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Research on Location Problem of Electric Vehicle Charging Station

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Abstract: The location problem of electric vehicle charging station is investigated. Base on how many people use electric vehicles, where they are, and their demand about the charging station, we construct a weighted network to describe electric vehicle usage. Furthermore, the location problem of electric vehicle charging station is transformed into a maximum covering problem on weighted network. Then we formulate the mathematical model for locating the electric vehicle charging station, the objective function of the mathematical model is to maximize meeting customer needs. We design a heuristic algorithm to solve the model. Finally, we do simulation using a numerical example. The result shows that the mathematical model and the algorithm are effective in solving the location problem of electric vehicle charging station.

Keywords electric vehicle charging station; location; weighted network; mathematical model; heuristic algorithm

INTRODUCTION

As resources increasingly tense, and with the promotion of sustainable development, people begin to turn their attention to new energy development, and gradually begin the research of electric vehicles. Electric vehicle has become an important development direction, and it can keep sustainability development in the future. The cities accelerate promotion of the use of electric vehicles in different ways. For example, an action plan about the promotion of electric vehicles from 2014 to 2017 in Beijing is proposed. The plan indicates that Beijing will orderly promote companies and individuals to buy electric vehicles, and vigorously advance the use of electric vehicles in the aspects of taxi and city bus. However, the development of electric vehicles depends on charging facilities. So, it will benefit the promotion and popularity of electric vehicles when the charging station locations are reasonable.

Currently, for electric vehicle charging station location problem, scholars have studied from many aspects. Zhang considered charging station construction and operation costs, and constructed a mathematical model, using the grid method to determine the locations of the charging station on planning area[Zhang et al.,2014]. Gao established a mathematical model. The model's objective function is to minimize the charging station construction costs[Gao et al.,2012]. Chen applied a single parent genetic algorithm to minimize the sum of invested cost and operating costs[Chen et al.,2013]. Meng analyzed the electric vehicle charging mode and planning principles of charging station, established an optimization model to minimize the cost of charging station location[Meng et al.,2013]. Most researchers studied the electric vehicle charging station location problem base on the perspective of investor, and minimize the cost of maximize the income.

And some researchers study the charging station location problem from consideration of user convenience. Zhang proposed a mathematical model for multi-level electric vehicle charging stations, and applied the tabu search algorithm to solve the model [Zhang et al.,2011]. Feng analyzed the charging cost of user, constructed a mathematical model according to the plan characteristics of electric car charging stations [Feng et al.,2013].

Electric vehicles are putting into use in recent years, the research on this aspect is also late. However, most people consider the interests of investors when building charging stations. This situation has severely hindered people's initiative to buy and use electric vehicles. For this case, the paper will mainly consider users' convenience of using electric vehicles. We construct a weighted network to describe electric vehicle usage. Then, the location problem of electric vehicle charging station is transformed into a maximum covering problem on weighted network.

MATHEMATICAL MODEL OF ELECTRIC VEHICLE CHARGING STATION LOCATION PROBLEM

Problem description

With the promotion of electric vehicles, it becomes increasingly important to build electric car charging stations. As the electric car endurance mileage is limited, and it will take some time to charge the car, so the majority of electric vehicles are used as commuter tool. When the electric car is used as a commuter tool, its main operating line is the route

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from the user's residence to work place, and parking places of electric vehicles are mainly residential parking and company parking. If someone has an electric vehicle, and there is charging station either in his residence or company, then his car can be charged conveniently. For example, one company parking lot builds a charging station, the company staffs can charge their electric vehicles on daytime, and one time charge can fully meet the daily commuting needs. On the contrary, someone has an electric vehicle, but both his company and residence haven't any charging station, he can’t charge his car conveniently. In this case, people will not buy any electric vehicle.

If the number of one city’s residence community is S, the corresponding parking lots are $A_1, A_2, ...A_s$, and the number of companies is T, the corresponding parking lots of the companies are $B_1, B_2, ...B_t$. As we have known, the number of electric vehicle from residence i to company j is r_{ij}. If the government want to build a certain number of charging station, we can use the letter P to express the number of charging station, and the charging station’s capacity is Q, how to choose a location to maximum meeting customer needs.

In order to build the mathematical model of locating electric vehicle charging stations, we express every residence and workplace parking by nodes. If there is one people using the electric vehicle from residence parking A_i to company parking B_j, we will connect nodes A_i and B_j by an edge, the weight r_{ij} denotes the number of electric vehicles between residence i and company j. Then we can construct a weighted network to describe electric vehicle usage (see Figure 1).

