Optimized Strategy for Electric Vehicle Charging Station Allocation

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table of contents

introduction.

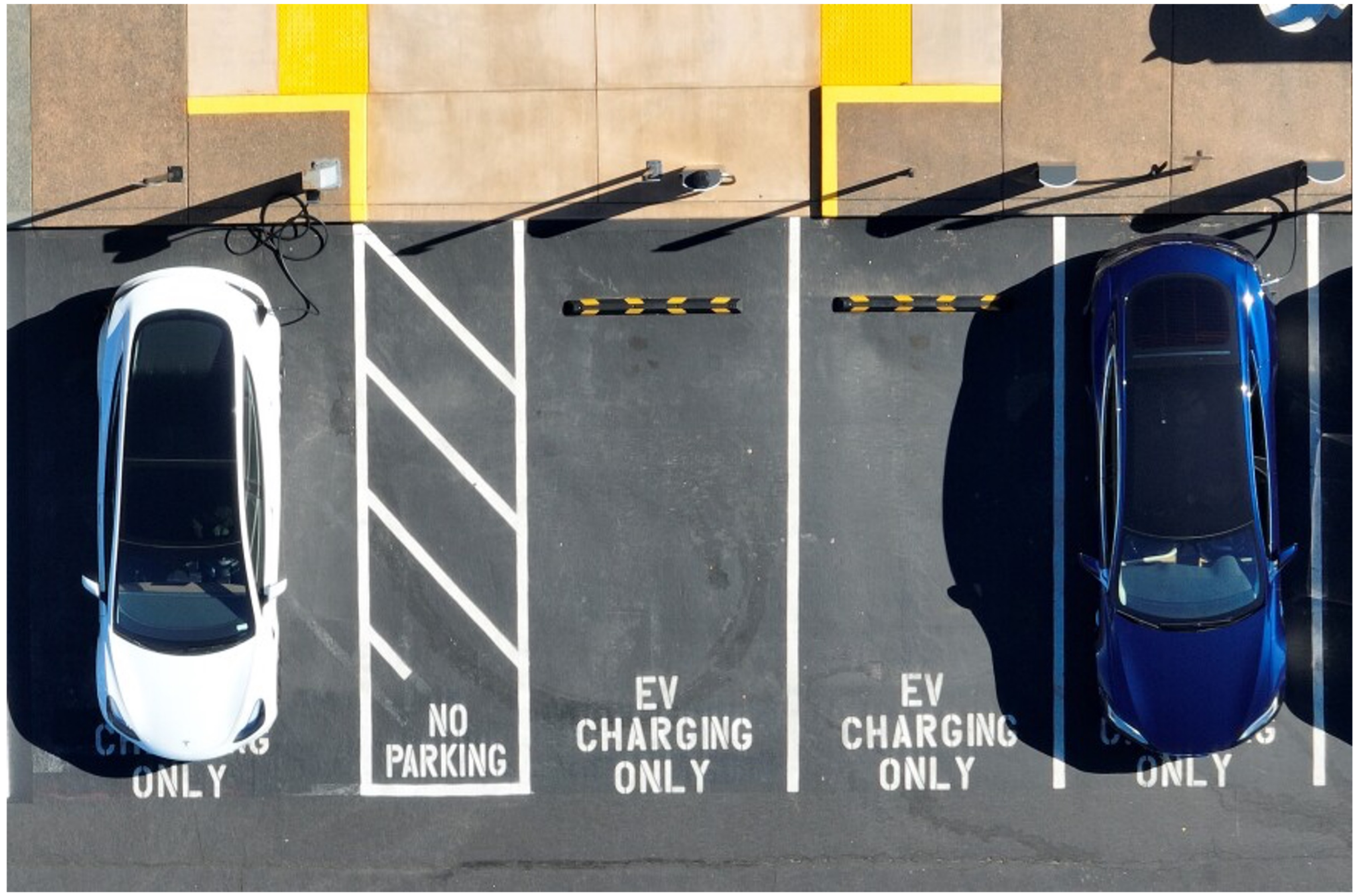
"

In order to have a clean air in cities, you have to go electric.

— Elon Musk (Founder of Tesla)

situation

Transportation is the largest source of **greenhouse gas emissions** in King County, accounting for nearly **50%** of all GHG emissions that occur within King County's geography.



- **50%** of **light-duty vehicles** are transitioned to electric by **2025** and **100%** by **2030**.
- **50%** of **medium-duty vehicles** are transitioned to electric by **2028** and **100%** by **2033**.
- **50%** of **heavy-duty vehicles** are transitioned to electric vehicles by **2038** and **100%** by **2043**.

→ Installation of **150 chargers** by **2030** in county facilities.

According to *King County Environmental Sustainability Program - Title 18*

Zero Emissions by 2035

A project lead by Metro, the only large transit agencies in the country working toward a 100% zero-emissions fleet, in King County, Seattle, aims for a fully *zero-emissions fleet by 2035*. This includes procuring ***zero-emissions buses***, investing in ***electric trolleys***, and enhancing ***charging infrastructure*** to cut air and noise pollution.

motivation

Increasing EV adoption highlights the importance of strategic charging station placement to optimize infrastructure efficiency and minimize redundancy. Despite progress in public transit initiatives like Metro's Zero Emissions project, there remains **a critical gap** in infrastructure for private EV vehicles.

vision

Our project aims to optimize the allocation of electric vehicle charging stations in **King County, Seattle,** using data from the official Washington state open data portal on registered electric vehicles. Our goal is to strategically design stations to **maximize coverage across locations** and **meet demand efficiently**.

