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Study of the optimal distribution of Charging stations

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Abstract. Electric vehicle is enjoying an increasing market share in car areas and starts to catch on. In order to ease the energy shortage and be more economic, many countries start to select electric drive, the popularization of electric vehicles is inseparable from the construction of charging stations. How to implement a rational planning of charging stations is the primary task. This paper proposes a Multi-objective optimization Model to determine the distribution of charging stations, predicts the charge demand by using Poisson distribution combined with normal distribution, then gets the optimal distribution of charging stations in the United States.

Keywords: Electric vehicle; charging stations; Multi-objective optimization Model

1. Introduction

Electric cars are becoming more and more popular. With energy getting more and more tense and the ecological environment getting worse, more and more people start to advocate reducing the use of fossil fuels. The release of all-electric Tesla model 3 has created a record, which opens the prelude to the era of electric cars. The development and popularization of electric vehicles could not be independent from the construction of charging stations. Therefore, the rational planning of charging station is the primary task facing this stage.

There are many factors that could influence the distribution of charging stations, including economic level, population density, traffic situation and so on. In order to promote the conversion of gasoline vehicles to electric vehicles and to meet the increasing demand for charging electric vehicles, we establish a model to solve the problem of optimal allocation of charging stations in different regions of different countries to achieve a reasonable distribution of charging stations.

2. Multi-objective optimization Model

2.1. The number and placement of charging stations

The number and location of charging stations often need to consider regional differences. According to the different economic development index, we divide the distribution of charging stations into three areas: cities, suburbs and rural area.For a given area, a reasonable and optimal allocation of charging stations should take into account not only the availability of electric vehicles in the area, but also other factors such as convenience. Through the analysis, we regard economy, convenience, driving distance, charging demand as a factor affecting the number of charging stations and location distribution.

2.1.1. Cost. Economic optimization is one of the important goals of charging station construction. Economy is mainly considered from three aspects [2], namely, the initial investment fixed cost W_1[1], the operating cost of charging station W_2 and the user charging costs W_3

$$\mathrm{Min}W = W_1 + W_2 + W_3$$

$$W_1 = \sum_{j=1}^{m} s \bullet \left[\frac{r(1+r)^a}{(1+r)^a - 1} \right]$$

s is the purchase of land, chargers and other equipment costs, m is the total number of charging stations, a is the operating life of the charging station, r is the investment recovery rate.

$$W_2 = \sum_{j=1}^{m} s \bullet (1 + \theta)$$

Operation cost W_2 includes maintenance costs and staff salaries, operating costs converted to initial investment costs[1], θ is the conversion factor.

$$W_3 = k \bullet t \left(\sum_{i \in I} \sum_{j \in J} v_{ij} r_{ij} e_{ij} \right) \times 10^{-4}$$

Where:

$W3$ for a year charging costs; k for a certain period of time the total number of vehicles per charge; t is the cost of driving a car per kilometer; I is a collection of charging demand points; J is a collection of charging stations; v_{ij} for point i is charged to the charging station j (to j charge is 1, otherwise 0) ; e_i is the number of vehicles to be charged at demand point i; r_{ij} is the straight line distance from point i to charging station j.

2.1.2. Traffic convenience. Traffic convenience is mainly reflected in the lane near the charging station and traffic flow size. The more the number of lanes, the greater the traffic flow, the better the traffic convenience at this point [1]. The construction of the charging station can maximize the profit here. Of course, the charging station service radius should not be too large or too small, Too large can not meet the range of battery life, It will lead to large economic waste when it is too small. We characterize traffic convenience by the average distance from each user to the corresponding charging station.

2.1.3. Charge demand. Charging demand refers to a certain period of time within a certain area of a certain number of electric vehicles on the demand for electricity, which directly affects the geographical location of the charging station and the power required to provide the size. Only building a charging station with sufficient charging capacity can satisfy the demand of the car to be charged. Therefore, before planning the charging station, you should first calculate the total electric vehicle charging capacity in the current area.

We assume that each day a single electric car in the process of whether to choose the nearest charging station charging and charging capacity is randomly distributed, Then for a given charging station, the number of EVs that come to recharge each day satisfies the Poisson distribution, the distribution function of which is:

$$P\{x = k\} = \frac{\lambda e^{-\lambda}}{k!}, k = 0, 1, \dots n$$

The charge of a single electric car meet the normal distribution, the probability density function:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{(x-\mu)^2}{2\sigma^2}}$$

The total charging capacity of a charging station electric car can be determined by the expectations of the electric car being charged daily and the expected amount of charging, then the total charging capacity of the charging station C:

$$C = \lambda\mu$$

2.2. Multi-target planning
Based on the previous explanation, we can combine these features for multi-objective optimization. In order to make all the features the same, we need feature scaling or data normalization because these features have significant changes in value[6].If not given higher value, the results of our integrated model may be governed by one of them. In our model, we use a normalized rescaled range of features so that the range is in [0,1]. The general formula is this:

$$S^` = \frac{S^{max} - S}{S^{max} - S^{min}}$$

Where:
S indicates the initial value;
S` represents the normalized value;
   In our model, the goal is to minimize the final value. Therefore, we will put W',D' and C' into [0,1], write our model as a nonlinear programming model and then get the multi-objective programming model.

$$\min Final\ Value = W^` + D^` + C^`$$

2.3. Ranking Submodels with AHP
Analytical Hierarchy Process (AHP) is a structured technique based on mathematics and psychology that organizes and analyzes complex decisions. Our goal is to rank the first three sub-models and assign the weights to the final model.We assume that the cost is0.5631,the convenience is 0.2438,and1the1multi-target planning is 0.1949.
   Then, we assign them to the derived model:

$$\min Final\ Value = 0.5613W^` + 0.2438D^` + 0.1949C^`$$

3. Implementation

3.1. Final distribution in U.S
We use the multi-objective optimization model above to simulate the final number of US charging stations and location distribution, By looking at available data and by referring to the existing per capita GDP in the United States [10]and the traditional car ownership[11], we predict the final distribution.

