A NOVEL APPROACH FOR THE LAYOUT OF ELECTRIC VEHICLE CHARGING STATION

HENGSONG WANG[1], STUDENT MEMBER, IEEE, QI HUANG[1], SENIOR MEMBER, IEEE, AND CHANGHUA ZHANG[1], AIHUA XIA[1]

[1] School of Automation Engineering, University of Electricity Science and Technology of China, Chengdu, 611731, China
E-MAIL: bruce0815@foxmail.com

Abstract:

As energy crisis poses a huge threat to human welfare, the electric vehicle is of vast potential for future development as an newly emerged traffic tool which is energy-conserving and environment-protective. However, the layout method of its charging station is far from a mature system even though the construction is being undertaken. Thus this paper presents a multi-objective planning model which is comprehensive for the layout of electric vehicle charging station taking in account factors including electric vehicles sustainable development, characters of charging station, characters of charging consumers, distribution of the charging demand, the power grid and factors of municipal planning. Then a solution algorithm is designed based on demand priority and the usage of the existing gas station. The model and the solution algorithm is sustainable and expandable. Many considered factors can be revised and optimized with the development of the electric vehicle and its charging station. This is of great importance and can promote the development of this new energy vehicle. In order to illustrate and verify the proposed model and algorithm, a numerical case is studied based on the background of Chengdu City in China, making decisions on the position to construct the charging station.

Keywords:

electric vehicle charging station; layout; model and algorithm; charging demand; priority; sustainable.

1. Introduction

As the world is faced with problems of environmental pollution and energy crisis [1]-[4], the electric vehicle, an recently emerged energy-conserving and environment-protective traffic tool, has vast potential for future development and market. The corresponding charging station is the vital supporting infrastructure and basis for the generalization of electric vehicles. Thus, the construction of energy supply net of high efficiency is a precondition for the commercialization and industrialization of the electric vehicle. Up to now, quite a few cities begin to construct the charging station while lacking a mature system for the planning and layout. Therefore the study of layout method for the charging station is in urgent need.

So far, studies concerning the construction of charging station are mainly focused on the external access, the internal layout of the station and the investment of funds. Small number of documents, even considering aspects related to the sites selection of charging station and the overall planning of a city's charging station network, turn out to discuss factors affecting the layout in quality, propose some principle suggestion and come up with no concrete method for the sites selection and layout [5]-[9].

Therefore, this paper tries to design a comprehensive multi-objection planning model from a sustainable perspective. The model takes into account the developing character of electric vehicle's technique quality, the increasing quantity, the character of charging consumer's behavior and the serve ability of the station. The model also make the most of the distribution network, especially the power transformers while fit for the demand and principle of municipal planning factors. Afterwards, a solving algorithm is designed to get the solution for the layout of the constructed charging station based on principles that charging demand should be satisfied first and that the existing gas station should be made the best use of whose the locations are proper.

super

Generally, the paper is organized as below: the character of the charging consumers' behavior, the developing trend of the electric vehicle and the serving ability of the charging station are discussed in section 2, which are the basis of the following sections; the comprehensive model considering various factors is introduced and the sub-objections and sub-constraint spaces of the demand distribution, the distribution network and the municipal planning factors are described in section 3; the solving algorithm based on the demand priority and the usage of gas station is designed in section 4; the "pseudo

Chengdu" case is simulated to test and verify the model and the algorithm in section 5; and section 6 provides the conclusion and further work.

2. Preparing Knowledge

可以参考gas station的部署方式

To begin with, the layout method for gas station provide beneficial reference and experience for electric vehicle charging station. The oiling quantity of a vehicle on a linear road L equals the consumption quantity in the realm of gas station layout [10]. However, this is not applicable to the layout of charging station in a city which is studded with various roads and numerous crosses. Another reason is that the travel range of electric vehicle is short, which leads to the need of high density of charging stations. Besides, the charging station should serve the road net as well as the community. All that factors make it improper to simplify city's traffic network into interweave of roads.

Thus, the number of electric vehicles, the ability of battles, the serving range of charging stations and the developing trend should be emphasized when dealing with the layout of charging station.