dataset

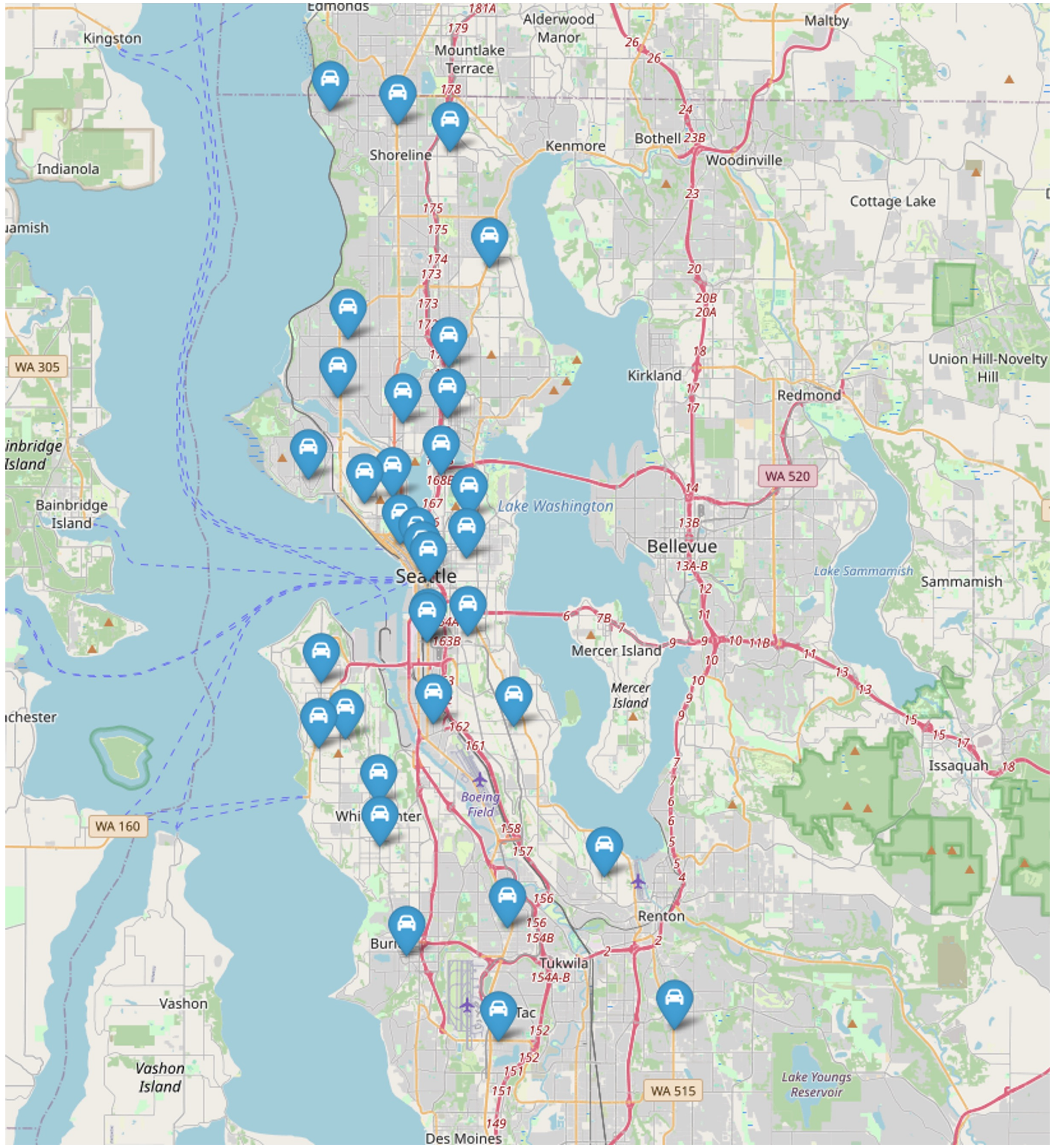
VIN (1-10)	County	City	State	Postal Code	Model Year	Make	Model	Electric Vehicle Type	Clean Alternative Fuel Vehicle (CAFV) Eligibility	Electric Range	Base MSRP	Legislative District	DOL Vehicle ID	Vehicle Location	Electric Utility	2020 Census Tract
5YJYGDEE1L	King	Seattle	WA	98122.0	2020	TESLA	MODEL Y	Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	291	0	37.0	125701579	POINT (-122.30839 47.610365)	CITY OF SEATTLE - (WA)|CITY OF TACOMA - (WA)	5.303301e+10
7SAYGDEE9P	Snohomish	Bothell	WA	98021.0	2023	TESLA	MODEL Y	Battery Electric Vehicle (BEV)	Eligibility unknown as battery range has not b...	0	0	1.0	244285107	POINT (-122.179458 47.802589)	PUGET SOUND ENERGY INC	5.306105e+10
5YJSA1E4XK	King	Seattle	WA	98109.0	2019	TESLA	MODEL S	Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	270	0	36.0	156773144	POINT (-122.34848 47.632405)	CITY OF SEATTLE - (WA)|CITY OF TACOMA - (WA)	5.303301e+10
5YJSA1E27G	King	Issaquah	WA	98027.0	2016	TESLA	MODEL S	Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	210	0	5.0	165103011	POINT (-122.03646 47.534065)	PUGET SOUND ENERGY INC||CITY OF TACOMA - (WA)	5.303303e+10
5YJYGDEE5M	Kitsap	Suquamish	WA	98392.0	2021	TESLA	MODEL Y	Battery Electric Vehicle (BEV)	Eligibility unknown as battery range has not b...	0	0	23.0	205138552	POINT (-122.55717 47.733415)	PUGET SOUND ENERGY INC	5.303594e+10

Electric Vehicle Population Data

Source: Washington State Department of Licensing (DOL) via data.gov

This dataset provides valuable insights into vehicle distribution and usage patterns, crucial for optimizing charging station locations.
The data contains **17 columns** and **177,867 rows**.

VIN (1-10)	County	City	Postal Code	Electric Range	Vehicle Location
5YJYGDEE1L	King	Seattle	98122.0	291	POINT (-122.30839 47.610365)
5YJSA1E4XK	King	Seattle	98109.0	270	POINT (-122.34848 47.632405)
5YJYGDEEXL	King	Seattle	98144.0	291	POINT (-122.30823 47.581975)
1N4AZ0CP0F	King	Seattle	98119.0	84	POINT (-122.363815 47.63046)
1N4AZ0CP6D	King	Seattle	98107.0	75	POINT (-122.37815 47.66866)



data exploration.

