International Journal of Control and Automation
Vol.7, No.5 (2014), pp.153-160
http://dx.doi.org/10.14257/ijca.2014.7.5.17

Analysis of Charging Stations' Layout based on the Study about Electric Vehicle Routine Optimizing

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Abstract

This paper studies on path optimizing of electric vehicles. By analyzing the problem of path optimizing, this paper establishes a multi-objective programming with two objects: the shortest total distance and the largest remaining power after arriving destination. This mode is resolved with linear weighted sum method. We can analyze charging stations layout by acquiring charging times of each charging station and bypass distance of each charging. Through analysis of above statistics, this paper concludes that the layout of charging stations in Beijing is not reasonable, because charging stations are not equally distributed.

Keywords: *Electric vehicle routine optimizing; Multi-objective programming; Linear weighted sum method; Charging stations layout*

1. Introduction

With the rapid development of economy in China, the demands of automobiles have increased dramatically. However, lack of resources and environment problems restrict the development of gasoline cars, and developing electric vehicles is an effective method to solve this problem. Charging is a key problem in the development of electric vehicles, and the layout of charging stations greatly affects the demands of electric vehicles. Charging stations' layout directly affects electric vehicles development, so the research of these questions is necessary. This paper take Beijing as an example and the result shows that layout of charging stations in Beijing is not reasonable.

2. Literature Review

More and more studies begin to focus on the problems of electric vehicles and charging stations layout both at home and abroad. T. Raviv [1] studied the problem of scheduling the charging process in a battery switch station with the objective of optimizing a weighted measure of service level and cost. R. Hiwatari [2] developed a road traffic simulator and proposed a search algorithm for the effective layout of charging stations based on the location of electric vehicles running out of electricity by the road traffic simulator. J. Liu [3] established an evaluation model of impact of charging stations distribution in Beijing on power grid, pointing out that the small the charging station service scope is, the small the charging station interference on the power grid is. S. Bae [4] proposed a mathematical model of electric vehicle charging demand for a rapid charging station. The mathematical model is based on the fluid dynamic traffic model and the M/M/s queuing theory. S. Erdogan [5] formulated and solved a green vehicle routing problem when considering the limited vehicle driving range in conjunction with limited refueling infrastructure. U. Christopher [6]

ISSN: 2005-4297 IJCA

compared the p-median and flow-refueling models for locating alternative-fuel stations. He concluded that the stations located by the flow-refueling model generally do better on the p-median objective than the stations located by the p-median model do on the flow-refueling objective. I. Capar [7] presented a radically different mixed-binary-integer programming formulation that does not require pre-generation of feasible station combinations when solving flow-refueling location model.

At home, K. Guo [8] put forward some unreasonable phenomena in electric vehicles industry in China. He gave electric vehicles development routing in his paper. By analyzing the charging conditions of electric vehicles, F. Xu [9] put forward the needs of charging technology to develop electric vehicles. Besides, he analyzed several factors that influence electric vehicles charging stations planning and come up with principled suggestions. X. H. Sun [10] studied about electric vehicles' three choices of charging stations, but she didn't consider electric vehicles' route choices.

3. Model Building

3.1 The routing plan of an electric vehicle

In this paper we assume that all electric vehicles are replaced their lower batteries at charging stations directly and needn't wait to charge. All electric vehicles move in a linear routing.

When an electric vehicle starts and plans to go a destination, it faces one of these situations:

1) the electric vehicle can reach the destination directly;
2) the electric vehicle need to replace battery at charging station firstly;
3) the electric vehicle is incapable of reaching the destination and any charging station.