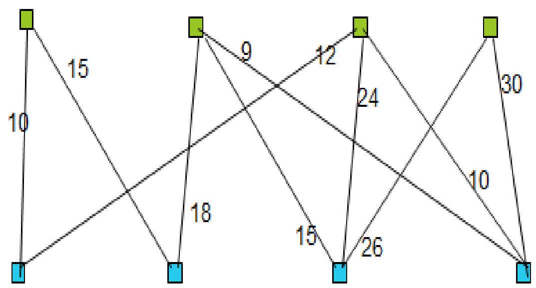

Figure1 Weighted network for describing electric vehicle usage

In Figure 1, the nodes represent parking lots of residence community and company. The link between two nodes means that there is someone from one node to another by electric vehicle. The weight of a link indicates the number of people driving electric vehicle between two parking.

Mathematical model

We assume the following conditions:

(1) The electric vehicle charging station can only be built on the site of parking. Since each charging station can charge limited number of electric vehicles one day, electric vehicles exceeding this limit will not be charged normally.

(2) If there is a charging station built in a parking, the electric vehicles running on the link road connected with this parking can be charged. If the parking at either end of a link build charging station, then electric vehicle will choose either parking by 50% probability.

Symbols and variables are defined as follows:

$$x_i = \begin{cases} 1 & \text{a charging station is built on parking i} \\ 0 & \text{charging station is not bulit on parking i} \end{cases}$$

$$y_{ij} = \begin{cases} 1 & \text{charging station is built on parking i or j} \\ 0 & \text{charging station is not bulit on parking i or j} \end{cases}$$

r_{ij} indicates the number of electric vehicle running between residence parking i and company parking j;

Q_i is the maximum number of electric vehicles that one charging station can service every day;

M is a large positive number;

Without considering charging station construction and operating costs, we construct an integer linear programming model to maximize meeting the need of electric car users.

The model can be described as follows:

$$\max Z = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij} y_{ij}$$

$$\begin{cases} 2y_{ij} \ge x_i + x_j & i = 1,2,3...n;\ j = 1,2,3...\ n \quad (1) \\ y_{ij} \le x_i + x_j & i = 1,2,3...n;\ j = 1,2,3...\ n \quad (2) \\ \sum_{j=1}^{n} r_{ij}(1 - \frac{x_j}{2}) \le Q_i x_i + M(1 - x_i) & \\ & i = 1,2,3...n;\ j = 1,2,3...\ n \quad (3) \\ P = \sum_{i=1}^{n} x_i & i = 1,2,3...n \quad (4) \\ x_i, y_{ij} = 0,1 & i = 1,2,3...n;\ j = 1,2,3...\ n \quad (5) \end{cases}$$

The objective function is to maximize the total number of electric cars which can be charged. Constraints (1) and (2) mean that once a charging station is built on a parking, all the electric vehicle running on the route connected with this parking can all be charged, it means that this charging station can cover the whole route connected with its parking. Constraints (3) mean that the number of electric vehicles served by one charging station does not exceed its service capacity of this charging station. Constraints (4) represent the number of charging stations to be established exactly equal to P. Constraints (5) mean the variables are binary.

HEURISTIC ALGORITHM

As the mathematical model of locating electric vehicle charging station is an integer linear programming, it will take much time to solve the mathematical model directly. So we design a heuristic algorithm for solving this model as follows.

Step 1. Organize data and establish relationship network about electric vehicle charging station candidates;

Step 2. Calculate the total number of electric vehicles on the route connected with parking A_i, which is $r_i = \sum_{j=1}^{n} r_{ij}$, then arrange them in descending order, we assume $r_{k1} \geq r_{k2} \geq \cdots \geq r_{kn}$;

Step 3. Choose the maximum one r_{k1} corresponding residence or company k_1, then build a charging station on this parking A_{k1};

Step 4. After we build a charging station on parking A_{k1}, all the electric vehicle can be charged on this station, if the quantity does not exceed the station's capacity. It means that for any node j, there is $y_{k1,j} = 1$. So when we choose another charging station, we will not consider the previous one, we will delete the node k_1, and the link connected with it;

Step 5. Recalculate the total number of electric vehicles on the route connected with parking A_i. Repeating steps 2, 3, 4, until the number of charging stations is P.

SIMULATION EXAMPLE

A city's residence communities and companies' distribution is shown in Figure 2. The circle nodes represent residential communities or residence parking, the number is from 1 to 6; and the small triangles indicate the workplace or company parking, the number is from 7 to 10.

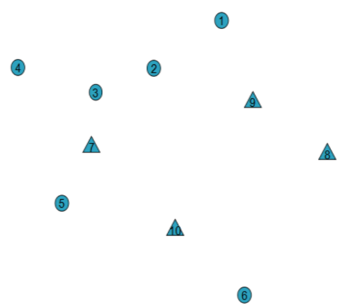

Figure 2 A city's residence communities and companies' distribution

People use electric vehicle as commuter tool from residence community to company. The number of electric vehicles is shown in Table 1. Residence parking is denoted by $A_1,\ldots,A_6$, and company parking is denoted by $B_7,\ldots,B_{10}$.

