Modeling the Placement of Charging Stations for All-Electric Vehicles

Xinyi Yi
North China Electric Power University
2428625965@qq.com

Abstract. All-electric vehicles are attracting everyone's eyes for its using clean energy rather than fossil energy. At the same time, Tesla, a rising and new born enterprise is famous for its futuristic design, which makes all-electric vehicles become more and more popular. However, the law that the development of supporting facilities is always likely to be relatively backward is confirmed in the progress of all-electric vehicles and charging stations.

1. Introduction
Some urban areas have a widespread utilization of all-electric vehicles, while others have limited one. Too concentrated and excessive arrangement of charging stations increase maintenance costs and construction costs, but too distracting and limited arrangement is likely to make customers of all-electric vehicles find it hard to charge their cars, making electric vehicles difficult to promote. Apparently, it is important to analyse the distribution and use of electric vehicles in different areas to decide the placement of charging stations.

This model is used to determine the placement and more exact distribution of charging stations under the case that all the personal passenger vehicles are migrated to all-electric vehicles. The principles of P-Median model and Particle Swarm Optimization are used to select address of logistics distribution. The key factors affecting the distribution and number of charging stations are the latitude and longitude of the city and the number of cars.

To test the validity of the model, the South Korea is chosen as testing object, and we use the data of the distribution and numbers of South Korean all-electric vehicle. There are two reasons to choose it. On the one hand, South Korea’s territory is both flat and small. Because of this, its regional difference is somehow limited, which makes the model of higher universality. On the other hand, it has a relatively developed level of appliance of all-electric vehicles, so it makes sense to study its data. After one hundred times iteration, the charging stations were generally distributed in a small scale, for abscissa from 37 to 38 and ordinate from 128 to 129, certifying the validity of the model.

2. Assumptions
(1) Vehicle distribution and population is in proportion.
(2) The final result is accurate to the latitude and longitude of administrative divisions of the first class.
3. Notation

\[ I = \{ i | i = 1, 2, 3...n \} : \text{Demand point set} \quad I \in \mathbb{N} \]

\[ J = \{ j | j = 1, 2, 3...n \} : \text{The candidate point set of charging stations} \quad J \in \mathbb{N} \]

\[ x_{ij} = \begin{cases} 1 & \text{Demand point } i \text{ is served by the candidate point } j \\ 0 & \text{otherwise} \end{cases} \]

\[ y_j = \begin{cases} 1 & \text{Facility is located at } j \\ 0 & \text{otherwise} \end{cases} \quad J \in \mathbb{N} \]

\[ D_{ij} \text{ The minimum distance between the demand point } i \text{ and the candidate point } j \]

\[ U \quad \text{Unit distance charging costs} \]

4. Model development

The P-Median model is often used in the address selection process of logistics distribution. [1]

If the total demands, the demand point and the candidate point location, and assign each demand point to a candidate point to minimize the transportation cost between the candidate point and the demand point. During the site selection process of this paper, consumers want to reduce the cost of recharging and their own charging services as soon as possible, and the service providers also want to increase the efficiency of charging stations for greater profits. Therefore, we use the P-Median model as the basic model to explore the location of charging stations. The object function and constraints of P-Median model are as follows:

\[
\text{Min}(z) = \sum_{i=1}^{n} \sum_{j=1}^{n} U D_{ij} x_{ij} \quad (1)
\]

\[ y_j \geq x_{ij} \quad \forall i \in I, \forall j \in J \quad (2) \]

\[ x_{ij}, y_j \in (0,1) \quad \forall i \in I, \forall j \in J \quad (3) \]

The target function (1) refers to the minimum charging cost of all requirements point i to charging station j. Constraint conditions (2) indicates that the requirement point is covered by candidate j.