2.1. Distribution of Charging Demand

Suppose there is an area of any shape or set φ for whom the leaving vehicles and the entering ones are equal in quantity, which is called the conversation of the number of vehicles (Figure 1). Suppose the flux of circle r_1 and r_2 are f_1 and f_2, the total number of vehicles are N, the velocities are v_1 and v_2, the consumed energy are E_1 and E_2:

$$\begin{aligned} N &= S_1 f_1 = 2\pi r_1 \Delta x f_1 \\ &= S_2 f_2 = 2\pi r_2 \Delta x f_2 \end{aligned} \tag{1}$$

Then the consumed energy can be represented as:

$$\begin{cases} E_1 = \dfrac{N t_1 E_0}{S_1} = \dfrac{N \dfrac{\Delta x}{v_1} E_0}{2\pi r_1 \Delta x} = \dfrac{N E_0}{2\pi r_1 v_1} \\ E_2 = \dfrac{N t_2 E_0}{S_2} = \dfrac{N \dfrac{\Delta x}{v_2} E_0}{2\pi r_2 \Delta x} = \dfrac{N E_0}{2\pi r_2 v_2} \end{cases} \tag{2}$$

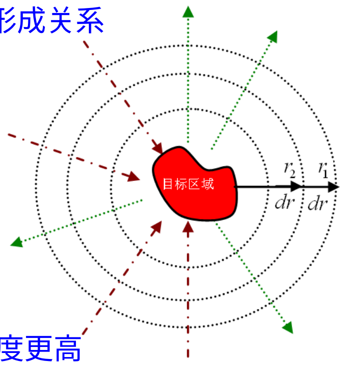
The relationship between the vehicles velocity and its flux are:

$$v = Q(f) \tag{3}$$

According to the practice in China, the relationship can be simplified as:

$$v = \frac{c}{f^b} \tag{4}$$

能量和距离形成关系



city需要的部署密度更高

Figure 1. Flux of set φ

Thus, for the neighboring area of set φ, the function of consumed energy can be described as:

能量消耗与半径的关系

$$\frac{E_1}{E_2} = \frac{r_2^{b+1}}{r_1^{b+1}} \tag{5}$$

In this case, the energy consumed per unit area are inverse ration to r^{b+1}. Suppose the radius of set φ is r_0, the distribution function of the energy is :

$$E = \begin{cases} E_0, & r \le r_0 \\ \dfrac{c}{r^{b+1}} + a, & r > r_0 \end{cases} \tag{6}$$

In sum, two conclusion are gained in this section:

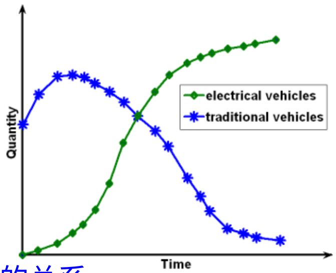
Conclusion 1: the demanding charging quantity in set φ equals to the energy consumed.

Conclusion 2: the consumed electrical quantity used by the area or set φ can be represented as a function of distance r, which is equation (6).

2.2. Developing Trend of the electric vehicle

The relationship between electric vehicles and traditional vehicles is competition and it is predictable that the electric vehicles will replace the traditional ones with the development of technology and the exhaustion of oil. Suppose the quantity of electric vehicles is $x(t)$ and that of traditional vehicles is $y(t)$. According to the Voltera Equation [11], the competition relationship can be described as:

$$\begin{cases} \dfrac{dx}{dt} = ax - bxy \\ \dfrac{dy}{dt} = cxy - dy \end{cases} \quad (7)$$



与原来传统加油站之间的关系
两者之间的结合

Figure 2. Development of electric vehicles

From the equation and the corresponding figure, traditional vehicles will quit market gradually as the electric vehicles develops. That will keep the gas station idle synchronously. Thus proper size charging station can be built inside the gas station to make the most of resource. This can integrate the oiling and charging serve (service?) during the developing process, which is more convenient for the overall consumers.

2.3. Serving ability of Charging Station

In the realm of gas station, the serving range is a circle with radius R_0 in which the serving ability is equal and can be described as $S = E_0(R \le R_0)$. As to the charging station, some revision should be made. At the edge of the serving range, a vehicle are likely to be charged in the neighboring station. Thus based on the existing documents and experience, we depict the serving ability of an electric vehicle charging station as the following function:

$$s = \begin{cases} E_0, R \le (1-\lambda)R_0 \\ -\dfrac{E_0}{2\lambda^2 R^2}(x-(1-\lambda)R_0)^2 + E_0, (1-\lambda)R_0 < R \le R_0 \\ \dfrac{E_0}{2\lambda^2 R^2}(x-(1+\lambda)R_0)^2, R_0 < R \le (1+\lambda)R_0 \end{cases} \quad (8)$$

Equation 8 is depicted vividly in Figure 3 :

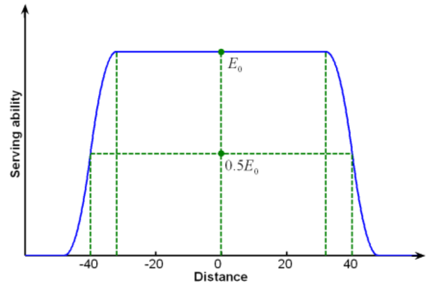


Figure 3. Serving ability

对不同的charger的能力如何区分

Further, the serving range should be discussed according to the cost of accessing. For example, the serving ability of station, which is built near a main road, has a larger serving range along the main road than that of the common community.

