Optimal locations of electric public charging stations: A case study for Cincinnati

by Gunjegai, A., Gupta, A., and Pham, K.

Instructor: Dr. Leonardo Lozano

Abstract

With the raising concern about environmental pollution, using electric vehicles (EVs) is one direction that is believed to be the future standard of transportation. While the idea itself is not new and the legal framework is already there to support it, the implementation of it still progresses very slowly. There are multiple reasons for this slow growth, one of the major reasons is the lack of charging stations, which makes it very hard to convince the people of it over traditional vehicles using fossil fuel.

With that in mind, in this paper, we propose an optimization model for setting up charging stations in the city of Cincinnati. Our objective is to satisfy the projected demand of charging at minimum investment. We do that by locating a number of candidate locations, then forming an integer programming model to choose the final suitable spots for implementation.

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1. Introduction

Cincinnati is a major city with the population of roughly 300,000. Its metropolitan area is a growing economic power in the Midwestern United States based on the increase of economic output. The heavy use of fossil fuel in the city causes air pollution, especially in urban areas. The new-era technology of Electric Vehicles (EVs) can be considered as a potential solution and possibly replace the existing fossil dependent vehicles in the future. Notable factors that impact the growth of EVs adoption in the city is the maximum distance that can be covered by a fully-charge vehicle and the access to public charging infrastructure. The geographic location of the city and its population distribution make an interesting playground to study and implement the solution of building Electric Vehicle Charging Stations (EVCS).

In the previous studies conducted on EVCS, several locations have been identified wherein there is a possibility of having an EVCS, using the public data of Cincinnati. The next steps involved are identifying the optimal locations using the Origin-Destination trip data for the city, budget constraints involving the setup of the EVCS costs and topology of the city. The objective of this study is to minimize the cost involving EVCS while having served the maximum number of customers. The result of this project can be used by the city authorities in implementing the electric charging network for the city.

By formulating the demand for energy and the location of the potential EVCS in each area of Cincinnati, we try to come up with a solution in which we can serve all the customers with the lowest amount of investment.

2. Literature review

There are many existing papers that tried to solve the optimization problem of building EVCS, in both theoretical level and case study for specific places.

In their theoretical paper, Tang et al. (2013) suggested dividing the population into a set of areas. You and Hsieh (2014) tried to serve as much demand as possible with limited budget.

Chen and Khan (2013), Wang (2007), and Wu et al. (2016) have case studies for Seattle, Phegu, and Beijing, respectively.

3. Problem definition

In this section, we provide the description of the problem and discuss the model for the said problem.

To begin with, we have a list of 45 zip codes in Cincinnati. For each of them, we have a total energy demand, as well as a potential location to build a charging station. The demand of a particular zip code can be satisfied by any station, not just the station in the said zip code, but in case of using other station, the energy needed to travel between them is taken into account.

There are 3 types of charging station that can be built, differed by the energy capacity. The construction cost for each station varies by station type and area.

Our objective is to satisfy all demand with minimum total construction cost.

4. Proposed model

In this section, we propose a general model to depict our problem.

First, we define the sets for the model:

Sets: $I = \{1, 2, \dots, 45\}$: index of zip codes

$K = \{1, 2, 3\}$: index of charging station types

Next, we obtain the input data for the model:

Data: c_{ik} : construction cost of a station of type k in zip code i

d_i : energy demand of zip code i

d : average energy demand of each vehicle

l_{ij} : average energy to charge in station j from zip code i

m_k : capacity of a station of type k

r_{ij} : neighboring flag, 1 if the distance between i and j is less than a certain value, 0 otherwise

Our decision variables are shown below:

Decision variables:

$$x_{ik} = \begin{cases} 1 \text{ if we build a station of type k in zip code i} \\ 0 \text{ otherwise} \end{cases}$$

e_{ij}: the energy demand of zip code i satisfied by station j

Note that this demand does not include the energy needed to travel between i and j to charge the vehicles.