Table 1. The final indicators in urban,suburban and rural

	Electric car ownership	The number of Supercharging	The number of destination charging	Charger utilizationrate
urban	1.13×10^8	3380000	4420000	104.6%
Suburban	5.1×10^7	1144000	1496000	82.4%
rural	3.6×10^7	676000	884000	76.8%

   Table 1 shows the differences between the number of EVs, the number of super-fast charging stations, the number of conventional charging stations and the charger utilization rates in the US cities, suburbs and rural areas by 2050.We can see that the number of charging stations in different parts of the United States is approximately proportional to the number of EVs. This is consistent with the fact that the population distribution and the relatively small gap between the rich and the poor in different regions of the United States are different. Due to the relatively high economic development index of cities and the large population density, the utilization rate of charging stations is too high and the electricity supply is in short supply, while the suburbs and rural areas are relatively moderate.

3.2. Current situation of Tesla
By reviewing the data, we obtained the location of more than 3,000 existing Tesla conventional charging stations and 1130 fast charging stations in the United States, According to the provided point distribution charts of U.S., we found that in the cities, suburbs and rural areas, the number of charging stations is

about 62%,25%and13% respectively, which is roughly in line with the final charge of charging stations in urban areas, suburban and rural areas in the United States .charging stations. As of 2017, the number of U.S. electric vehicles is around 766,000. The current location and number of charging stations can basically meet the charging needs of electric vehicles.
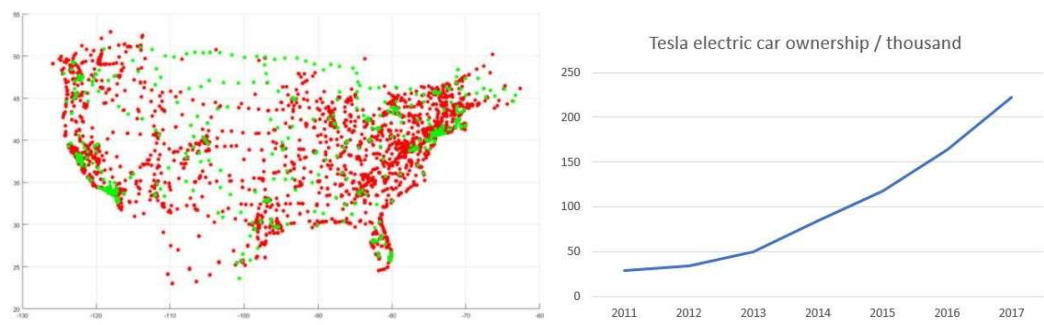

Fig. 1 Dot plot of two types of charging in U.S. **Fig. 2** Tesla electric car ownership stations over time

Fig 1 shows the current location of the Tesla charging station in the United States, where the red dot represents the destination charge and the green dot represents the fast charge. Obviously, the charging stations are mainly concentrated in economically developed and densely populated cities such as the east and west coasts of the United States (such as New York and Chicago)This is not yet mature with the technology of electric vehicles, electric vehicles have yet to achieve full coverage of the status quo consistent.

Fi 2 shows the recent changes in the continuous reforming of fast charging technology and the enhancement of electric vehicle endurance, the development of electric vehicles will become an inevitable trend of alleviating energy shortage. In the future, with the state's restrictions on gasoline vehicles, electric vehicles will develop at a faster rate. Therefore, we have full assurance that the current distribution of Tesla charging stations is on the right track.
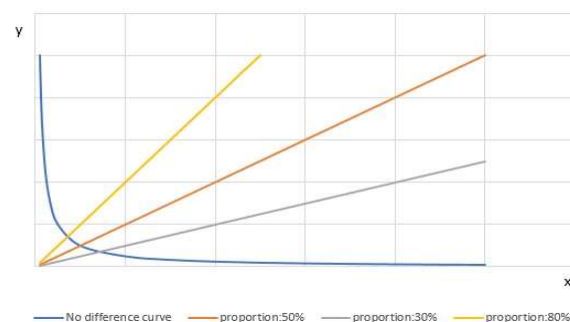

Fig. 3 Different proportion lines intersect with the No difference curve

Fig 3 shows the weights for establishing a charging station first or purchasing an electric car with an indifference curve, where x denotes the car purchase after the station construction, and y is opposite. When the share of electric vehicles is relatively low, the intersection of the straight line and the curve is more biased towards x ,which means the state should consider building electric stations first to stimulate the market of electric vehicles , which will speed up the development of electric vehicles to a certain extent. When the proportion of electric vehicles is relatively large, the development speed of electric vehicles will be slow and the growth of charging demand will slow down as well. At this moment, encouraging consumers to purchase first could avoid the waste of resources caused by the extra charging station and realize the electric vehicle balance with charging station.

4. Conclusion

This paper provides a detailed analysis of the distribution of charging stations considering different factors. It takes cost, convenience and the charge demand into consideration and makes a balance of them. After Normalization, the Multi-target planning is adopted to get the final distributions of charging stations in US.

In the future electric vehicles markets, state should consider building electric stations first to stimulate the market of electric vehicles , which will speed up the development of electric vehicles to a certain extent. When the proportion of electric vehicles is relatively large, the development speed of electric vehicles will be slow and the growth of charging demand will slow down as well. At this moment, encouraging consumers to purchase first could avoid the waste of resources caused by the extra charging station and realize the electric vehicle balance with charging station.

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