Below the routing plan of an electric vehicle will be discussed respectivelyin these three cases. The following notations are used in the model:

R theelectric vehicle's available distance based on the remaining battery capacity

S the distance between the starting point and the destination

S_1 the distance between the starting point and the nearest charging station

S_2 the distance between the destination and the nearest charging station

S_3 the distance between the starting point and the charging station

S_4 the distance between the charging station and the destination

$S_3(i)$ the distance between the starting point and the charging station$i$

$S_4(i)$ the distance between the charging station $i$and the destination

$D(i)$ the distance between the destination and charging station$i$

C the charging stations set

K(i) 0-1 variable

3.2 Reaching destination directly

In the first case, the electric vehicle can reach the destination directly. In other words, the remaining battery capacity can guarantee the electric vehicle reach the destination and reach one or more charging stations after that, that is

$$R \geq S+S_2 \quad (1)$$

This situation is shown in Figure 1.

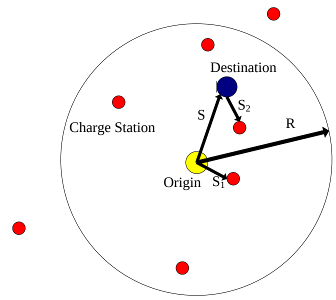

Figure 1. $R \geq S+S_2$

3.3 Moving to a charge station firstly

In the second case, if an electric vehicle mileage range can't meet formula (1), $R<S+S_2$, it must find a charging station to replace its battery.

In this condition, as the electric vehicle can reach charging stations, R must be greater than or equal to S_1, that is

$$R<S+S_2 \text{ and} R \geq S_1 (2)$$

Two kinds of situation are included: $R \leq S$, the remaining battery capacity is unable to guarantee the electric vehicle reach the destination; $S \leq R \leq S+S_2$, the electric vehicle is capable of reaching the destination but incapable of reaching any charging station after that. This kind of situation is relatively complex, for the electric vehicle should visit a charging station to replace the battery firstly, then drive to the destination. So the total travel distance is S_3+S_4, which is shown in Figure 2.

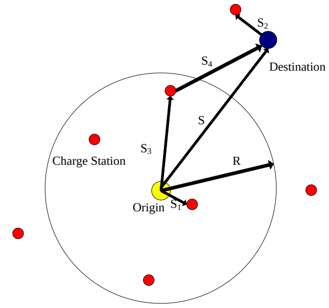

Figure 2. $R \geq S_1$**and** $R \leq S+S_2$

In this case, we should find a proper charging station for the electric vehicle, so a multiple-programming model is built. The model contains two objectives: shortest total distance and the maximum of the remaining power when arriving at the destination. The remaining power is up to S_4. The greater the distance between the charging station and the destination, the greater the power consumption and the less the power remains. So the route optimization model of the electric vehicle under this situation is obtained:

$$Z_1 = \mathrm{Max}(-(S_3(i) + S_4(i)) * K(i)) \qquad i \in C \; (3)$$

$$Z_2 = \mathrm{Max}(-(S_4(i)) * K(i)) \qquad i \in C \; (4)$$

$$\text{s.t.} \quad K(i) = \begin{cases} 1 & S_3(i) \le R \le S + S_2 \\ 0 & \text{else} \end{cases} \qquad i \in C \quad (5)$$

$$S_2 = \mathrm{Min}\big(D(i)\big) \qquad i \in C \qquad (6)$$

This is a multi-objective programming problem containing two objectivs, and it could be solved by the method of linear weighted sum. We gather the two objective functions into a function with only one target:

$$Z = -(\alpha * Z_1 + (1-\alpha) * Z_2) \qquad 0 < \alpha < 1 \qquad (7)$$

α reflects the weights of the objectives Z_1 and Z_2. The bigger the α is, the driversmore tend to choose the path with a shorter total distance. The α is affected by many factors, including drivers' time plenty,preference, economic conditions, the consciousness of environmental protection and so on.

3.4 Can't move to anywhere

In the last kind of situation, as the electric vehicle is incapable of reaching the destination, R should be smaller than S_1, that is:

$$R < S_1 \; (8)$$

Similarly, as the electric vehicle is incapable of reaching any charging station, R should be smaller than S.

$$R < S \; (9)$$

This situation should be avoided as possible as we can.