For the objective function, we want to minimize the total construction cost:

$$\text{Minimize} \sum_{i \in I} \sum_{k \in K} c_{ik} x_{ik}$$

The constraints of the model:

$$\sum_{k \in K} x_{ik} \leq 1 \; \forall \, i \in I \quad (1)$$

$$\sum_{j \in I} e_{ij} \geq d_i \; \forall \, i \in I \quad (2)$$

$$\sum_{k \in K} m_k x_{ik} \geq \sum_{j \in I} e_{ji} \left(1 + \frac{l_{ij}}{d}\right) \; \forall \, i \in I \quad (3)$$

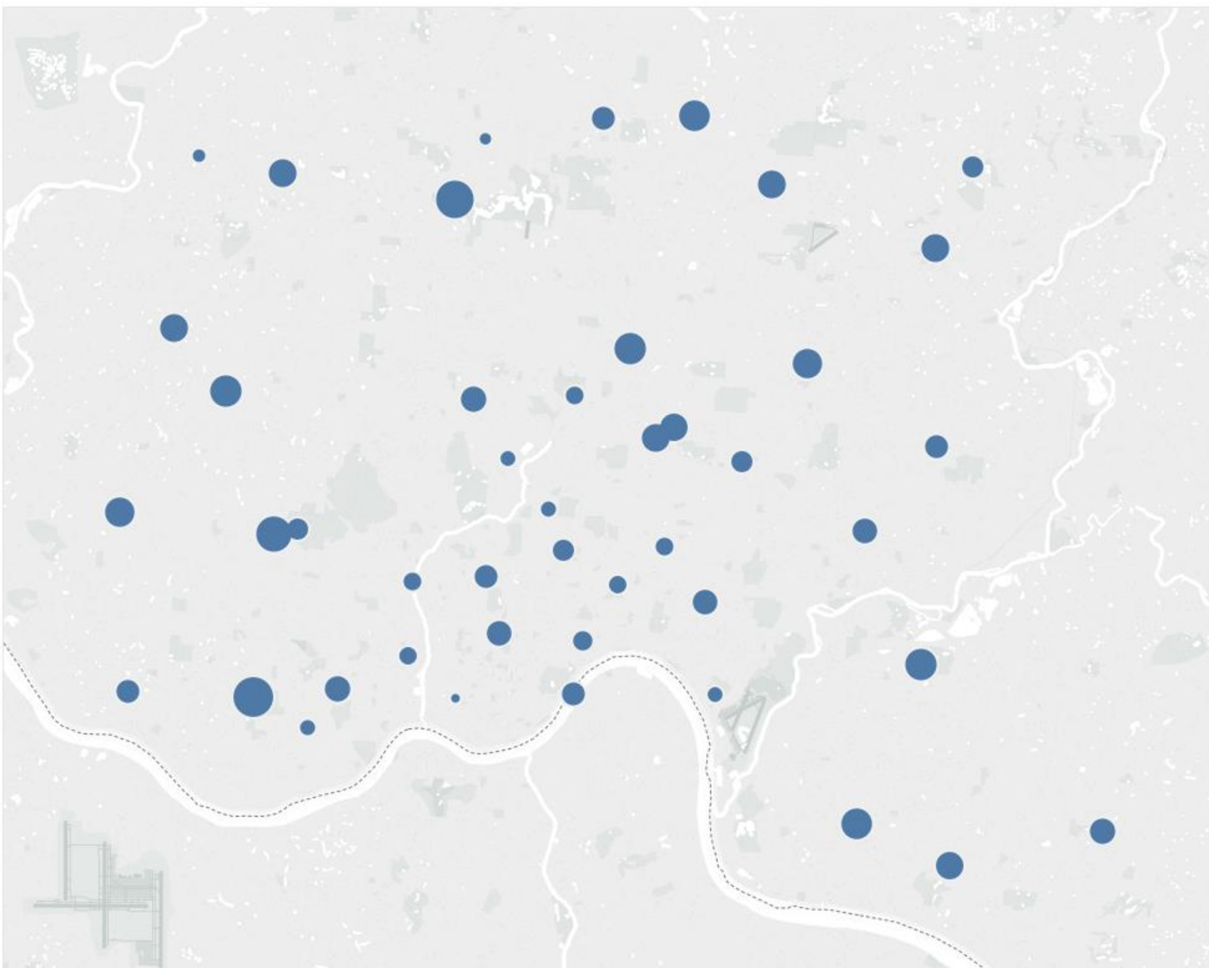
$$e_{ij} \leq M.r_{ij} \; \forall \, i, j \in I \quad (4)$$