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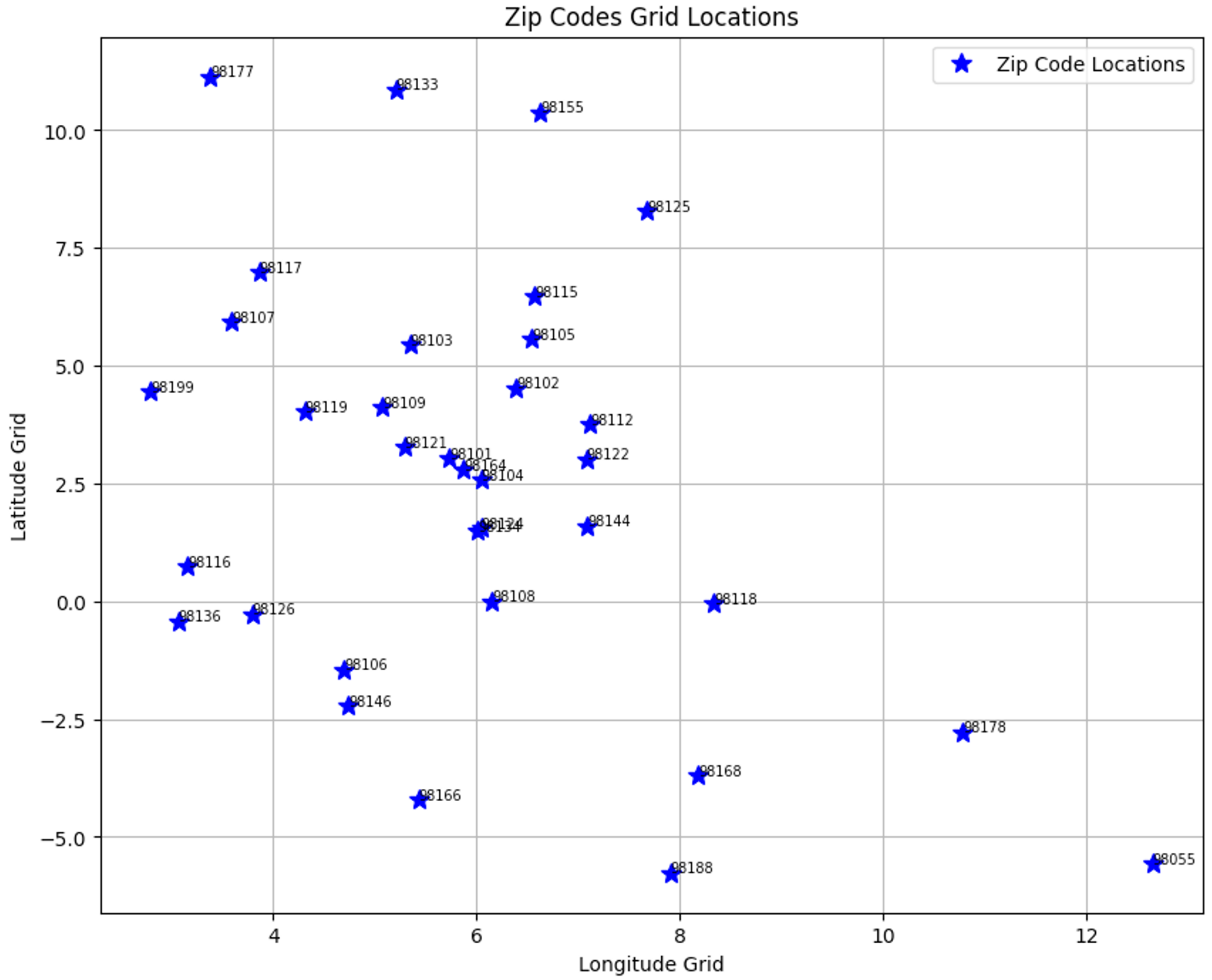
1N4AZ0CP6D	King	Seattle	98107.0	75	POINT (-122.37815 47.66866)

what we do?

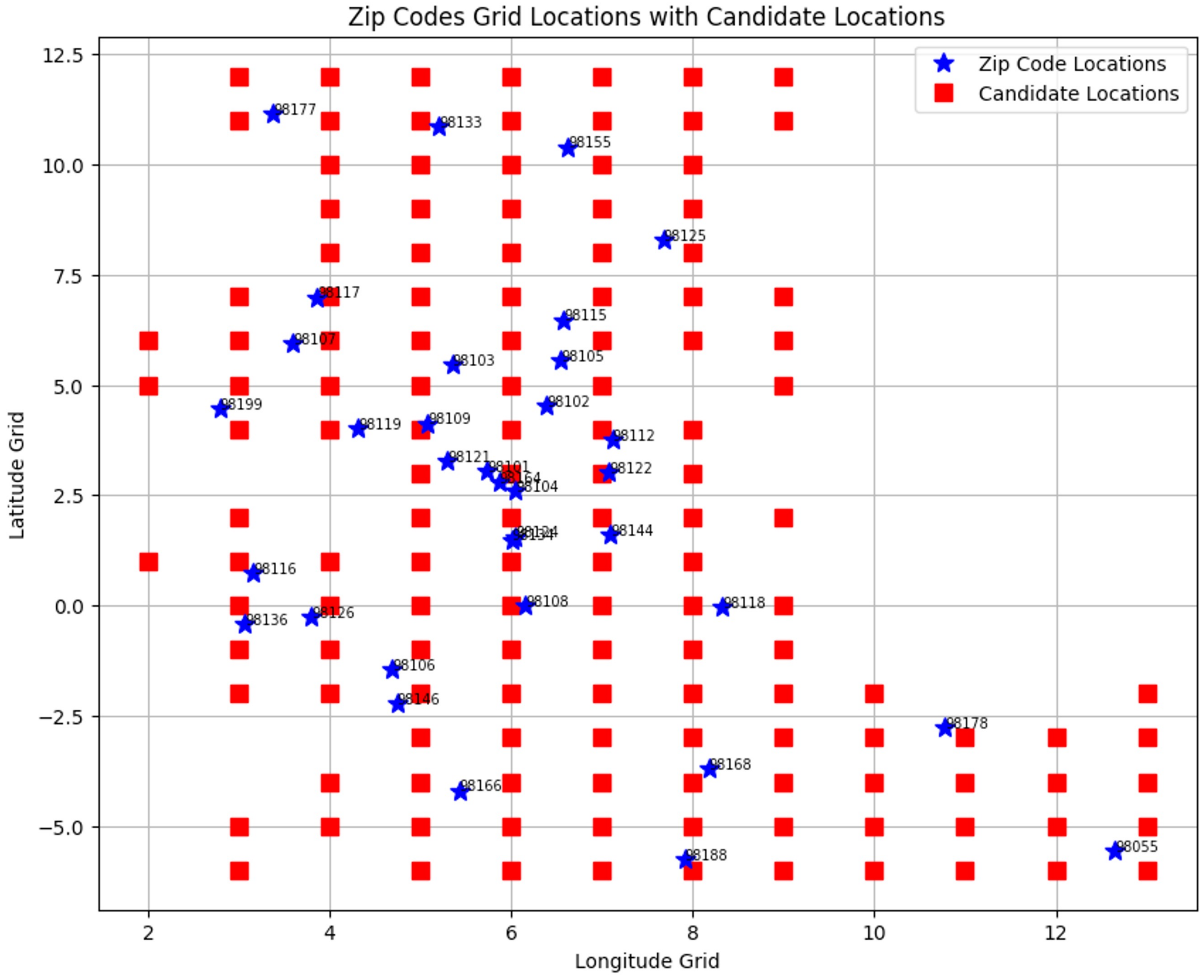
We use **Postal Code** to identify where the EVs are registered in Seattle.

