Battery Electric Bus Deployment in the Greater Salt Lake Region

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1. Overview and Motivation

This project presents the result of a bi-objective spatio-temporal optimization model for the strategic deployment of Battery Electric Bus (BEB) in the Greater Salt Lake Region. The first objective is to minimize the cost of purchasing BEB and installing both on-route and in-depot charging stations while maintaining current bus schedules. The other objective is to maximize environmental equity by incorporating the disadvantaged population in the decision-making process.

Motivated by the advancement of battery technology and the increasing need for a cleaner source of energy, BEB is receiving a growing amount of attention from the transit vehicle industry and transit agencies including Utah Transit Authority (UTA). UTA has been practicing deploying BEB in Utah in a relatively small scale. This project used empirical data from UTA to offer a potential framework that can be adopted or expanded by transit agencies to optimally deploy BEBs by accommodating multiple goals and objectives that the transit agencies set forth.

Moreover, the transit system is what social functions depend highly upon, especially in areas where disadvantaged populations are transit-dependent and tend to be the socio-economic status groups that are particularly vulnerable to air pollution. Full electrification could potentially improve environmental equity significantly. This project aims to improve social equity by incorporating it as an imperative objective in the decision-making process.

2. Related Work

The idea of the project is inspired by a previous paper, Optimizing the spatio-temporal deployment of battery electric bus system from Wei et al., 2018. This paper considers the deployment of BEB where the single objective is to minimize total cost. In this project, we have decided to extend the potential of the framework by incorporating another objective so as to favor the disadvantaged population.

The design of the visualization is inspired by the class contents about Multiview and Joint Highlight. The design has also been inspired by this visualization, https://poloclub.github.io/ganlab/. We decided to incorporate the visualization and storytelling in our visualization as well.

3. Questions

The question we try to answer is that how different is the deployment plan under different budgets given by transit agencies. This also what the optimization model tries to answer.

When generating result, constraint method is used which converts the objective which minimizes cost into a constraint, thus converting the bi-objective model into single objective. In this case, when the upper bound (budget) is chosen differently for the new constraint, different deployment plan is generated.

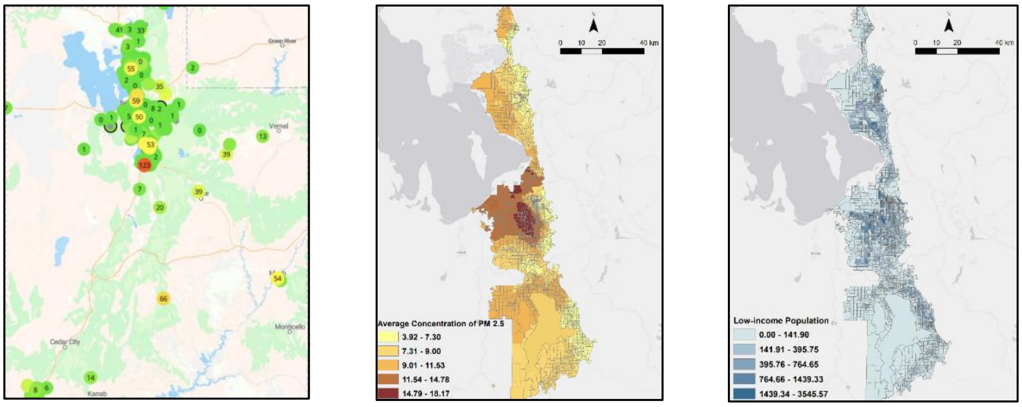
The deployment plan generated using the method we proposed are hard to be understand for some audience who has no knowledge or experience on the transportation discipline and people might be not able to understand the connection between the data and result as well. In this case, we have designed the join-highlight features to reinforce the connection between the source data and results. For instance, when budget is low, the buses chosen to be replaced should be the buses who go through the most polluted and most populated region. Through visualization, people will see the correct reflection of this type of connection between base data and results.

4. Data Source and exploratory analysis

The data we collected can be categorized into 3 different groups.

(1) Air quality data

Air quality data is extracted from https://www2.purpleair.com/ using API provided by the website. Air quality data consists of two-week air monitoring data in Utah. The interface of the website is shown in Fig.1(a). While extracted, the data is stored as JSON file and it's processed into a CSV file for further analysis. Fig.1(b) demonstrates the color-encoded concentration level of PM 2.5 in Utah, which is generated from a shapefile and has been converted into a geo-json file.



(a) (b) (c)

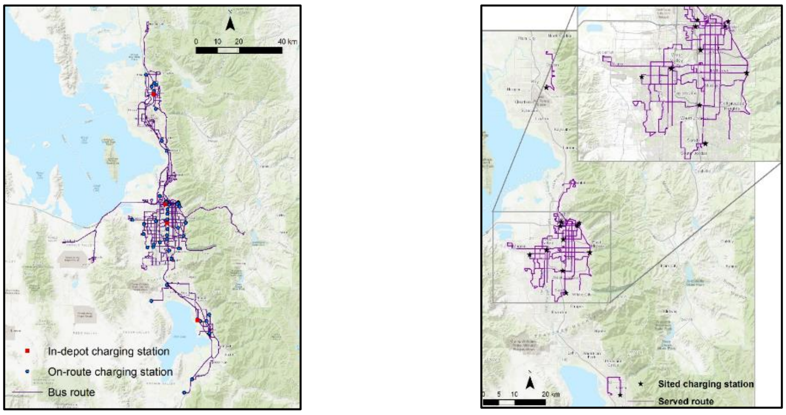
Fig. 1: (a) Air quality collection site distribution; (b) Concentration level of PM 2.5 in each traffic analysis zone; (c) Distribution of low-income population over Greater Salt Lake City region.