3. Framework of the Model

The layout of charging station relates with multiple factors and the model should be sustainable or expendable as the electric vehicles are in developing process. Thus it is necessary to classify the factors and objections, which is called modularization (figure 4).

The preparing section discusses the characters of the layout issue. It makes the fundament for the formulating of the demanding distribution of charging energy.

The following work is to satisfy the need of this distribution to the utmost.

Beside the demand, the remaining concerns are from the municipal planning and the distribution network.

As to the municipal, we should focuses on the factors such as the busy road, the ordinary road, the crosses, the public infrastructures and some other factors.

As to the distribution network, we should analysis the structure of the power network, the power flow, the site and the available capacity of the power transformer.

Then form the model in figure. First construct the demanding map. Then find the most demanding point. Around the point, find existing gas station which satisfy the conditions and the constraint factors as well as make the objection optimal.

If the gas station can not be found, find the vacant place to construct a new station for charging service alone while satisfying the constraint and the objection optimal.

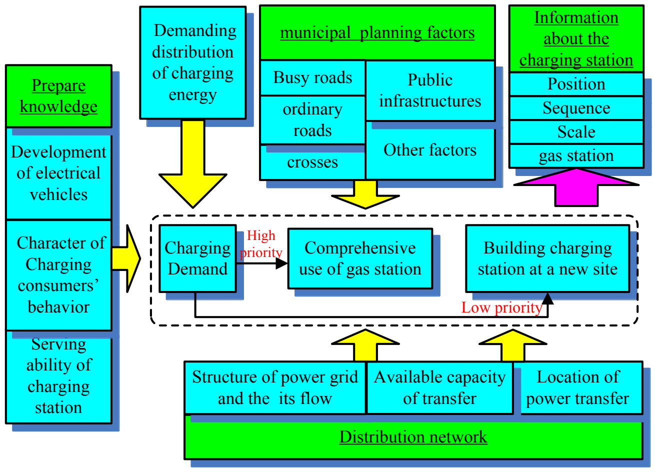


Figure 4. Framework of the model

3.1. Demanding distribution

计算总能量

The demanding distribution of a city is determined be the existing quantity of electric vehicles, the travel distance per day and the consumption of energy per mile. The developing function of the quantity of electric vehicles which are at the starting point cannot be determined at the moment. However, the developing pattern is analogous with the tradition vehicles, which is also the competitor. The relationship is described in section 2.2. which is the foundation for the demanding distribution.

Referring to the classification by Ma Luoming in [2], the traffic flow of a city can be decomposed into three subspaces: the node standing for public facilities, the linear road, the plane standing for communities. And the total demanding distribution can be get through the weighted sum:

$$e(x,y,t)=(\sum e_1(x,y)+\sum e_2(x,y) + \sum e_3(x,y))x(t) \quad (9)$$

Where $e_1(x,y)$ stands for the contribution of the points, $e_1(x,y)$ stands for the contribution of the roads, $e_1(x,y)$ stands for the contribution of the planes and $x(t)$ stands for the quantity of electric vehicles at time t.

3.2. Supply space of the distribution network

The charging station should be supplied by the available capacity of the power transformers. The location of the transformers should also be considered, which should have an influence on the power flow of the distribution network and the compensation of the reactive power.

考虑电网

A charging station can be supplied by several transformers and the minimal cost solution should be found to make sure that the operation of the network is economical and reliable.