5. Particle Swarm Optimization

| Symbol | Description |
|--------|-------------|
| \( X_i = (x_{i1}, x_{i2}, x_{i3},..., x_{iD}) \) | Position of the particle |
| \( V_i = (v_{i1}, v_{i2}, v_{i3},..., v_{iD}) \) | Speed |
| \( P_i = (p_{i1}, p_{i2}, p_{i3},..., p_{im}) \) | The best position the particle has experienced |
| \( P_g = (p_{g1}, p_{g2}, p_{g3},..., p_{gD}) \) | The optimal position of the particle swarm |

The particle swarm can be mathematically expressed as follows:

We assume that in a d-dimensional search space, there is a particle swarm of m particles. The position of the \( i^{th} \) particle is \( X_i = (x_{i1}, x_{i2}, x_{i3},..., x_{iD}) \), the speed is \( V_i = (v_{i1}, v_{i2}, v_{i3},..., v_{iD}) \), the best position the particle has experiences is \( P_i = (p_{i1}, p_{i2}, p_{i3},..., p_{im}) \), the corresponding adaptive value is called the individual extreme \( p_{Best}i \). The optimal position of the particle swarm is expressed as \( P_g = (p_{g1}, p_{g2}, p_{g3},..., p_{gD}) \). The corresponding adaptive value is the group extreme value \( g_{Best} \). Particle Swarm Optimization Iterate through the following formula to update the current velocity and position of each particle. [2]
\[
\begin{align*}
\mathbf{v}_{k+1}^d &= w_{k+1}^d + c_1 r_1 (\mathbf{p}_k^d - \mathbf{x}_k^d) + c_2 r_2 (\mathbf{p}_g^d - \mathbf{x}_k^d) \\
\mathbf{x}_{k+1}^d &= \mathbf{x}_k^d + \mathbf{v}_{k+1}^d
\end{align*}
\]

In the above formula, \( k \) and \( k+1 \) represent the number of iterations. \( \mathbf{v}_{k}^d \) is the \( d \) dimension component of the velocity vector of the \( k^{th} \) iteration particle. \( \mathbf{p}_k^d \) is the \( d \) dimension component of the group optimal position \( \mathbf{p}_g \) in the \( k^{th} \) iteration. \( c_1, c_2 \) are two positive number. \( w \) is inertia weight. \( r_1, r_2 \) are two random numbers, which obey the uniform distribution in the interval \([0,1]\).

From this, it can be seen that the current velocity, the distance between the current position and the individual optimal position, and the distance between the current position and the optimal position of the group, can be used to update the speed of the particle.

6. Implementation
We use the latitude and longitude of South Korean all-electric cars to determine the placement of charging stations through programming our model.

![Figure 1. Abscissa of particles of the first iteration.](image1)

![Figure 2. Abscissa of particles of one hundred times iteration.](image2)
From the figures above, we can infer that the abscissa and ordinate of particles were originally distributed randomly. However, after one hundred times iteration, the particles were generally distributed in a small scale, for abscissa from 37 to 38 and ordinate from 128 to 129, in which places the objective function can be minimum. Therefore, the results can sufficiently illustrate the capacity of Particle Swarm Optimization.

Figure 5. South Korean charging stations.
References
[1] Rongxing. Location of electric vehicle charging station. Capital University of Economics and Business, 2017.
[2] He zhanyong. Electric vehicle charging station planning method and operation mode. Beijing Jiaotong University, 2012.
[3] Yi Liu, Jiawen Peng, and Zhihao Yu. 2018. Big Data Platform Architecture under the Background of Financial Technology: In The Insurance Industry As An Example. In Proceedings of the 2018 International Conference on Big Data Engineering and Technology (BDET 2018). ACM, New York, NY, USA, 31-35.
[4] Y. Wu, Y. Liu, A. Alghamdi, K. Polat, and J. Peng. \Dominant dataset selection algorithms for time-series data based on linear transformation," CoRR, vol. abs/1903.00237, 2019. [Online]. Available: http://arxiv.org/abs/1903.00237.
[5] Zhang Yanjun, Yang Xiaodong, Liu Yi, Zheng Dayuan, Bi Shujun. Research on the Construction of Wisdom Auditing Platform Based on Spatio-temporal Big Data [J]. Computer & Digital Engineering, 2019, 47 (03): 616-619+637.