(2) Socio-economic data

The socio-economic data is retrieved from Metropolitan Planning Organizations (MPOs) in Utah for the year of 2019. It contains the income level, employment level, and various other aspects that we are going to demonstrate. e.g. Fig.1(c) shows the distribution of the low-income population in Utah. It has been processed into a geo-json file.

(3) Bus network data.

The bus network data is provided by Utah Transit Authority. The study area is shown in Fig.2(a)~(b). The data related to the bus network data such as the coordinates of bus stops is saved in shape files. And we have extracted these essential data sets and saved them into geo-json files.

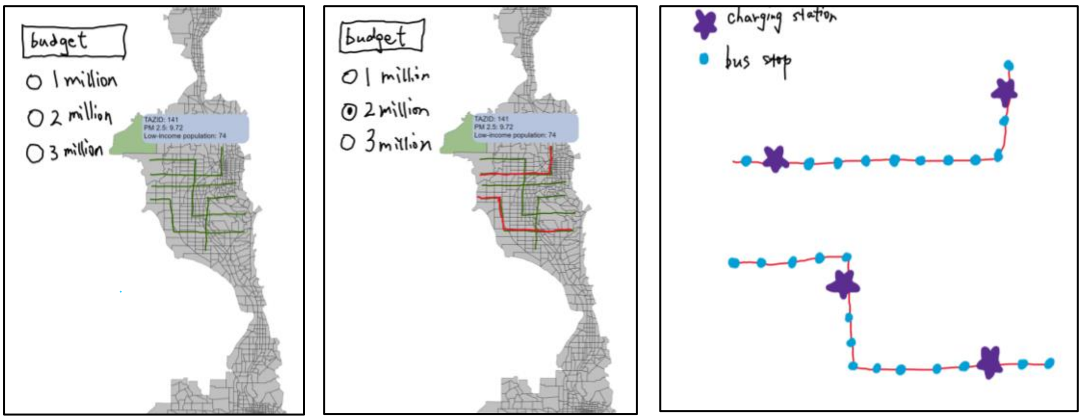


(a) (b)

Fig. 2: (a) The bus network from a whole perspective; (b) The bus network in a higher-resolution in which the battery electric bus deployment is shown.

Design Evolution:

Through an initial exploratory analysis of the three data resources, we plan to design a multi-view visualization. On the one hand, one goal of this project is to design battery electric bus deployment plan in which the residents, who earn lower income and live at traffic zones with worse pollution issues, would obtain the benefits of deploying battery electric buses in first priority. Based on this consideration, it is essential to display he the basic attribute data such as the ID, pollution index and low-income population for each traffic analysis zone, which is shown in the first view. On the other hand, different financial budget will generate distinct deployment plan in terms of the number of electrical buses used and the amount of charging stations. Therefore, the bus network will be visualized in the first view as well. In order to show the plan in detail, the second view is designed to display the deployment plan and the audience will have a clear understanding of which route will be equipped with electric bus and where the charging stations locate. A sketch for the first-stage design is presented in Fig. 3.

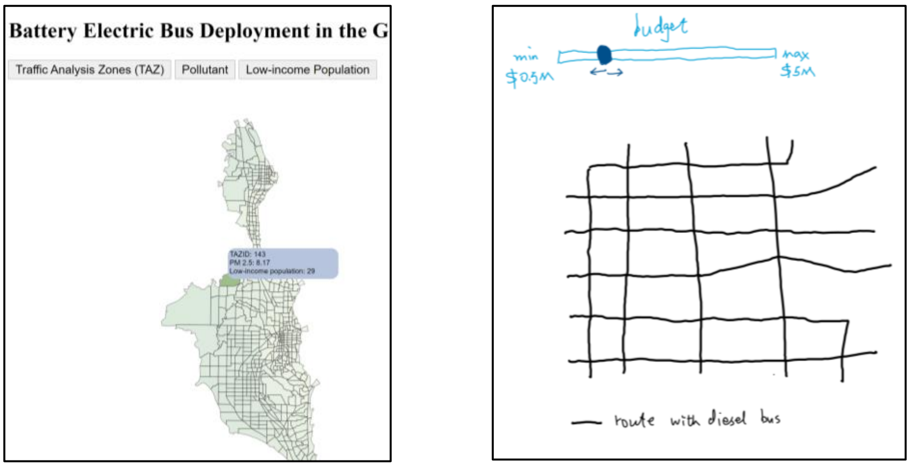


(a) (b) (c)

Fig. 3: The initial visualization design: (a) The first view shows the overal perspective of traffic analysis zones. (b) A battery electric bus deployment plan is displayed given a specfied financial budget (e.g., an investment of \$ 2 million.); (c) The second view presents the electric deployment in detail including the electric bus routes and charging station locations.