Table 1 The number of electric vehicle from residence to company

	B_7	B_8	B_9	B_{10}
A_1	1	8	10	14
A_2	8	7	4	20
A_3	22	13	0	14
A_4	14	0	19	0
A_5	5	26	23	6
A_6	25	9	9	10

Now government intends to construct three electric vehicle charging stations in this city, each charging station can service for 100 electric vehicles one day, which candidate charging station can be chosen so as to service for maximum electric vehicles users?

According to the figure of residence communities and companies distribution and the number of electric vehicles running on the links, we can construct a weighted network about electric vehicle usage in Figure 3.

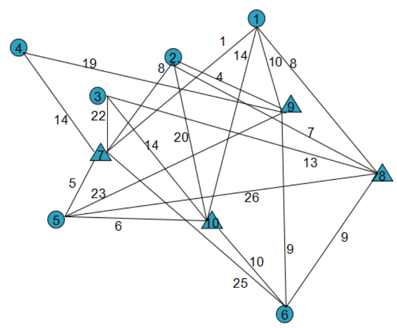

Figure 3 Weighted network for the city electric vehicle usage

The mathematical model is as follows:

$$\max Z = \frac{1}{2}\sum_{i=1}^{10}\sum_{j=1}^{10} r_{ij} y_{ij}$$

$$\begin{cases} 2y_{ij} \geq x_i + x_j \quad i=1,2,3...10; j=1,2,3...10 & (1) \\ y_{ij} \leq x_i + x_j \quad i=1,2,3...10; j=1,2,3...10 & (2) \\ \sum_{j=1}^{10} r_{ij}(1-\frac{x_j}{2}) \leq 200x_i + 1000(1-x_i) \\ \qquad i=1,2,3...10 ; j=1,2,3...10 & (3) \\ 3 = \sum_{i=1}^{10} x_i \quad i=1,2,3...10 & (4) \\ x_i, y_{ij} = 0,1 \quad i=1,2,3...10 ; j=1,2,3...10 & (5) \end{cases}$$

Using Lingo software, we can get the optimal solution $x_7 = x_9 = x_{10} = 1$, Z=204, it means we will build electric vehicle charging stations on company 7, 9 and 10.

The steps of applying heuristic algorithm are as follows:

(1) Calculate the total electric vehicle quantities on the route connection with every parking, as shown in Table 2.

Table 2 The quantities of electric vehicle for every parking

parking	A_1	A_2	A_3	A_4	A_5	A_6	B_7	B_8	B_9	B_{10}
quantities	33	39	49	33	60	53	75	63	65	64

(2) The maximum number is 75, the corresponding parking is B_7, and we will choose the company 7 to building charging station. Because the quantity does not exceed the maximum load of charging stations, this charging station can load all electric cars on its route.

(3) When considering the second charging station, we can delete the company 7, and then calculate the total electric vehicle quantities, as shown in table 3.

Table 3 The quantities of electric vehicle for every parking

parking	A_1	A_2	A_3	A_4	A_5	A_6	B_8	B_9	B_{10}
quantities	32	31	27	19	55	28	63	65	64

(4) Choose the company 9, and build the second charging station. We can delete the company 9, and calculate the total electric vehicle quantities, as shown in table 4.

Table 4 The quantities of electric vehicle for every parking

parking	A_1	A_2	A_3	A_4	A_5	A_6	B_9	B_{10}
quantities	22	27	27	0	32	19	63	64

(5) Choose the company 10, and build the third electric vehicle charging station.

According to the mathematical model and heuristic algorithm, we can both get the solution that building the charging stations on company 7, 9 and 10, the value of Z is 204, it means the charging station can supply service for 204 electric vehicles. The total amount of electric car actual use is 267, we can calculate the charging station coverage rate is 76.4%. If we build charging stations on company 8, 9 and 10, we can get the value of Z is 192, the charging station coverage rate is 71.9%. By contrast, we can see that the mathematical model and algorithm can get optimal solution, and they have the validity.

CONCLUSION

This paper studies electric vehicle charging station location problem, by establishing a network of electric car usage, the location problem of electric vehicle charging station can be transformed into a maximum covering problem on weighted network. By appropriate assumptions, this paper established a mathematical model to maximize meeting users' need, and designed a heuristic algorithm to solve this location problem. The model and algorithm are validated by a numerical example. Result shows that the model and algorithm in this paper can solve electric car charging station location problem effectively.

With the development of social and new energy, the promotion of electric vehicles will be faster, and the demand for charging station will also be growing. Therefore, study for electric vehicle charging station location will be more in-depth. The thought of this paper can provide a theoretical basis for further study on location of charging station, the mathematical model also has some reference value. However, some factors of locating electric vehicle charging station are not taken into account in this paper, such as charging station construction costs and electric current on charging station, these questions have yet to be further explored.

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