus (https://kingcounty.gov/en/dept/metro):

$$C_{Mtai} \square b_{et} \cdot C_{AMtai} \tag{12}$$

where C_{Mtai} is the cost of maintenance for all the e-buses; C_{AMtai} is the average cost of maintenance for one e-bus.

5.5 Electricity Cost

The electricity uses are often measured in the units of KWH, it is easy to calculate the annual KWH of electricity used by one e-bus when the KWH use per kilometer and how many kilometers one bus travel in one year is provided with detailed information. The cost for ach KWH will follow the local universal pricing. The total electricity should be the product of the number of buses, the average distance a bus travel annually, the amount of electricity consumed for one kilometer's distance and price for one KWH of electricity. (Based on the data, the fee for one KWH electricity is 10.09 cents (https://www.ipcc.ch/); an e-bus consumes 1.265 KWH of electricity as it travels for one kilometer (https://kingcounty.gov/en/dept/metro/fares-and-payment/prices); the average distance one bus pass in one year is 54125.85 kilometers (https://www.treehugger.com/what-is-nitrogen-oxide-pollution-1204135):

$$C_{elc} \square b_{et} \times D_{Bs} \times W_C \times P_e \tag{13}$$

where C_{elc} represents the cost of all electricity in one year; D_{Bs} is average distance a bus travel annually; W_C represents the amount of electricity consumed for one kilometer's distance; P_{elc} is price for one KWH of electricity.

5.6 Disposal of Wasted Batteries

The e-buses King County use commonly renew the batteries only three times (https://www.newflyer.com/site-content/uploads/2023/01/Xcelsior-CHARGE-NG.pdf) in their twelve-year operation career during 2023 to 2035. The expenses to properly disposal each battery by government and the fee to buy new batterie are both accessible---for each one 350 thousand dollars (https://cptdb.ca/wiki/index.php/New_Flyer_Industries_XE40), and 4,000 to 20,000 dollars to recycle:

$$C_{Bt} \square C_{ABt} \times N_{Bt} \tag{14}$$

where cost (include recycle of wasted batteries and price of new batteries) of all the batteries from 2023 to 2035; C_{ABt} is the average cost of one battery; N_{Bt} is the number of batteries need to be recycled and renewed.

5.7 Construction of Charging Station

Average cost of building up one charging station is 1.5 million dollars (https://www.oppcharge.org/dok/OPPCharge%20Specification%202nd%20edition%2020190421.pdf). We assume that the charging time of each car is charged during the night when it is not driving. Each charging station can charge up to one car at the same time, which takes 3.8 hours to charge, so one charging station can charge two buses every night (https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm). There are 30 cars, so we need 15 charging stations.

$$C_{Cs} = C_{ACs} \times N_{Cs} \tag{15}$$

where C_{Cs} is the cost on the construction of all the charging station after during the transitioning; C_{ACs} is the average cost of one charging station; N_{Cs} refers to the number of charging station built.

5.8 Result and Judgement

After plugging the data into models, we build, we obtained the final financial cost of total 500 million dollars during this period of 13 years. Since Los Angeles, which holds a population of 39.7 million people, got a $1 billion (twice of our estimate cost) grant After Bipartisan Infrastructure Law was initiated. It is acceptable for the result as King County hold a population of roughly half of Los Angeles' population.

6. Problem 3: Ten-year Replacement Program

Public transport systems play a vital role in urban mobility, connecting people to their destinations efficiently. Optimizing route planning and fleet management is crucial to improving the quality of public transport services. Using the example of King County, Washington, we present a detailed plan to achieve this goal.

6.1 Prerequisite Description

To develop our route planning and fleet management strategy, we make the following assumptions:

Prerequisite Statement 1:

Daily ridership for the five categories: 2000, 1500, 1000, 500, and 250 passengers, respectively.

Prerequisite Statement 2:

Continued procurement of the New Flyer Industries XE40 electric buses, the largest fleet currently in use.

