# Electric Trucking

## 21-393 Operations Research II Final Project

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## Abstract

In this paper, we analyze the industry of electric trucking, formulate a problem statement relating to how to optimally place charging stations, and solve that problem using integer programming.

## Background

Trucking is a massive industry in the United States, accounting for approximately $36.6 billion in terms of total annual GDP impact, and supporting over 257,000 jobs. As with personal vehicles, the trucking industry is beginning to look towards electric vehicles as an alternative to the gas or diesel vehicles that have dominated the industry since the beginning. There are many significant advantages to electric vehicles. First and foremost, they do not release greenhouse gases into the atmosphere, which means that they are not contributing to the runaway greenhouse effect that is causing global warming and climate change, unlike traditional gas or diesel vehicles. Also, electric vehicles are much more efficient with the energy they produce, funneling the majority of their energy into motion, whereas most of the energy produced in a gas car is released as heat energy. Finally, on the consumer level, paying for electricity to charge your car or truck is much cheaper than paying for gas.

However, there is one key disadvantage that limits the usefulness of electric trucks in today's landscape: the lack of established infrastructure for electric vehicles. There are over one hundred thousand gas stations in America, giving truck drivers the ability to drive from any one location to any other location in the country without having to even think about where to fill up the gas tank. In most cases, the highways they are driving on will have pull offs with gas stations every 20 miles or less. On the other hand, electric vehicle charging stations are not nearly as common yet. For the purposes of our project, we decided to act like there are zero electric truck charging stations in the country, and we are tasked with building them in the most efficient locations.

## Problem Statement

We would like to minimize the cost of building the charging stations required to maintain the trucking industry in the United States of America. This is done in two parts that are dependent on each other: building as few charging stations as possible and placing them in the most convenient locations.

## Problem Description

We assume that each electric truck has a fixed driving range (R). Using this assumption, we model the charging network as a graph whose nodes represent both (i) the cities that must be served and (ii) candidate locations where a charging station could plausibly be built (for example, existing gas stations, cities, or towns). We then add an edge between two nodes when an electric truck can travel directly between the two locations on a single charge. The weight of each edge is the distance between the locations: ideally the road-network (path) distance, though Euclidean distance can be used as a simplifying approximation. To enforce the range constraint, we include only those edges with distance less than (R).

Within this graph, our goal is to choose a set of charging-station locations that makes every city reachable (possibly through intermediate charging stops) while minimizing the total cost of building the stations. In other words, we want the least-cost placement of charging stations such that trucks can travel between cities by moving along edges that respect the range limit (R). For interpretability, (R) can be set using real-world vehicle specifications; for example, one reasonable choice is on the order of 200 miles, consistent with reported maximum ranges for some electric truck configurations under heavy loads.