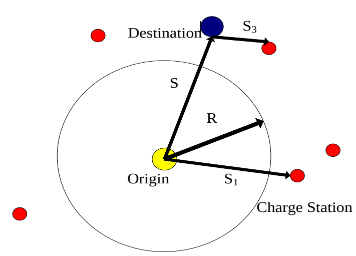

Figure 3. *R<S₁* and *R<S*

3.5 Agent model

In this thesis, the Agent model contains *Destination Agent* and *Electric Vehicle Agent*. Among them, *Destination Agent* is to generate destinations and put the generated destinations into a queue. The following figure shows the state diagram of *Electric Vehicle Agent*.

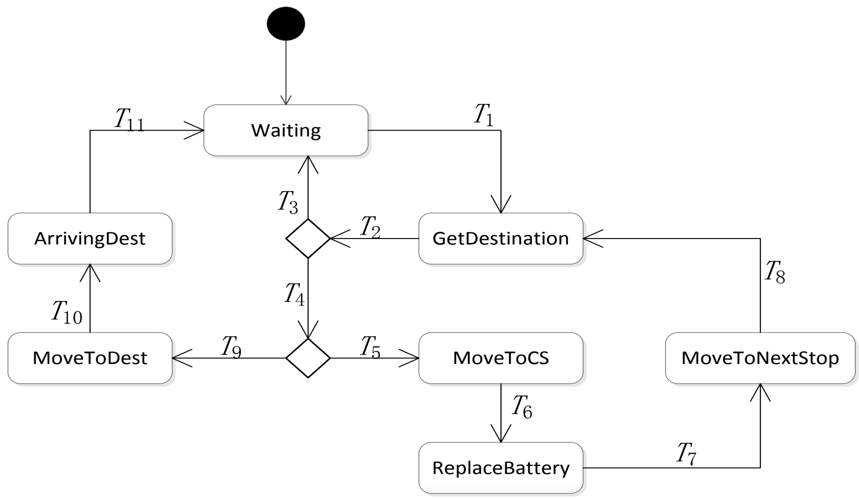

Figure 4. state diagram of Electric Vehicle Agent

In Figure 4, the electric vehicle starts in the state *Waiting* and arrive at *GetDestination* when the task queue is not empty. Then the electric vehicle will decide driving path by the above algorithm according to the current location and the destination position.

If $R<S$ and $R<S_1$, the electric vehicle cannot go anywhere and will return to the state of *Waiting*.

If $R \geq S+S_2$,the electric vehicle will enter *MoveToDest*state. Then the electric vehicle will enter into *ArrivingDest*state, and it will arrive at the destination. After that, the remaining battery capacity will be decreased according to the travelled distance and the electric vehicle will go back to *Waiting*, waiting the next path optimization.

Otherwise, the electric vehicle will choose a charging station to replace battery. The electric vehicle will enter *MoveToCS*. After that, the electric vehicle will enter *ReplaceBattery* to replace the battery with a fully-charged one. Then, the transition T_7 will be fired and the electric vehicle will enter *MoveToNextStop*state. Then, the electric vehicle will return to the state of *GetDestination*, and the starting point will become the place of the charging station to replace the battery. Then a new path will be optimized by the above algorithm according to the new starting point and the destination.

4. Experimental Design and Data Analysis

4.1Electric vehicle's available distance with fully-charged battery

In this paper, we take Beijing as the example and the destination range of electric cars is only within the Fifth Ring Road in Beijing. In order to guarantee that electric cars are available to any point within the Fifth Ring Road in Beijing, electric vehicle's available distance with fully-charged battery should be studied. Here, we only consider an extreme situation that the electric vehicle starts at a charging station with fully-charged battery, and return to the charging station after reaching the destination. Let D denotes the set of all destinations within the Fifth Ring Road, $D(i)$denotes the destination i.$G(i)$ denotes the distance between the destination i and the nearest charging station. Therefore we can get the minimum range

$$W = 2 * Max\big(G(i)\big) \qquad \forall \ D(i) \in D \qquad (10)$$

The map of Beijing is shown in Figure 5 and the positions of the 13 charging stations are marked.