Prerequisite Statement 3:

Each bus can operate one round trip per hour, with a capacity of 42 passengers per trip. Buses operate for ten hours a day, transporting a total of 420 passengers per bus per day.

6.2 Route Categorization

King County's bus routes can be categorized into five groups based on ridership levels, as follows.

6.2.1 Downtown Routes

The Downtown Routes are the backbone of King County's public transit system, serving as a vital artery that connects Downtown Seattle with the city's core areas and satellite cities. These routes are characterized by the highest ridership levels, making them the busiest and most critical lines in the network. Their significance is denoted by the prominent "Downtown Seattle-route" label located in the upper right corner of the bus route map. Passengers on these routes predominantly consist of daily commuters, tourists, and residents traveling between the city center and various destinations.

6.2.2 Core-to-Core Routes

Core-to-Core Routes encompass the second-highest ridership levels in King County. These routes facilitate transportation between core areas within the county, excluding Downtown Seattle. While they do not venture into the city center, they connect key urban hubs and include areas outside the core regions, contributing to the overall accessibility of the county. Core-to-Core Routes are vital for providing residents with convenient options for commuting and accessing essential services, as well as for supporting regional connectivity.

6.2.3 Core-to-Suburb Routes

Core-to-Suburb Routes are characterized by moderate ridership levels, serving as connectors between core areas and satellite cities within King County. These routes offer a balance between regional accessibility and ridership demand. Their presence is denoted by the detailed map of core areas in the upper right corner of the bus route map, which also encompasses non-core regions. Core-to-Suburb Routes play a pivotal role in bridging the gap between urban and suburban areas, catering to the transportation needs of diverse communities.

6.2.4 Suburb Routes

Suburb Routes operate exclusively within the confines of satellite cities within King County. These routes serve as essential links within suburban areas, providing residents with local transportation options. While they have lower ridership levels compared to routes in urban areas, Suburb Routes are indispensable for ensuring mobility and accessibility within satellite cities. Their distinct feature is the presence of a map depicting the specific satellite city in the upper right corner of the bus route map.

6.2.5 Satellite Routes

Satellite Routes represent the lowest ridership category within King County's public transit system. These routes exclusively serve satellite cities with limited demand for public transportation. While their ridership levels may be lower, they are still integral for addressing the unique transportation needs of these smaller communities. Satellite Routes contribute to the inclusivity of the transit system by ensuring that even less densely populated areas have access to public transportation options.

6.3 Phased Vehicle Replacement Plan

In order to ensure the smooth operation and longevity of King County's public transit system, a meticulously planned vehicle replacement strategy is imperative. The phased approach outlined below is designed to systematically upgrade the existing bus fleet, enhancing both efficiency and effectiveness while minimizing disruptions to daily service.

Figure 10. Bus Changeover Program Timeline Diagram

6.3.1 Phase One: Strategic Replacement

Phase One of the vehicle replacement plan involves the simultaneous replacement of eight buses, strategically selected to impact 34 routes. This phase focuses on routes where aging buses are causing increased maintenance costs and service disruptions. By replacing these vehicles, we aim to address reliability issues and improve the overall passenger experience. The careful selection of routes ensures that the initial phase's impact is felt where it matters most, ultimately leading to a more dependable and efficient transit system.

6.3.2 Phase Two: Incremental Enhancement

In Phase Two, six buses are scheduled for replacement, affecting 15 routes. This phase emphasizes incremental improvements to the transit system, targeting routes with medium ridership levels and the potential for optimization. By replacing a portion of the buses in these routes, we aim to enhance operational efficiency, reduce emissions, and maintain a high level of service quality. This approach allows for a balanced allocation of resources while steadily advancing the overall fleet's modernization.