Suppose that locations of m transformer stations to be built are (u_j, v_j) and that the locations of the h charging station are (x_i, y_i). According to the principles of equal loads, minimal investment, minimal distance to loads and the minimal cost of network, the objections can be described as following:

$$\min C=\sum_{j=1}^{m}\sum_{i=1}^{h}\delta_{ji}[(u_j-x_i)^2+(v_j-y_i)^2]^{\frac{1}{2}} \quad (10)$$

$$\min C=\sum_{j=1}^{m}\sum_{i=1}^{h}\delta_{ji}S_i[(u_j-x_i)^2+(v_j-y_i)^2]^{\frac{1}{2}} \quad (11)$$

$$\min C=\sum_{j=1}^{m}\sum_{i=1}^{h}\delta_{ji}P_i[(u_j-x_i)^2+(v_j-y_i)^2]^{\frac{1}{2}} \quad (12)$$

$$\min C=\sum_{j=1}^{m}\sum_{i=1}^{h}\delta_{ji}\beta_i P_i[(u_j-x_i)^2+(v_j-y_i)^2]^{\frac{1}{2}} \quad (13)$$

$$s.t.\ \sum_{j=1}^{m}\delta_{ji}=1(i=1,2,3,\cdots h) \quad (14)$$

Where δ_{ji} is flag variable: $\delta_{ji}=0$, load i is not supplied by j; $\delta_{ji}=1$, load i is supplied by j. h stands for the number of loads; S_i stands for the area of power line; P_i stands for the power of load; β_i stands for the factor of cost per mile per power.

3.3. Municipal planning factors

The constraint factors or the objections can be classified into four categories: factors kept away, factors close, factors with point shape and factors with linear shape.

Points that should be kept away are: the intersections of roads, the public facilities such as hospital, tour site. The lines should be kept away are busy roads. The lines should be close to are ordinary roads.

$$\min D_I=[(x_i-x_{I_l})^2+(y_i-y_{I_l})^2]^{\frac{1}{2}} \quad (15)$$

$$\max D_B=[(x_i-x_{I_B})^2+(y_i-y_{I_B})^2]^{\frac{1}{2}} \quad (16)$$

多重限制条件

$$s.t.\begin{cases}[(u_j^1-x_i)^2+(v_j^1-y_i)^2]^{\frac{1}{2}}\geq R^1\\ [(u_j^2-x_i)^2+(v_j^2-y_i)^2]^{\frac{1}{2}}\geq R^2\\ \vdots\\ [(u_j^k-x_i)^k+(v_j^k-y_i)^2]^{\frac{1}{2}}\geq R^k\end{cases} \tag{17}$$

This is a nonlinear multi-objection planning problem. According to the magnitude of those factors, method of weighting factors can be applied to form a integrated function.

4. Solving Algorithm Based on Demanding Priority

Based on the model, the electrical energy demanding space, the distribution network supply space and the municipal planning space and be constructed. As the electric vehicles develop from none and the number becomes larger and larger, the construction of the charging station is step by step. This character require the construction of station where is most need if it is possible according to the standards of the distribution network and the municipal planning. And the solving algorithm is mainly based on the requirement. Following are the steps of the algorithm:

Step 1: input the municipal map and the traffic flow of main road so as to simulate the energy demanding distribution according to the conclusion of section 2.1.

Step 2: according to definition of serving ability in section 2.2, calculate the total energy demanding quantity if charging station is built in any point (x_0, y_0). Find the biggest average energy demanding area of (x_0, y_0). That is:

$$e_{\max} = \max \bar{E}(x_0, y_0) = \frac{\iint\limits_{(x,y)\in s} E(x,y)dxdy}{\iint\limits_{(x,y)\in s} dxdy} \tag{18}$$

Where s stands for a circle area with radius r_0 and center (x_0, y_0).

Step 3: search the circle area with distance $R < \alpha R_0$ to the center (x_0, y_0). If a gas station exists, then charging station can be built at the same site to satisfy the need of both the electric vehicle and the traditional vehicle. Output the location of the gas station (x_j, y_j), and the total energy demanded E_{sum} in the area to determine the scale of the charging station to be built, and turn to step 5; else, go to step 4.

Step 4: set the objection of integrated function $F(x,y) = f(c(x,y),\ D(x,y))$ which is formulated by the distribution network space and the municipal planning space. As in step 3, search the circler area with a distance $R < \alpha R_0$ to the center (x_0, y_0), find the point with $\min F(x,y)$, output the charging station location (x_j, y_j) and the total demanding E_{sum}. $c(x,y)$ is determined by equation (5) and $D(x,y)$ is determined by equation (7). The integrated function can be formulated as $F(x,y) = w_1 C(x,y) + w_2 D(x,y)$ with the method of weighing factors where $w_1 > 0$ and $w_2 > 0$.