We set charging station 1 as the origin. A coordinate system is constructed which is shown in Figure 5 (Scale:1-0.0304). Now 13 charging stations' coordinates are obtained as the following Table 1(a), Table 1(b).

Table 1(a).coordinates of 13 charging stations in Beijing

Charging Stations	1	2	3	4	5	6	7
x-axis	0	-30	-52	-223	-120	-200	-240
y-axis	0	40	80	94	180	230	300

Table 1(b).coordinates of 13 charging stations in Beijing

Charging Stations	8	9	10	11	12	13
x-axis	-340	-250	-130	70	60	110
y-axis	290	360	430	110	220	370

Through the simulation operation table in Excel, we can find $G(i)$is maximum when the destination coordinate is (-400,600) and M is 566. In reality, the value of M is 17.2km according the above scale and 17.2kmis set as electric vehicle's available distance with fully-charged battery in the simulation.

4.2 Model validation

This article only gets α= 0.5 to verify this model and others are similar. When α= 0.5, Z=-(Z_1+Z_2)=0.5S_3+1.5S_4. Starting point A and four destinations B,C,D,E are randomly generated within the Fifth Ring Road in Beijing and the data is shown in Table 2.

Table 2. informationsabout origin and 4 destinations

Points	A	B	C	D	E
Coordinates	（94，32）	（-84，69）	（88，262）	（-67，23）	（-269，540）
Nearest charging stations	——	3	12	2	9
Distances to nearest charging station	——	33.8	50.5	40.7	181.0

As the trip D-E is enough to verify above model, we only discuss this trip. When the electric car reaches D, D becomes the starting point of next optimization and Rdecreases to 265.5.

Destination E (-269,540) is randomly generated and the distance d_{DE} is 555.1. The nearest charging station of E is charging station 9 and the nearest distance d_E is 181.0. Since $R<d_{DE}+d_E$, the electric car cannot reach the destination, it must search for a charging station to change its battery and then drives to the destination. A circle centered at E is drawn whose radius is R and charging station 1,2,3,4,5,6,11,12 are within the circle. When changing battery at station 6, Z is minimum, so the electric vehicle should go to station 6 to replace battery. So, we get that the simulation results are in conformity with reality.

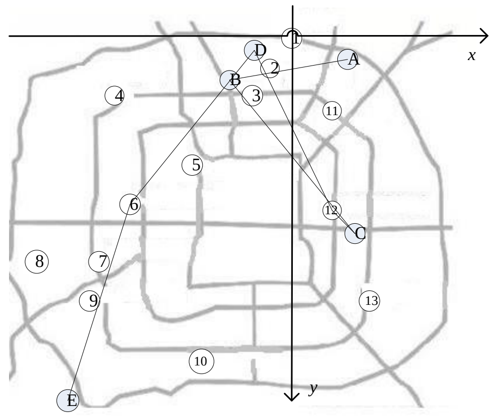

Figure 5. model validation

4.3 Data Analysis

From above analysis, we know that the weighting coefficient α is affected by many factors. In order to make the experiment can reflect the preferences of various people, we use a series of α value namely 0.1,0.3,0.5,0.7,0.9 when doing the experiment. The meanings when α take different value is shown in table 3.

α	meaning
0.1	The driver extremely prefers to choose the path that distance between charging station and destination is shortest.
0.3	The driver slightly prefers to choose the path that distance between charging station and destination is shortest.
0.5	The driver’s preferences to total distance and distance between charging station and destination are similar.
0.7	The driver slightly prefers to choose the path that the shortest distance is shortest.
0.9	The driver extremely prefers to choose the path that the shortest distance is shortest.