Constraint (1) makes sure that no more than 1 station is built in each location. Constraint (2) states that all demand must be satisfied. Constraint (3) limit the total energy supplied by each station by its capacity. (4) prevents vehicles from charging in a station too far away.

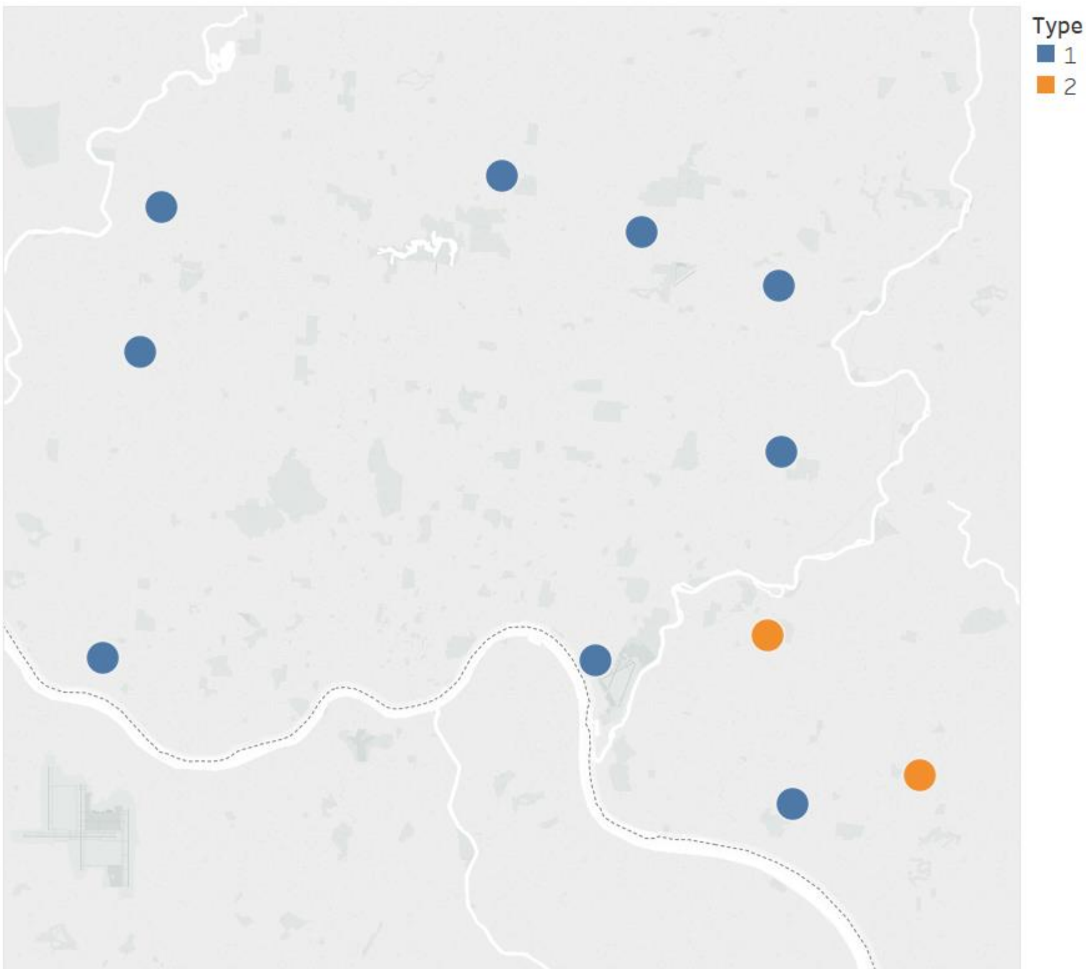
5. Model results

In this section, we run the model with different configurations. For the initial model, the construction cost differs mostly by area.