Step 5: according to the results of step 3 and step 4, the serving ability of the newly added station can be described as $s(x,y,x_j,y_j)$ based on equation (3) and the remaining demanding map are $e(x,y) = e(x,y) - s(x,y,x_j,y_j)$. Search the remaining map for the biggest total demand $e_{\max}$, where $e_{\max}^0$ is the minimal energy for a charging station.

*Step 6:*optimization. Adjust the position of the sites.

After these six steps, the construction schedule can be gained including the construction sequence, the construction scale and the construction location as well as whether to make use of the existing gas station.

5. Case Study

In order to illustrate the model and the solving algorithm, a study case is constructed according to the available data of Chengdu City in the background of developing stage, which can be called as “pseudo Chengdu”. The distribution of traffic flow is depicted according to Google Earth and Google map. The roads are classified into three categories: the main road including busy sections and ordinary sections, the ordinary road and the small road. 45 gas stations are satiated as well as 90 public infrastructures. Each of the elements make a contribution to the energy distribution map with a certain factors. Then based on the conclusion in section 2, the energy distribution map can be depicted in Figure 5.

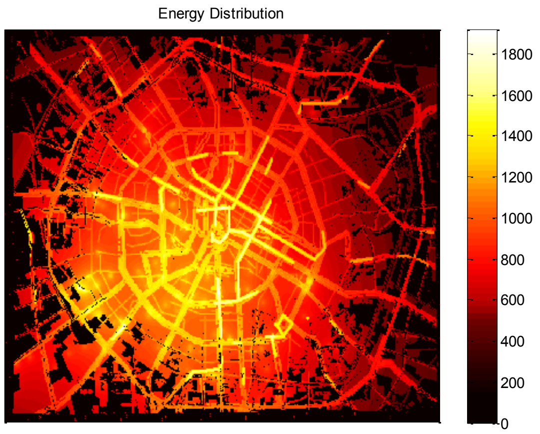


Figure 5. Energy distribution of the pseudo-Chengdu

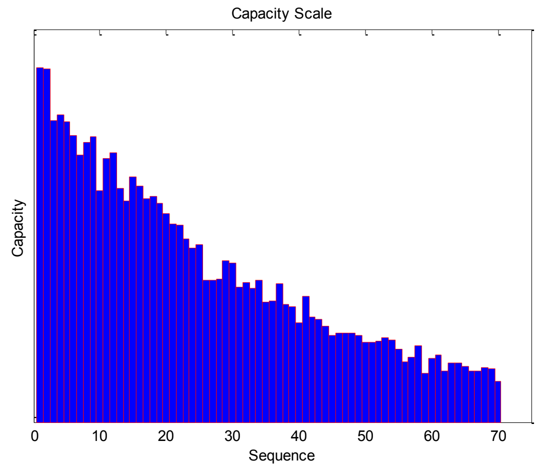


Figure 7. Construction sequence and capacity

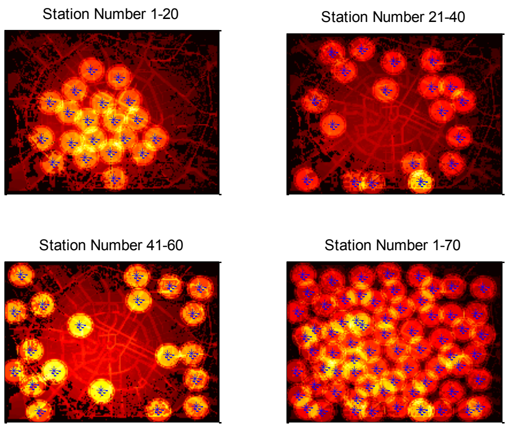


Figure 6. Position of the stations

Using the model and the solving algorithm, the scheme to construct the charging station can be gained. This scheme including the construction sequence, the capacity scale of each station, whether to use the existing gas station comprehensively and the position of the station. The sequence matters as the electric vehicles are not mature at the moment; hence construction in batch is necessary (Figure 6). For the area in urgent need of the new energy vehicles, the station should be built first while other area is of low priority.