Then we convert the location using latitude and longitude into grid location for further development and analysis.



what we do?

- Based on the grid location, we established the range within which candidate locations should be selected: **longitude [3, 13]** and latitude **[-6, 12]**.
- We prioritized **integer points** on the grid as potential candidate locations.
- To reduce our computability time, we removed points that are either located in the sea when converted back to the map or located in the area that are outside the maximum distance threshold.



model formulation.

key assumptions

- Uniform **power consumption demand** for each vehicle, based on average electric car consumption.
- Consistent **construction cost** and **power capacity** for new stations across all locations.
- Vehicle location specified by **Postal Code**.
- We consider the candidate locations as **potential sites** for station installations.

model

data

- Z: the set of postal codes obtained from the dataset.
- S: the set of candidate charging locations.
- D: the distance threshold between the vehicles and their assigned stations
- ST: the maximum number of candidate locations can be opened.
- S_j: the maximum supply of the candidate location j.
- d_{ij}: the distance between vehicle in postal code i and station j.
- n_i: the number of cars require charging in postal code i.

decision variables

- C_j: Binary variable indicating whether to open the candidate station j.
- X_{ij}: Continuous variable representing the proportion of vehicles in postal code i chooses location j for charging service.

objective function

Maximize the station coverage of the stations opened:

$$\max \sum_{i \in Z} n_i X_{ij}$$

model

constraints

- Only charge at the stations that have been selected:

$$X_{ij} <= C_j \quad \forall i \in Z, j \in S$$

- Vehicle charging constraint:

$$\sum_{j \in S} X_{ij} \leq 1 \quad \forall i \in Z$$

- Limit the distance between each postal code and its assigned candidate location to a maximum threshold of D units: *D = 2.0*

$$d_{ij} C_j \leq D \quad \forall i \in Z, j \in S$$

- Ensure that the total demand supplied by each candidate location does not exceed its maximum supply: *S = 300*

$$\sum_{i \in Z} n_i X_{ij} \leq S_j \quad \forall j \in S.$$

- Ensure that only ST candidate locations are chosen: *ST =100*

$$\sum_{j \in S} C_j <= ST$$

results.

- 81 locations are chosen
- Number of vehicles can be covered: 22,749 vehicles
- Coverage: 77.25% of the total demand