When α= 0.5, Z=0.5S_3+S_4. One starting point and 100 destinations are randomly generated in the simulation. Experiment result shows that the actual total travelled distance is 30128.99 and the shortest theoretical distance is 28355.19.The detour distance is 1773.81 and the detouring rate is 6.26%. The results are shown in the following Table 4.

Table 4. result when α=0.5

Charging Stations	1	2	3	4	5	6	7
Charging Times	1	2	4	9	9	6	1
%	1.4%	2.8%	5.6%	12.5%	12.5%	8.3%	1.4%
Charging Stations	8	9	10	11	12	13	sum
Charging Times	1	6	10	7	8	8	72
%	1.4%	8.3%	13.9%	9.7%	11.1%	11.1%	100.0%

When α takes the values of 0.1, 0.3, 0.7, 0.9, the results are alike. The touring rate vary from 5% and 10%, which is a small fluctuation. Charging stations 4,5, 10, 12, 13 are always the ones with high using frequency.

5. Conclusions

This paper designs an algorithm to verify the rationality of electric vehicle charging stations layout and applies it to the analysis of the charging stations layout. We take Beijing as an example and the results show that the charging stations layout in Beijing is not reasonable, in some areas too densely located while some other areas are too thin. With the popularity of electric cars, unreasonable charging stations layout will not be able to meet the requirements of electric vehicles and hinder the development of the electric car, so it is necessary for some redefining for charging stations layout in Beijing. Besides, detouring rate fluctuates in the range of 5%~10% no matter what people prefer, which means that the object of shortest total distance has little effects on the choice of charging station when needing to replace battery. In reality, drivers are more likely to select the route that the distance between charging station and destination is shortest, because the total distance is similar based on the above analysis. In the model, the specific road conditions and traffic problems are not taken into account.

Acknowledgements

This paper is funded by National Natural Science Foundation of China (71132008) andthe Lab of Logistics Management and Technology

References

[1] T. Raviv, “The Battery Switching Station Scheduling Problem”, Operations Research Letters, vol. 40, no. 6, **(2012)** June, pp. 546-550.
[2] R. Hiwatari, “A Road Traffic Simulator to Analyze Layout and Effectiveness of Rapid Charging Infrastructure for Electric Vehicle”, Vehicle Power and Propulsion Conference (VPPC), Chicago, **(2011)**, pp. 1-6.
[3] J. Liu, “Electric Vehicle Charging Infrastructure Assignment and Power Grid Impacts Assessment in Beijing”, Energy Policy, vol. 51, **(2021)** December, pp. 544-557.
[4] S. Bae, “Spatial and Temporal Model of Electric Vehicle Charging Demand”, Transactions on Smart Grid, vol. 3, no. 1, **(2012)**, pp. 394-403.
[5] S. Erdogan, “A Green Vehicle Routing Problem”, Transportation Research Part E-logistics And Transportation Review, vol. 48, no. 1, **(2012)** January, pp. 100-114.
[6] C. Upchurch, “Comparing the p-median and flow-refueling models for locating alternative-fuel stations”, Journal of Transport Geography, vol. 18, no.6, **(2010)**, pp. 750-758.
[7] I. Capar, “An efficient formulation of the flow refueling location model for alternative-fuel stations”, IIE Transactions, vol. 44, no. 8, **(2012)**, pp. 622-636.
[8] K. Guo, “Consideration of the Industrialization of Electric Vehicles in China”, China Engineering Science, vol. 13, no. 9, **(2011)** September, pp. 4-7.
[9] F. Xu, “Tentative Analysis of Layout of Electrical Vehicle Charging Stations”, East China Electric Power, vol. 37, no. 10, **(2009)** October, pp. 1678-1682.
[10] X. H. Sun, “Electric vehicle charging stations layout model based on time and space constraint”, Progress In Geography, vol. 31, no. 6, **(2012)**, pp. 686-692.