Table 1. Detailed results

Sequence	Capacity	Integration	Position
1	6312400	No	368, 291
2	6287600	No	303, 359
3	5379300	No	305, 270
4	5474500	No	379, 221
5	5357900	No	410, 347
6	5110800	Yes	246, 320
7	4766400	Yes	364, 121
8	4981400	No	277, 209
9	5088900	No	299, 432
10	4126600	No	429, 265
15	4379900	Yes	159, 372
17	3987000	Yes	448, 159
18	4026200	Yes	243, 149
20	3710700	Yes	366, 391
24	3090700	Yes	315, 151
30	2837400	Yes	448, 537
37	2458600	Yes	449, 413
41	2246200	Yes	148, 124
67	911260	Yes	113, 239
69	960420	Yes	461, 41
…	…	…	…
56	1077800	No	91, 637
57	1156700	No	378, 32
58	1354700	No	178, 615
59	0866400	No	517, 113
60	1143600	No	323, 533

6. Conclusion

This paper presents a non-linear multi-objective planning model which is comprehensive for the layout of electric vehicle charging station taking in account factors such as electric vehicles sustainable development, characters of charging station, characters of charging consumers, distribution of the charging demand, the power grid and factors of municipal planning. Then a solution algorithm was designed based on demand priority and the usage of the existing gas station. The model and the solution algorithm is sustainable. Many considered factors can be revised and optimized with the development of the electric vehicle and its charging station. This is of great importance and can promote the development of this new energy vehicle. Finally, a "pseudo-Chengdu" case was simulated to test and verify the model and algorithm according to some available data of Chengdu City.

The model and the algorithm is of good sustainability and expansibility through classifying the objects and affecting factors. Many new factors and optimal objection can be added as the cognition deepens and the experience accumulates.

The research in this paper is a new explore especially in the layout strategy of electric vehicles charging stations. Lots of more efforts should be make to improve the model and the solving algorithm, for example, the weight of each factor and the affecting function based on stochastic issues. These works would be carried out in the following research. Hopefully, the paper could provide new ideas in the research area of developing charging station for electric vehicles which are of vast potential.

Acknowledgements

This paper is partially supported by the Fundamental Research Funds for the Central Universities and UESTC (JX0756, Y02018023601059).

References

[1] IPCC, "Intergovernmental panel for climate change fourth assessment report," Cambridge, U.K., Cambridge Univ. Press, 2007.

[2] EPRI and NRDC, Environmental Assessment of Plug-In Hybrid Electric Vehicles, vol. 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030, Palo Alto, CA, July 2007.

[3] Xiujun Zhang, Analysis of Global Environmental Problem[J], Science Friend, 1:92-931,2006 .

[4] Peiwei Yu, Mainstream of Global Energy Problem[J], Journal of Beijing Institute of Petroleum Management Translation, 3:4-5, 2008.

[5] Fan Xu, Guoqin Yu, Tentative analysis of layout of electric vehicle charging stations[J], East of China Electric Power,10:1678-1682, 2009.

[6] Larry Dickerman, Jessica Harrison, A New Car, a New Grid, IEEE power and energy magazine, march/April 2010.

[7] Jianxin Yao, Mei Wang, Ming Luo, Construction and application of Charging system for electric mobiles[J], East of China Electric Power,8:983-986, 2008.

[8] J. Dowds, C. Farmer, P. Hines, R. Watts, and S. Blumsack, "A review of results from plug-in hybrid electric vehicle impact studies," technical report, Univ. of Vermont, Dec. 2009.

[9] Ali Nourai and David Kearns. Batteries Included. IEEE power and energy magazine, march/april, 2010.

[10] Yifei Ma, Rongxiao Gao, A gas station distribution Model[J], Operation Research and Management Science,10:63-68, 2005.

[11] Frank R. Giordano, Maurice D. Weir, William P. Fox, A first course in mathematical modeling, Brooks Cole, July 2002.

[12] Weiming Luo, Yuan Shi, Gas station Layout and Planning faced to Different spatial Level Demand[J]. 2008 Annual National Planning Conference, 2008.

[13] A. L. Madian, L. A. Walsh, K. D. Simpkins, and R. S. Gordon, "U.S. plug-in hybrid and U.S. light vehicle data book: Hybrid vehicles, battery technology, travel patterns, vehicle stock, sales trends, performance trends," in Proc. Plug-In Electric Vehicles, June 2008.

[14] F. Nemry, G. Leduc, and A. Muñoz, "Plug-in hybrid and battery-electric vehicles: State of the research and development and comparative analysis of energy and cost efficiency," Office for Official Publications of the European Communities, Luxembourg, Rep. JRC 54699, 2009.

[15] Hao Yu-Jie. An Efficient Tcp Flow Reassembling Algorithm Based On Pf_Ring. International Conference on Apperceiving Computing and Intelligence Analysis, ICACIA 2009

[16] Hao Yu-Jie. Distance measure between vague sets. International Conference on Apperceiving Computing and Intelligence Analysis, ICACIA 2008