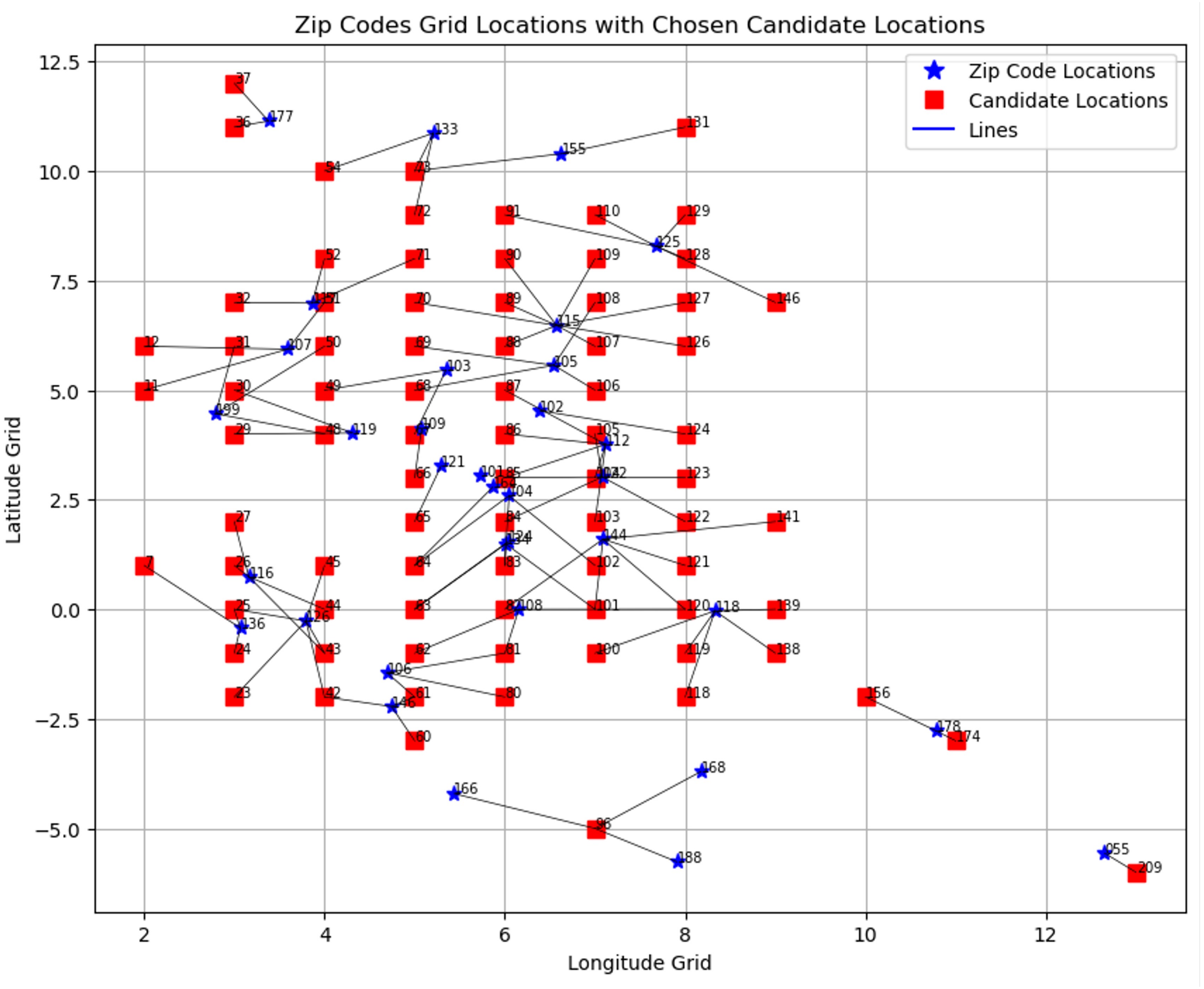


Figure1: zip codes' names and candidate stations' indices

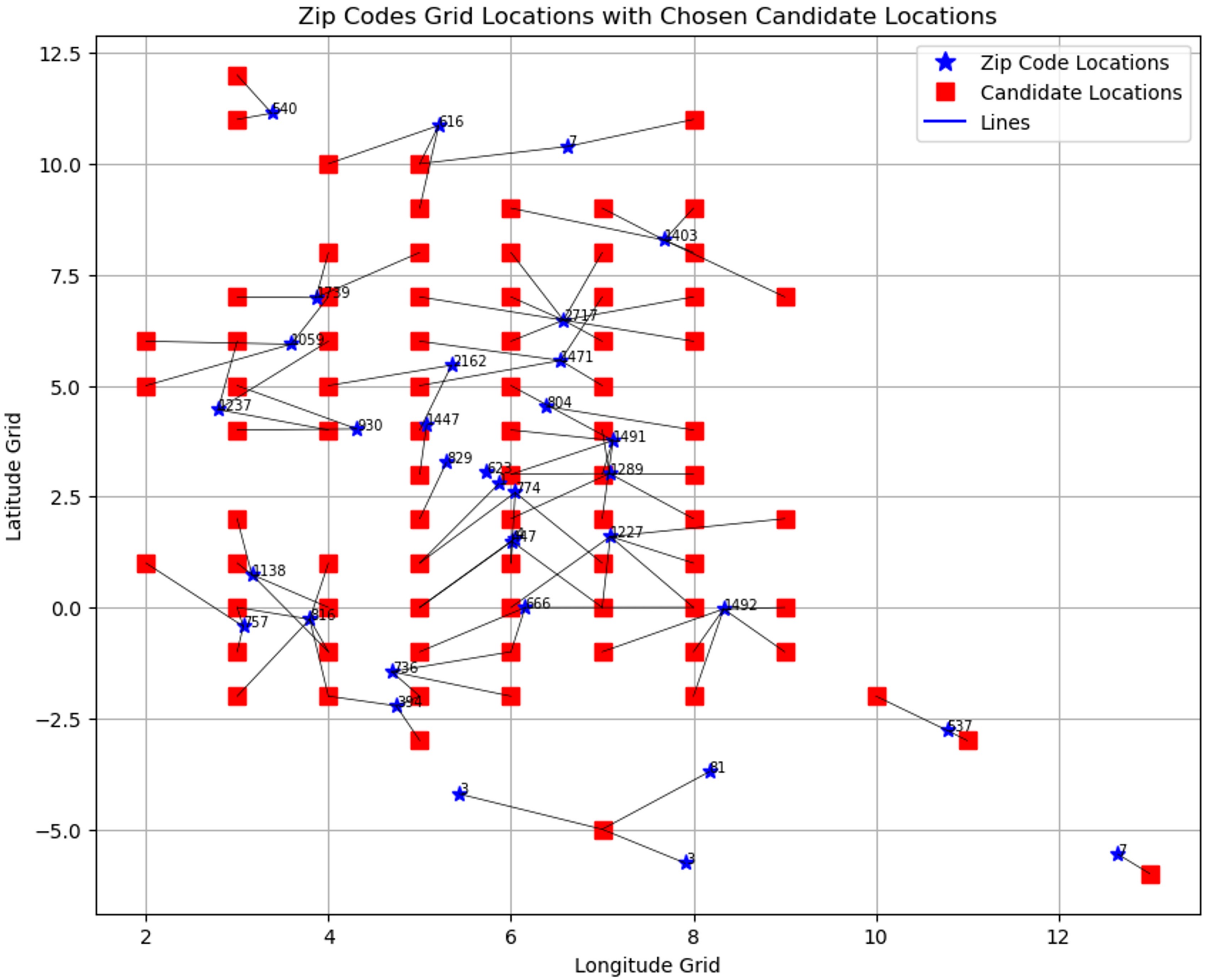


Figure 2: zip codes and their corresponding demand

The candidate locations are mainly placed in **densely populated central areas** to cover as many postal code as possible. Placing stations here allows them to **serve multiple ZIP codes** effectively.