6.3.3 Phase Three: Coverage and Expansion

Phase Three calls for the replacement of four buses, impacting 33 routes. This phase extends the reach of the vehicle replacement plan to a broader set of routes, focusing on coverage and expansion. Routes serving both core and suburban areas benefit from upgraded buses, improving accessibility and reliability. By expanding the scope of the replacement plan, we continue to address aging fleet issues and create a more comprehensive, passenger-centric transit network.

6.3.4 Phase Four: System-Wide Optimization

The final phase of the vehicle replacement plan involves replacing two buses, affecting a total of 68 routes. Phase Four represents the culmination of our efforts, aiming for system-wide optimization. These buses are strategically placed on routes that span the entire transit network, ensuring that every corner of King County benefits from the modernization process. By the end of Phase Four, the transit system will have undergone a significant transformation, marked by improved reliability, reduced operational costs, and enhanced passenger satisfaction.

6.4 Results and Discussion

Implementing our proposed route categorization and vehicle replacement plan provided valuable insights for improving King County's public transit system. Daily ridership reached 264,000 passengers, closely aligning with the 18-year daily average of 283,637 passengers. It's important to note that slight differences can be attributed to challenges in estimating ridership based solely on bus capacity.

Ridership depends on various factors like external events, economic conditions, and travel behaviors, not just bus capacity. While our ridership figures provide a strong foundation for transit system improvement, they are indicative rather than absolute. Nevertheless, these results confirm that our approach can significantly enhance the transit experience for King County passengers.

6.5 Comparative Analysis

To validate our approach, we applied it in Hong Kong and Chicago, in addition to King County. In

Hong Kong, we saw potential improvements in ridership and efficiency. Despite unique challenges, our approach proved adaptable and promising. Similarly, in Chicago, we found promise in optimizing public transit, even in a different urban context. Our approach's core principles remained effective, though challenges varied.

In conclusion, we've presented a tailored solution for King County, Washington's route planning and fleet management, which can be adapted to other cities. Key components include route categorization and phased vehicle replacement to improve public transportation for residents and visitors.

While promising, further research and real-world testing are necessary to refine these strategies for broader use, as urban environments differ. Nonetheless, our paper provides a useful framework for transit authorities and policymakers to enhance public transit systems and meet the evolving needs of cities.

7. Strengths of the Model

- **Interpretability and comprehensiveness**

The coefficients and intercepts generated by the model in problem two have intuitive interpretations and can be used to explain the effects of individual independent variables. At the same time, the variables we consider includes many effective aspects, which essentially means a wider applicability and higher accuracy.

- **Visualization**

The results of a quadratic regression model in problem one can be visualized in a two-dimensional or three-dimensional plot, helping to intuitively understand the relationships between variables.

8. Weaknesses of the Model

- **Sensitive to Outliers**

The number of public transport vehicles may be affected by seasonality, holidays, special events and other factors, which may lead to the existence of outliers in the data, and the minimum quadratic regression model is more sensitive to outliers, which may lead to the inaccuracy of the model.

- **The Hypothesis Problem**

The minimum quadratic regression model assumes a quadratic relationship between the dependent and independent variables, and if the true relationship is not of this form, the fit of the model may not be accurate.

LETTER OF PROPOSAL

DEAR KING COUNTY'S TRAFFIC OFFICER

First of all, on behalf of our research team, I would like to extend our highest regards to you. Secondly, allow me to show you the latest research results of our team on transportation in this area. According to our research, we find that adopting electric buses can have many advantages, including environmental, economic and high-tech advantages.

From the aspect of environment, if the current policies of your government are continuously implemented, the air pollutant emissions (PM10 and nitrogen oxides) and greenhouse gas emissions (CO_2) in the field of public transportation can be effectively reduced by 2035, which will make effective contributions to the improvement of local ecological environment. This can improve the prevalence of local respiratory diseases and improve the quality of life of the local population.