Here is the map with the demand size in each area:



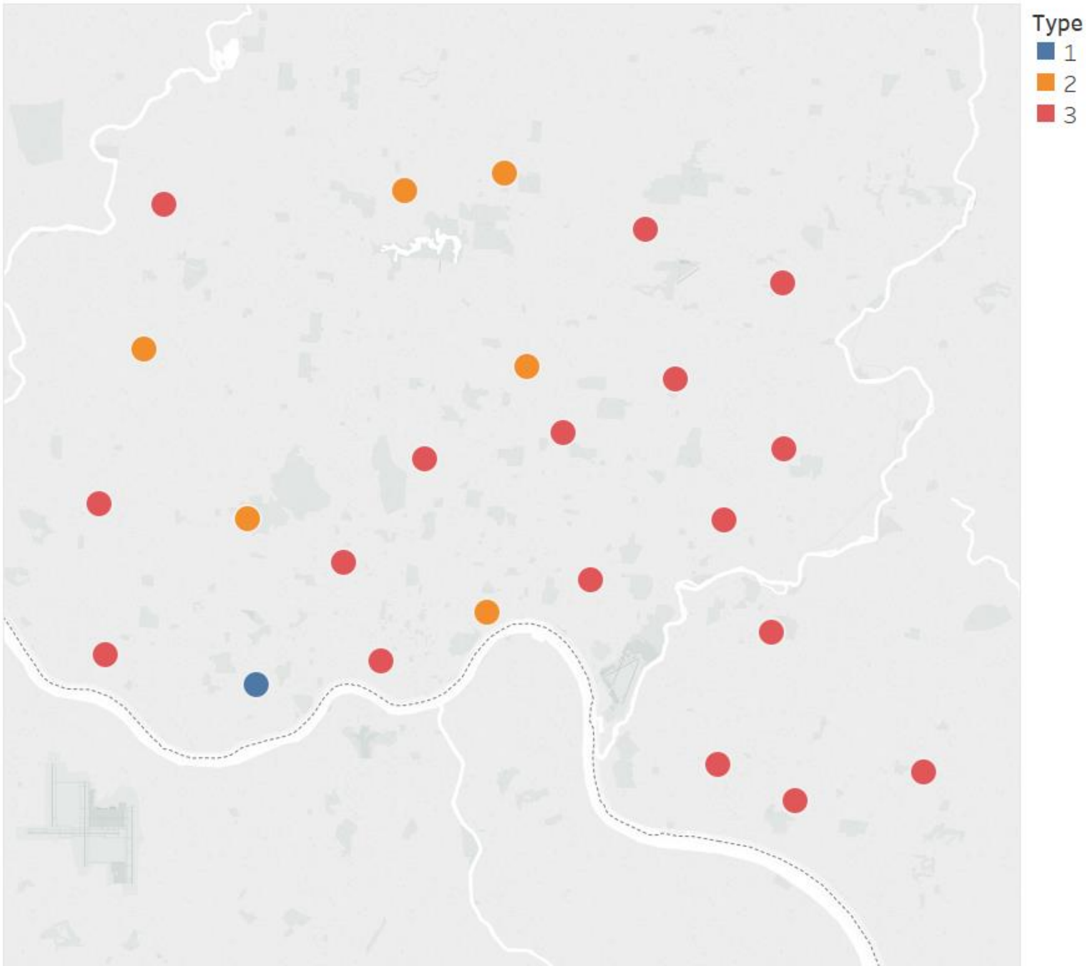
First, we run a model without constraint (4), meaning that demand from any zip code can be satisfied by any station.



Note that type 1 station is the type with biggest capacity, we can see that the optimal building pattern is to build big stations in the outskirt of the city where the construction cost is lower than the center.