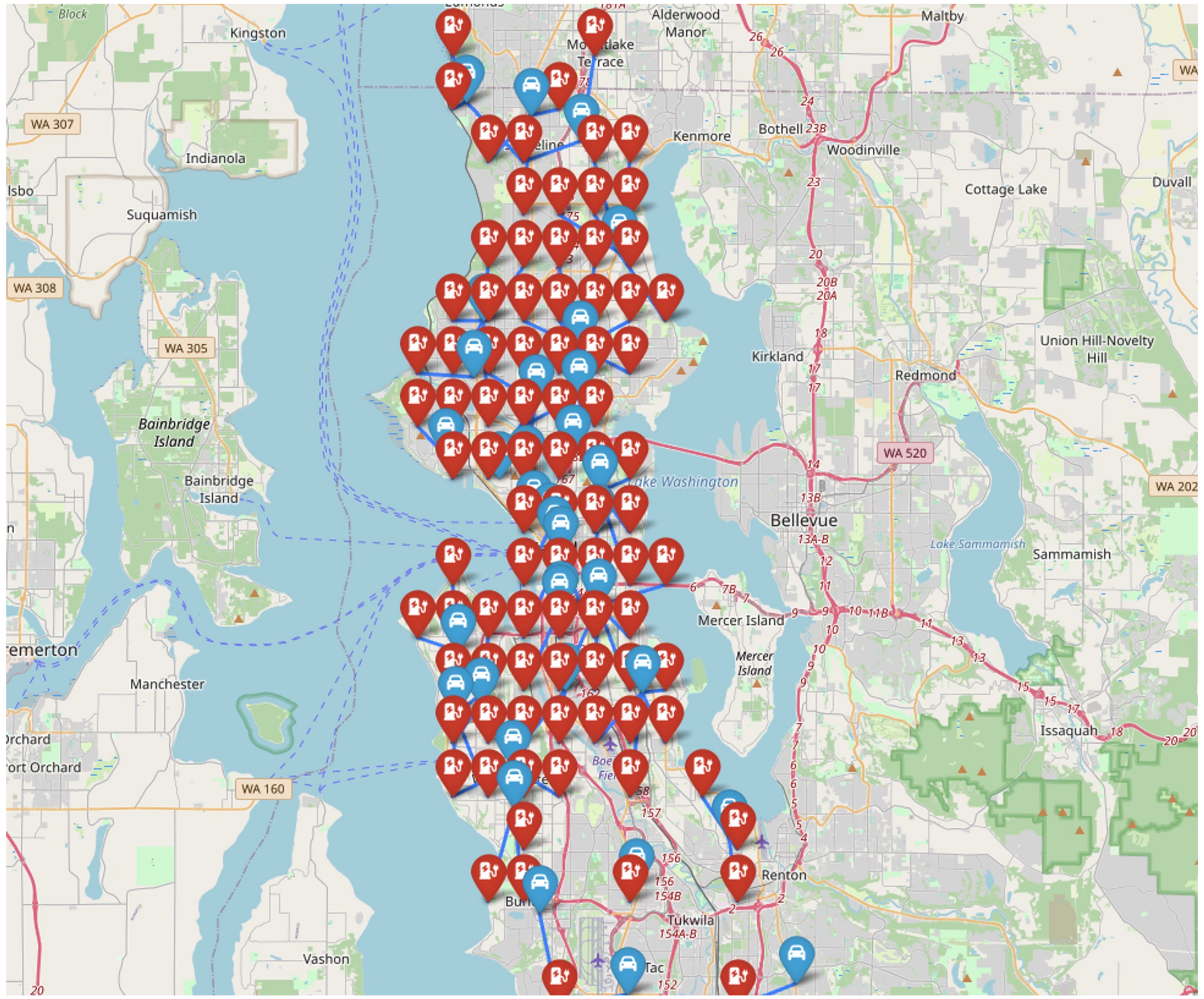
However, because each location has a limit on how many cars it can charge (300), they tend to cluster around these central areas. This clustering ensures that each station can meet the demand within its capacity while still covering a wide area. So, the strategy is to **balance demand, supply limits, and coverage goals** to create an efficient charging network.

Proportions of Vehicles Covered by each Station in each Postal Code

Postal Codes	Station	Percentage coverage	Number of cars	Distances
98136	7	39.63	300	1.779751
98107	11	28.33	300	1.845683
98107	12	28.33	300	1.593909
98126	23	36.76	300	1.907455
98136	24	39.63	300	0.578804
98126	25	17.52	143	0.838083
98136	25	20.74	157	0.430133
98116	26	26.36	300	0.303849
98116	27	26.36	300	1.268197
98119	29	32.26	300	1.309452
98119	30	32.26	300	1.633605
98199	31	24.25	300	1.554399
98117	32	17.25	300	0.862648
98177	36	55.56	300	0.403623
98177	37	44.44	240	0.940166
98146	42	73.35	288	0.773870
98126	42	1.35	11	1.746105
98116	43	20.91	238	1.933733
98126	43	7.60	61	0.762157
98116	44	26.36	300	1.120413