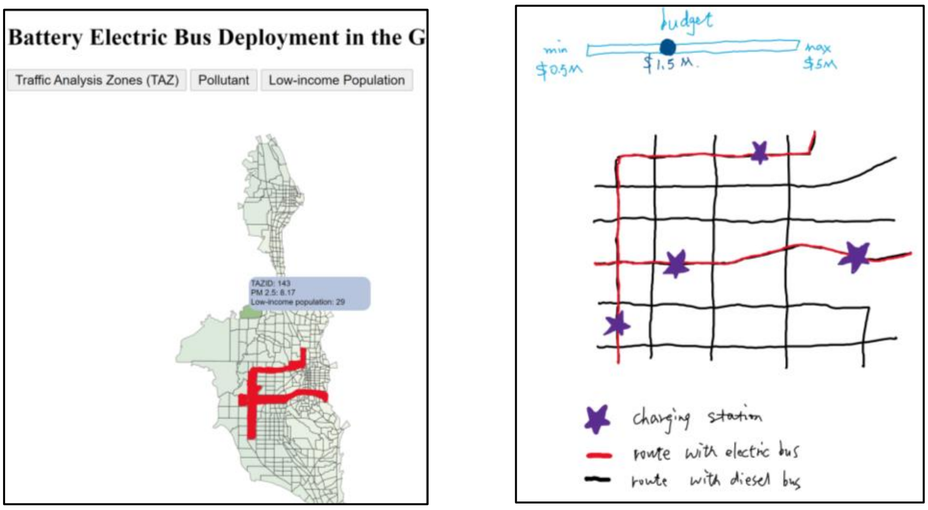
Fig. 3 shows a rough draft of an initial design. As we see in the left panel, the main elements are the traffic analsis zones and bus network. Each of traffic zones is represented with a small block and the green lines represent the bus routes. On the left top side, a button is designed and we can select a certain budget in the list and then a electric bus deployment under the seleted budget is shown (see Fig. 3(b)). The bus routes operating with electric buses are highlighted using red lines. In order to give some details about the deployment plan, the second view is designed. From Fig. 3(c), the routes highlighted in first view are exhibited in detail. The blue circles are used to represent buses while the purple pentagrams stand for the charging stations.

When implementing this design, we met some issues such as putting two layers on the same view messes up the visualizations. In order to make the appearance of the view looking more tidy, we discussed with our mentor and redesigned a new visualization shown as follows.



(a) (b)

Fig. 3: (a) The first view: the exhibition of the distribution of pollution index for the traffic analysis zones; (b) The second view: the bus network within the region.



(a) (b)

Fig. 4: (a) The first view: highlighting the traffic analysis zones through which the electric buses travel; (b) The second view: the buses equipped with electric buses are highlighted.

In this design, we still keep two views. Different from the initial visualization design, we separate the traffic analysis zone layer and bus route layer. From Fig. 3(a), we can see the first view show the traffic analysis zones and there are 3 buttons which is able to display the distribution of pollution and low-income population over these zones when clicking the corresponding button. Fig. 3(b) displays the second view which include the bus network. On the top of the view, we set a slider of investment budget and a certain budget provided by the Utah transportation authorities would be specified through sliding the blue circle. In Fig. 4(b), it can be seen that a battery electric bus deployment is determined after selecting a budget of $ 1.5M as an example. Meanwhile, once the routes equipped with electric buses, then the traffic analysis zones travelled across by these buses will be emphasized using a color like red (see Fig. 4(a)).

We think the second design are better organized and help the audience to have a better understanding of the impact of the change in financial budget on the coverage of traffic zones. One of the goals is to replace traditional buses with electric buses in the regions with worse pollution issues and more low-income population. The first view will provide audiences a direct visualization through highlighting the regions the electric bus could serve.

Implementation:

Our new design has some interactions with users. For example, in the first view, the attribute data will be shown when moving the mouse over a zone. This interaction will help user to get the basic data related to the zones they are interested in quickly. Another interaction is that if someone wants to check the zones that an electric bus route serves, he can click the route and then the corresponding zones will be highlighted in the first view.

Evaluation:

Through implementing the visualization based on the data we have, we have a better understanding of the pollution distribution over the Salt Lake City regions. Besides, exploring the bus network data used in this project helps us to be more familiar with the infrastructure related to the public transit. More important, we design a visualization which could be used to help people who are interested in the development of green-energy transportation to have a direct experience about battery electric bus deployment.

As mentioned before, one question we need to answer is how different the deployment plan is under different budgets given by transit agencies. This visualization is able to answer this question. Through using the slider to change the budget, a electric bus deployment under a selected budget will be shown in the second view. The difference between various deployment plan are pretty to be identified through highlighting the routes with electric buses and regions covered by these roues.