This solution satisfies 375980 kWh demand and 11637 kWh travelling expense just for charging. Judging by those numbers, we believe that the expense is not punishing enough, thus we want to limit the distance between each vehicle location and its charging location.

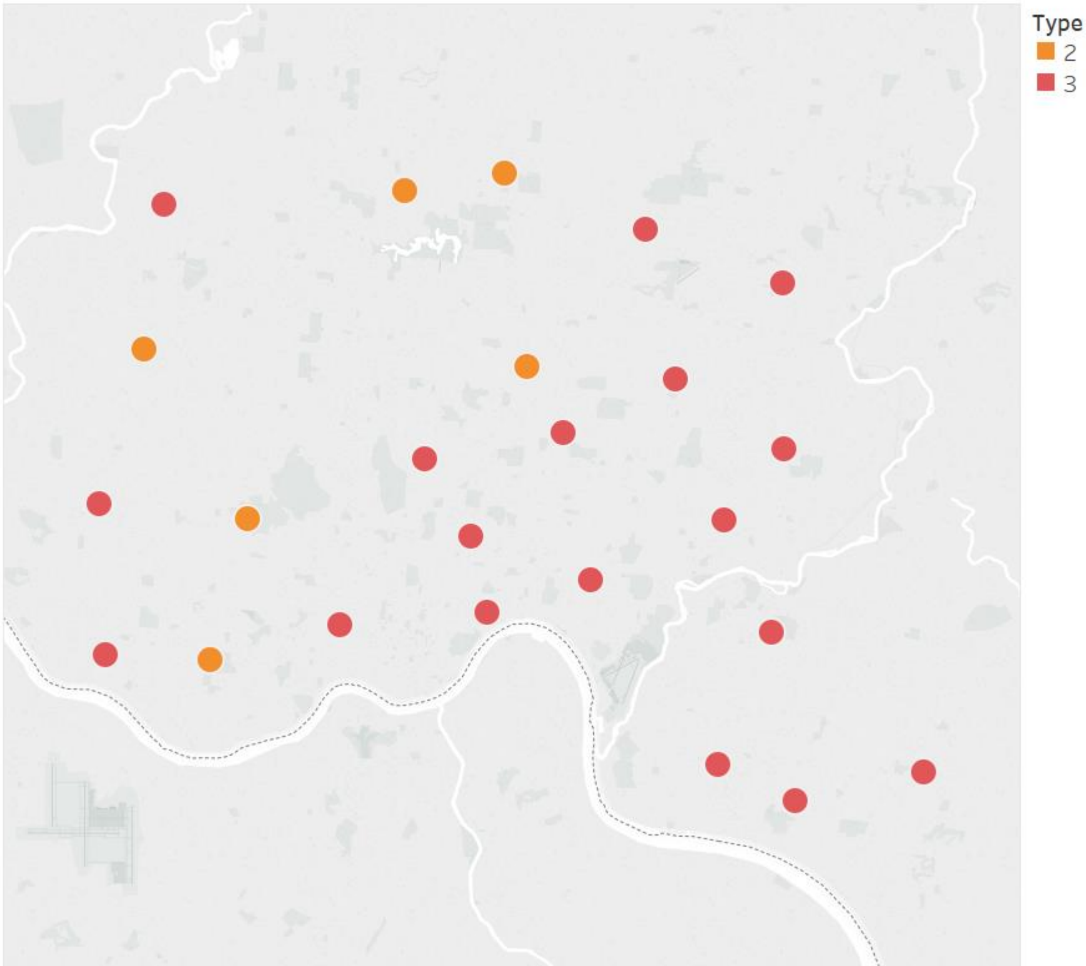
So, for the next step, we run the model with constraint (4) with max distance being 1.5 miles.



We can see that now the optimal solution is to build many smaller station spread out the map.