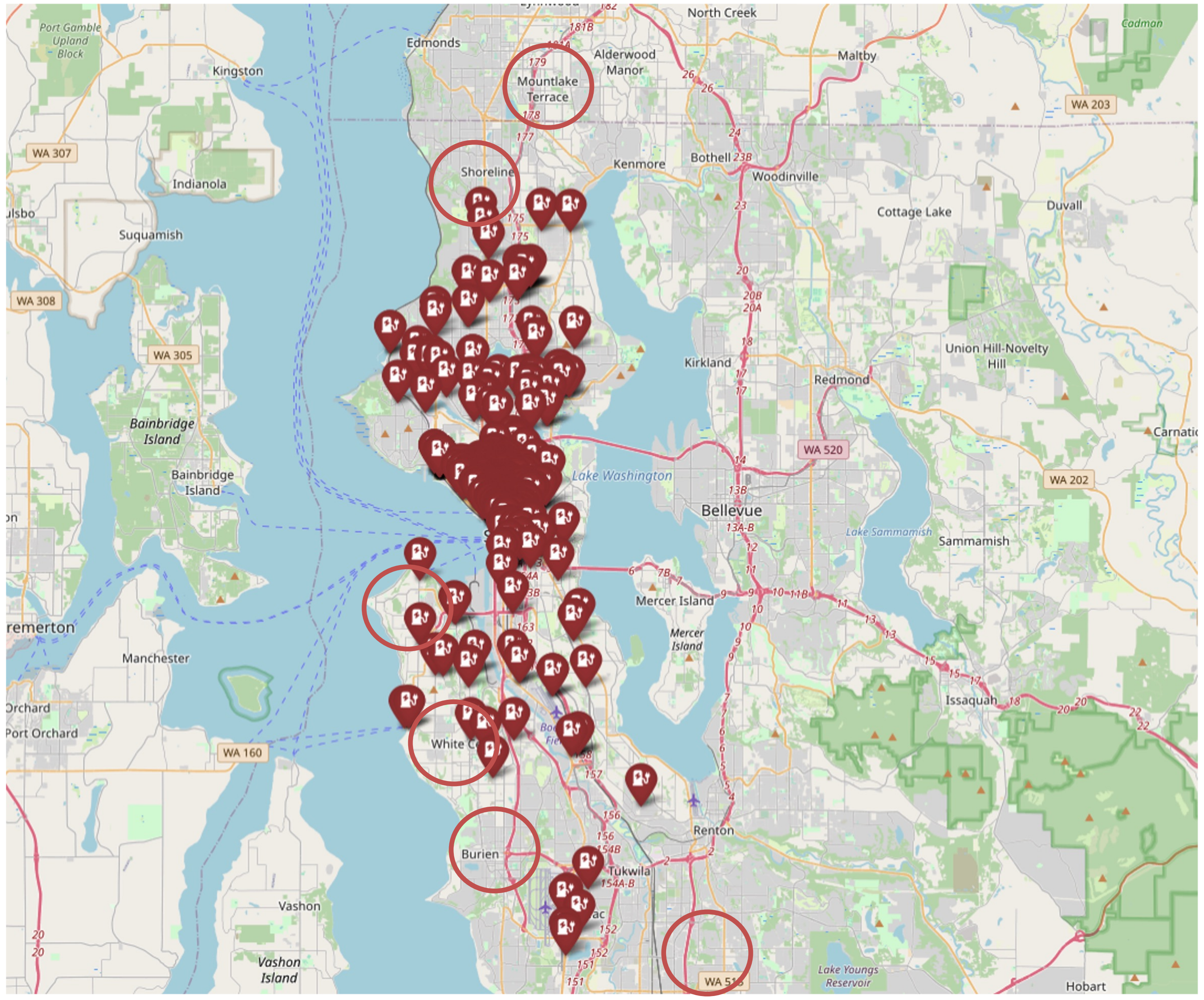
summary table: 20 first rows

our results



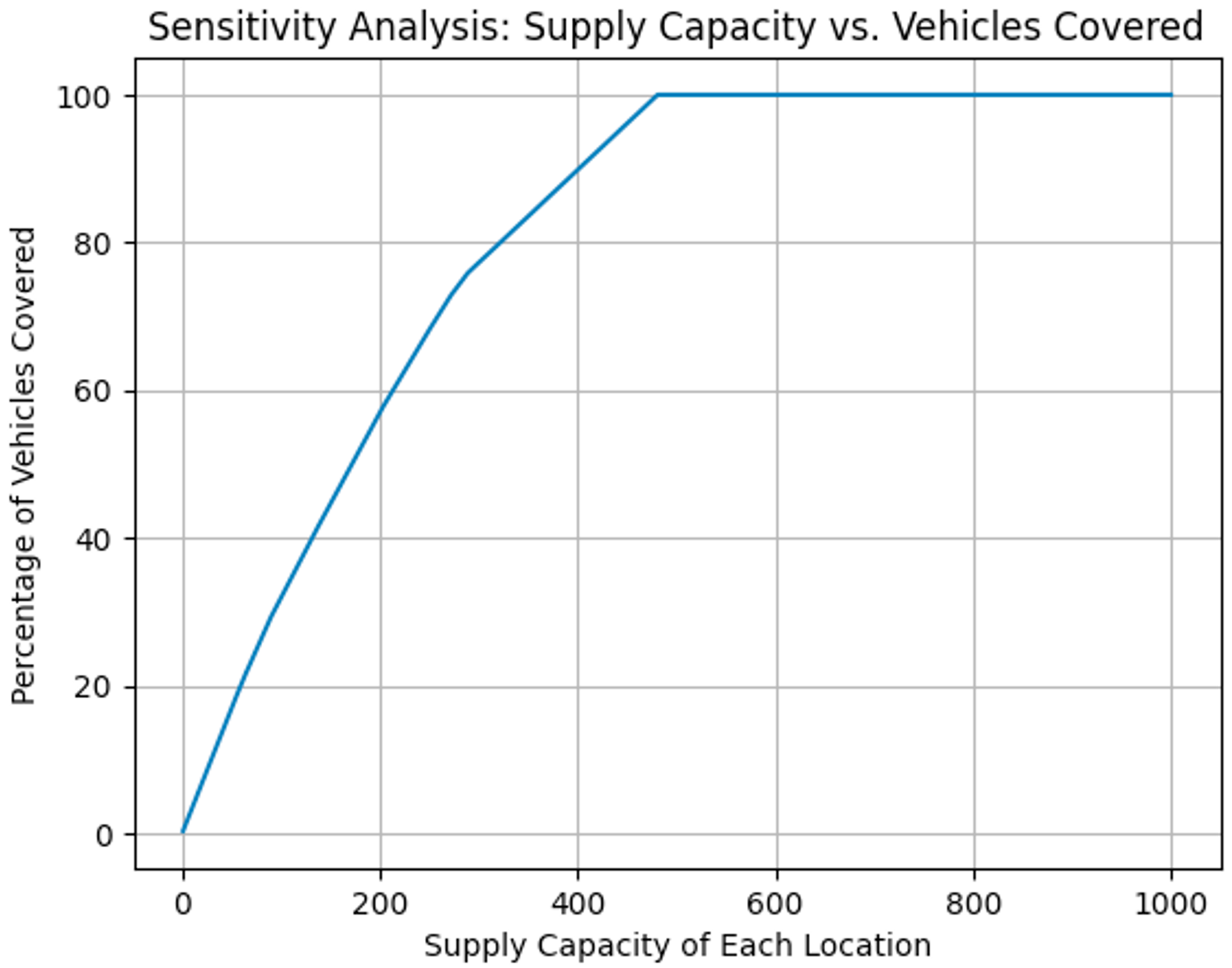
After comparing our result with the current map of charging stations in Seattle, we found a **remarkable similarity** between the two maps.