In terms of economic advantages, after the process of online research, information search and mathematical modeling, we find that electric buses have significant economic advantages. From the perspective of spending on electric buses we are far ahead in terms of the cost of maintaining the vehicle, the cost of the fuel needed to run it and the cost of disposing of the old car. Compared with traditional buses, the cost of electric buses may be relatively large at the beginning of purchase, but in the long run, electric buses will have economic advantages compared with traditional buses.

From the perspective of scientific and technological advantages, the use of electric buses using electric motors has almost no noise compared with traditional diesel engines, which can really improve the riding environment to achieve the environment of silent carriages. There are also new new energy trams that generally have advanced ultrasonic radar to ensure the safety of electric buses. Compared to other traditional buses, electric buses will have better fresh air system and filtration system.

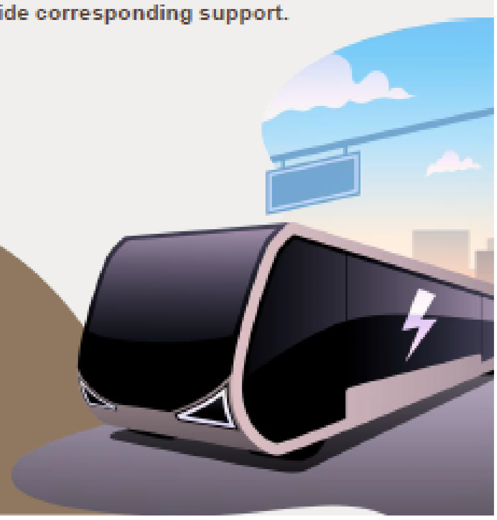
In view of the advantages of the above three aspects, we strongly suggest that the authorities can formulate a detailed replacement plan for electric buses, study relevant policies, and set up operational routes so that the public can have a comfortable public transport experience.
Of course, if your government has relevant plans and plans, you can contact us. As a professional data analysis and research team, we are willing to provide corresponding support.
The most

Best regards,

TEAM NO. 14206

best.math.team.2023@gmail.com

From Any City For the World



References

https://kingcounty.gov/~/media/depts/metro/about/advertising/transit-advertising-policy

https://kingcountymetro.blog/2018/04/18/metro-updates-transit-advertising-policy-regarding-campaign-speech/

https://chargedevs.com/newswire/washingtons-king-county-metro-to-purchase-up-to-120-new-flyer-electric-buses/

https://www.newflyer.com/bus/xcelsior-charge-ng/

https://www.electricitylocal.com/states/washington/

https://en.wikipedia.org/wiki/King_County_Metro

https://www.sustainable-bus.com/electric-bus/new-flyer-xcelsior-charge-ng/

https://cptdb.ca/wiki/index.php/New_Flyer_Industries_XE40

https://www.ncesc.com/how-much-does-a-battery-cost-for-an-electric-bus/

https://www.urban-transport-magazine.com/en/bus-electrification-a-comparison-of-capital-costs/

https://usa.streetsblog.org/2022/08/16/us-dot-seeks-to-double-the-nations-electric-bus-fleet-which-is-currently-tiny-and-will-still-be

https://about.bnef.com/electric-vehicle-outlook/

https://kingcountymetro.blog/2022/06/07/ridership-over-200000-weekday-bus-service-adjustments-begin-june-13/

https://kingcountymetro.blog/2020/04/30/covid-19-update-estimated-weekday-bus-ridership-for-april-20-24-as-metro-connects-people-to-work-and-necessities/

https://worldpopulationreview.com/us-counties/wa/king-county-population

https://kingcounty.gov/en/dept/metro

https://www.ipcc.ch/

https://kingcounty.gov/en/dept/metro/fares-and-payment/prices

https://www.treehugger.com/what-is-nitrogen-oxide-pollution-1204135

https://www.newflyer.com/site-content/uploads/2023/01/Xcelsior-CHARGE-NG.pdf

https://cptdb.ca/wiki/index.php/New_Flyer_Industries_XE40

https://www.oppcharge.org/dok/OPPCharge%20Specification%202nd%20edition%2020190421.pdf

https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

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