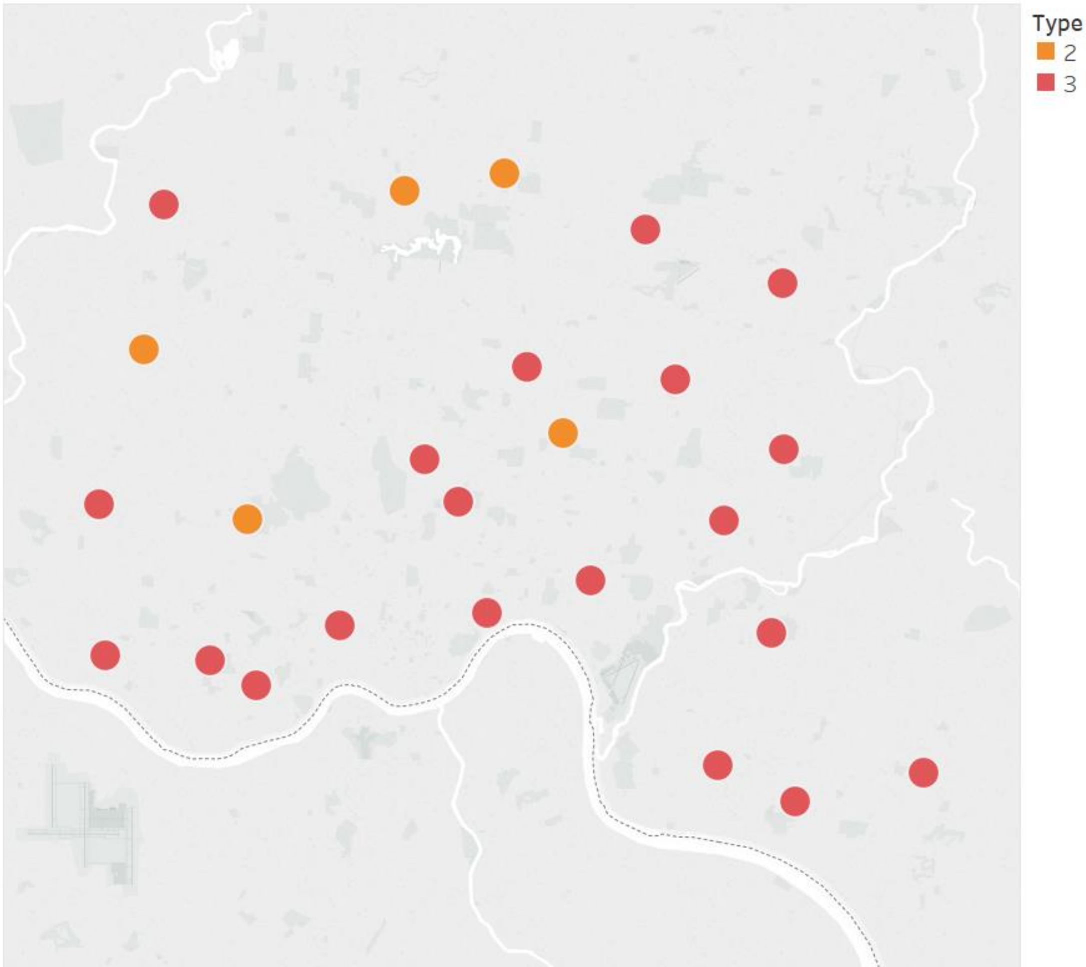
This solution satisfies 385779 kWh demand and 2405 kWh travelling expense. Compared to the first model, this reduces the expense by 79.3%.

Next, we change the construction cost so that it differs mostly by station type and less varied by zip code.



This time, with the cost being more sensitive to station type, we can see that the model divided some big stations into smaller ones, but only a couple of them.

Next, we change the max distance to 3 miles and rerun the model.



The result does not differ much from the previous model.

With this fourth model, we conclude our project.

6. Conclusion

In this project, we discuss a charging station case study for the city of Cincinnati. We divide the city into areas by zip code, and use the location and population of each area to simulate energy demand and distance between them.

We propose an optimization model for building charging stations to satisfy all demand with minimum total construction cost. The model works well in all configurations.

We believe the model can be used with more precise data for actual implementation.

References

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