current location



However, our result suggests that more charging station should be opened and expanded in the following locations: **Shoreline**, **Mountlake Terrace**, **Magnolia**, **Burien**, **White Center**, and **Fairwood**. In addition, regarding the central parts of Seattle, the number of charging locations should be reduced.

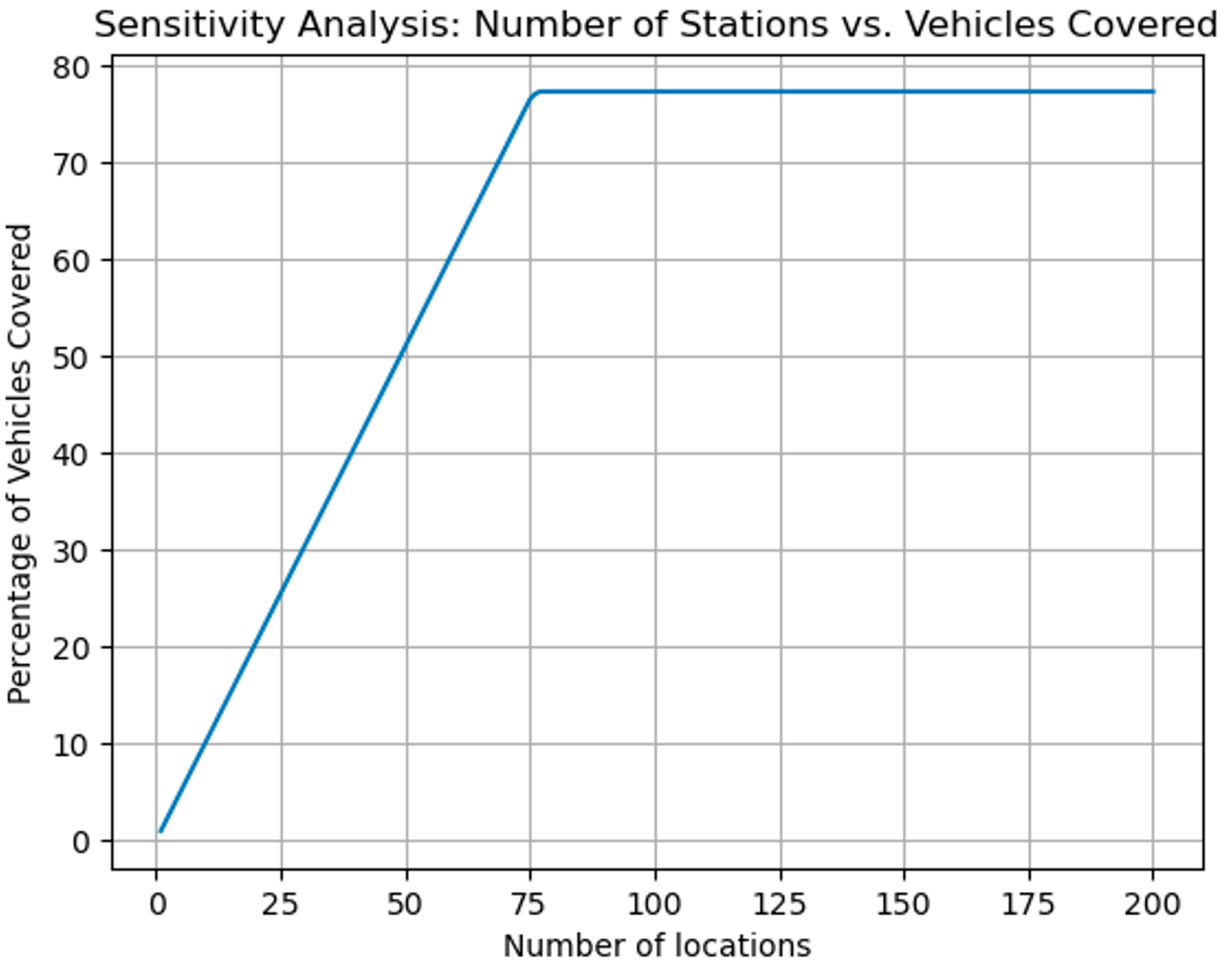
sensitivity analysis.



- Increasing the supply capacity of each station leads to a higher percentage of cars covered.
- The coverage percentage rises notably until it reaches **300 cars per station**.
- Beyond 300 cars per station, the coverage still increases but at a slower rate.
- It stabilizes at **100%** coverage when the supply reaches around **500 cars per station**.

sensitivity analysis.

- Increasing the number of stations initially leads to a linear rise in vehicle coverage.
- However, after exceeding **81** locations, the coverage growth begins to stabilize at around **78%** of the demand.
- This indicates that adding more stations doesn't improve coverage much, likely due to location constraints and limited options for placing stations



conclusion.

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limitations

- use of ZIP codes for EV user location representation limits optimization of station selection.
- overlooks factors like land ownership, existing infrastructure, and consumer behaviors.
- potential constraints include prohibited construction areas or inadequate electricity supply.
- model assumes fixed maximum supply per station and regulations on station construction, which may not reflect real-world variability.
- factors like construction and environmental costs are not accounted for in location selection.

conclusion.

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future studies

- incorporate different data sources, such as land ownership, charginging station construction costs, and real-time traffic data to get a more comprehensive understanding of charging demand and selections within different geographic areas
- explore alternative objectives (minimize total cost, including construction and environmental costs)

thank you for listening!