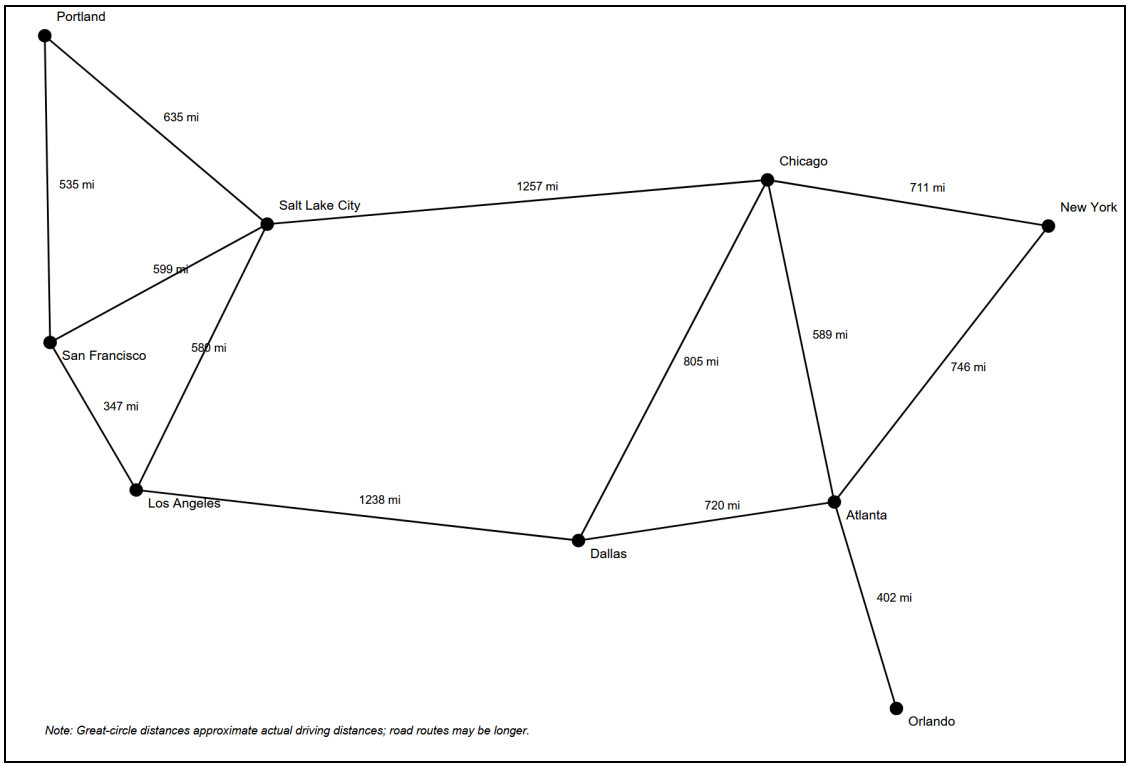



Figure 1: The constructed graph

# IP Formulation

To formulate an integer program to solve the problem, we decided to use an approach that uses a variable for each location and a variable for each pair of locations and each pair of cities.

Therefore, the variables we used were the following:

· $x_{aijb}$ – a Boolean (1 or 0) denoting whether the edge between locations $i$ and $j$ is used for the path between cities $a$ and $b$

· $y_i$ – a Boolean (1 or 0) denoting whether a charging station is built at location $i$

We also decided to use the following constructs:

- $G$ – the adjacency matrix of the graph
- $B$ – a table containing Booleans (1 or 0) for each location that denote whether a location already has a charging station.
- $C$ – a table containing the cost of building a charging station at each location

In particular, $B$ and $C$ allow for the solution to be modified by using pre-existing charging stations and by modifying the costs of building charging stations at different locations.

With these variables and constructs, we developed the integer program shown in figure 2.

$$
\begin{aligned}
\min \quad & \sum_j C_j y_j \\
\text{Subject to:} \quad & y_i \geq x_{aijb} \quad \forall a, i, j, b \\
& y_j \geq x_{aijb} \quad \forall a, i, j, b \\
& y_i \leq \sum_a \sum_b \sum_j x_{aijb} \quad \forall i \\
& y_j \leq \sum_a \sum_b \sum_i x_{aijb} \quad \forall j \\
& \sum_j x_{aajb} = 1 \quad \forall a, b \\
& \sum_i x_{aibb} = 1 \quad \forall a, b \\
& \sum_j x_{ajib} = \sum_j x_{aijb} \quad \forall i, a, b \\
& x_{aijb} \leq G[i, j] \quad \forall a, i, j, b \\
& y_i \geq B[i] \quad \forall i \\
& x_{aijb} \in \{0, 1\} \quad \forall a, i, j, b \\
& y_i \in \{0, 1\} \quad \forall i
\end{aligned}
$$

Figure 2: The integer program

We note the following:

- The objective is to minimize the cost of building the charging stations
- The first four constraints guarantee that we build a charging station at location $i$ if and only if we're using an in edge or out edge at $i$.
- The next three constraints guarantee that we have 1 path between each pair of cities
- The next constraint guarantees that we can't create an edge if that edge is not in the graph we created before solving the integer program
- The last constraint guarantees that if there is already a charging station, then we build it there

# IP Solution

We set R = 200 miles to mimic the range of Volvo's electric trucks. The graph as shown in the problem description was used.

Portland → San Francisco (535 mi): at 179, 358

San Francisco → Los Angeles (347 mi): at 174

San Francisco → Salt Lake City (599 mi): at 200, 400

Salt Lake City → Chicago (1257 mi): at 180, 360, 540, 720, 900, 1080

Chicago → Atlanta (589 mi): at 197, 394

Dallas → Atlanta (720 mi): at 180, 360, 540

Chicago → New York (711 mi): at 178, 356, 534

Atlanta → Orlando (402 mi): at 134, 268

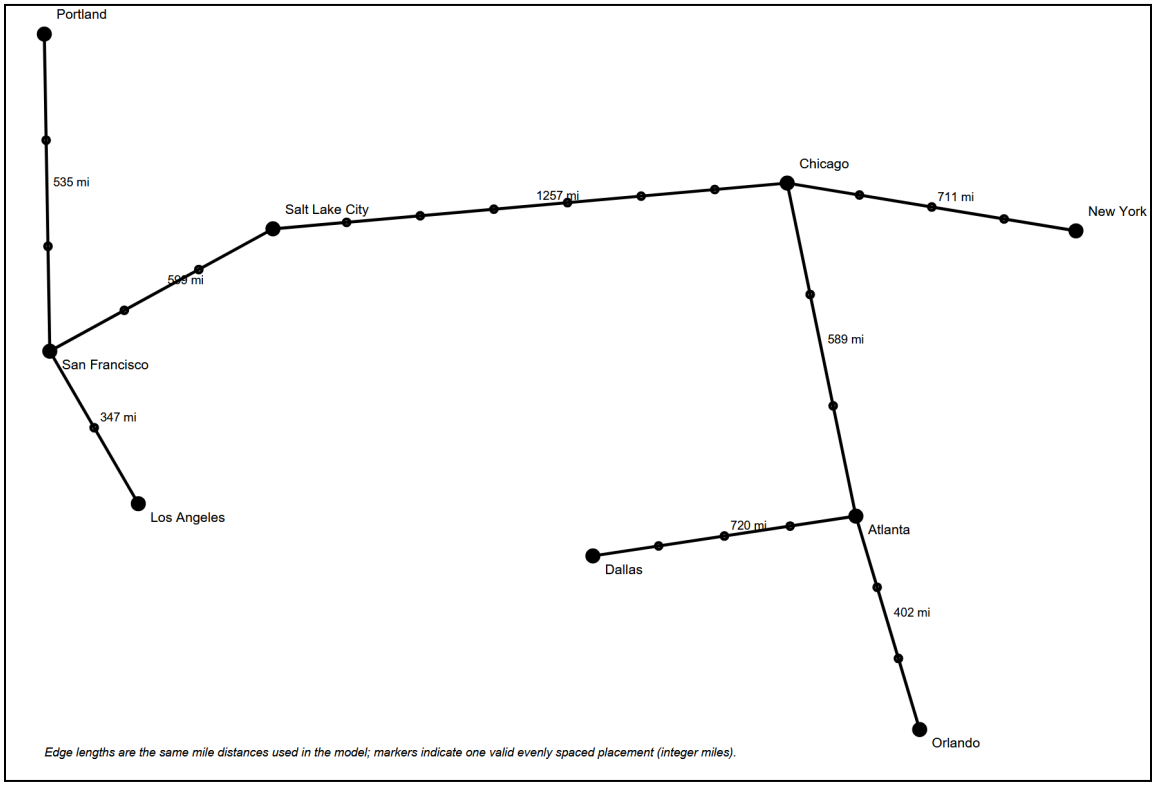



Figure 3: The IP solution

## Future Steps

This project models the placement of electric truck charging stations using integer programming in order to minimize total construction cost. One possible improvement would be to refine the objective function by incorporating additional cost factors, such as maintenance or operating costs, rather than focusing solely on construction costs. This would allow the model to better represent the long-term implications of infrastructure decisions.

Another extension would be to add more realistic constraints to the model. For example, constraints related to the maximum distance an electric truck can travel between charging stations could be included to ensure feasibility along major routes. Additionally, upper bounds could be placed on the number of charging stations built in certain areas, reflecting practical or budgetary limitations. These changes would preserve the integer programming structure while making the model more representative of real-world conditions. Overall, these extensions would build directly on the optimization techniques used in this project and further demonstrate how operations research methods can be applied to large-scale infrastructure planning problems like electric truck charging networks.