A Electric Vehicle Charging Station Optimization Model Based on Fully Electrified Forecasting Method

Xinyu Tian, Huake Su, Fan Wang, Kun Zhang and Qinghe Zheng

***Abstract*—In the global context of reducing the use of fossil fuels and turning to the usage of electric vehicles. The location and ease of charging stations have the crucial impact on early adopters and volunteers who will eventually become mainstream consumers. In this transition, national planning needs to take into account the final network planning of charging stations and the development and evolution of charging station systems, and seek to develop policies to facilitate the transition of vehicles to electric vehicles, making the best solution for each country. In this paper, we first determine that the standard measurement of full electrified electric vehicles should reach 90%. By fitting and forecasting the data of Tesla electrification rate in recent years, we draw the conclusion that it is difficult to realize a complete electrification at present. Based on this conclusion, we estimate that the number of electric vehicle charging stations required in the United States is about 29.7 million under the constraints of demand and service by using the multi-objective programming model. Moreover, we have suggested to countries the factors to be taken into account in the development of electric vehicles and the timing of banning the use of fuel vehicles. Finally, we use the asymmetric Nash negotiation model to discuss the impact of the number of vehicles, population density, road network density, GDP, geographical environment and other factors. The results show that the urban, suburban, and rural areas have reached 63.52%, 23.41%, and 13.07%.**

***Index Terms*—charging station optimization, fully electrified forecasting, pos, asymmetric Nash, multi-target planning**

I. Introduction

Climate change and growing energy shortages are forcing all the countries to look for more energy-efficient energy sources. And new energy vehicles (especially electric vehicles) have attracted increasing attention due to the superior energy efficiency and environmental protection. At present, many countries [1] in the world have increased the support to the electric vehicle industry, and issued policies or statements to support the development of electric vehicles. In May 2009, the City of London [2] released the Electric Vehicle Delivery Plan for London Sound [3], establishing the comprehensive strategy to stimulate the electric vehicle market. Singapore was also announced at the same time by CEO of EMA [4], an energy market agency, to implement Electric Vehicle Test Bed Program [5]. In December of the same year, the mayor of Los Angeles, Southern California Regional Plug-In Electric Vehicle Plan, mainly discussed investment in facilities and standardization issues in the cities of the Paris, San Francisco, New York [6]. As early as 2010 [7] [8] [9] [10], China's four ministries and commissions jointly issued the notice on the pilot program of private purchase of new energy vehicles, which has clearly indicated that the direction of China's new energy development should be oriented to electric vehicles, especially pure electric vehicles. The development of electric vehicle industry has been agreed to solve the problems of the energy shortage and the environmental pollution [11], but the imperfection of charging facilities in major cities has become the biggest obstacle to the development of electric vehicles.

Electric vehicle charging stations are the important factor [12] affecting the development of electric vehicles, while the promotion of electric vehicles is kind of great significance. At present, the construction of the supporting facilities of the charging station lags behind the development of the electric vehicle, which has already hindered the development of the electric vehicle. And for the charging station construction site is reasonable to affect the operating efficiency of charging stations, quality of service, and security. The industrialization process of electric vehicles [13] [14] [15] depends to a great extent on whether the problem of battery charging can be solved reasonably. The location of charging station [16] is the core of the layout of charging station. Only if the location of charging stations is scientific and reasonable [17], can it be convenient for users to charge, attract more users to buy electric vehicles, and improve the efficiency of charging station operation. Whether the location is reasonable or not plays an important role in the operation safety and economy of the charging station. In fact, State Grid [18] proposed to build charging stations for electric vehicles nationwide in 2010, and since then the PetroChina [19] and the Sinopec [20] have also stepped up the construction process of the layout charging stations. Therefore, it is urgent to analyze and study the location of electric vehicle charging station.

However, there is no systematic research on the decision [21] and evaluation [22] [23] of charging station location for electric vehicles, and a set of perfect process and evaluation

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TABLE I. MAIN VARIABLE ANNOTATIONS IN THE PAPER

$CORT$	C	k_g	γ_j	W_q	p_z
The service coverage	Total social cost	Evaluation factor	Distribution coefficient	Waiting time	Probability of all chargers idle

method of charging station location have not been formed in many countries to guide the construction of charging station network of electric vehicles. There are many factors [24] [25] involved in the location of electric vehicle charging station. It is necessary to carry out comprehensive planning and design according to the technical level of electric vehicle [47] [48], quantity and distribution of electric vehicle [49] [50] [51] [52] [56] [57], charging mode [53] [60] and so on.

In this paper, we determine that the standard measurement of full electrified electric vehicles should reach 90%. By fitting and forecasting the data of Tesla electrification rate in recent years, we draw the conclusion that it is difficult to realize a complete electrification at present. Based on this conclusion, we estimate that the number of electric vehicle charging stations required in the United States is about 29.7 million under the constraints of demand and service by using the multi-objective programming model. Moreover, we have suggested to countries the factors to be taken into account in the development of electric vehicles and the timing of banning the use of fuel vehicles. Finally, we use the asymmetric Nash negotiation model to discuss the impact of the number of electric cars, population density, road network density, GDP, geographical environment and other factors. The results show that the urban, suburban, and rural areas have reached 63.52%, 23.41%, and 13.07%. Then the charge stations are distributed at the city level based on the asymmetric Nash negotiation model. And through the nesting with the PSO optimization location model based on Voronoi diagram, we achieved the precise distribution in Seoul. By measuring the demand for electric vehicles in urban and rural areas, the evaluation factor is used to analyze whether the charging stations should be established starting from urban or rural areas. For the issue of scheduling, this paper obtained the prediction function based on linear regression and formulated the development schedule in detail.

Furthermore, we define the following three development models (policy-driven model, city-first development model and coordinated development model based on two key factors: oil resources and the gap between urban and rural areas. The countries are classified according to oil storage index I and Gini coefficient G. And we get the conclusion that the China and Singapore are suitable for city-first development model, while Indonesia and Australia are suitable for coordinated development model, and the Saudi Arabia is suitable for the policy-driven development model. Korea is propitious to the model of city-first development. In fact, there are no suitable development plans apply to all countries. In Table I, we show the notation used in the paper.

The proposed optimization model is based on the following assumptions:

(1) The location of the charging station is not affected by other buildings at the site.

(2) The service vehicles entering the charging station will not leave midway.

(3) The charging pile construction costs are the same.

(4) The coverage of the charging station does not overlap.

The rest of this paper is organized as the follows. We first introduce and analyze some related works of electric vehicle charging station optimization method in Section II. Then the electric vehicle charging station optimization model based on fully electrified forecasting is presented in Section III. Layout and optimization program of charging stations in South Korea are introduced in Section IV. Development program and the suitability of the proposed optimization model are given in Section V and Section VI, respectively. Finally, we discuss what we learned, our conclusions, and future works in Section VII.

II. RELATED WORKS

In this section, we introduce the related works of electric vehicle charging station optimization method, including the factors affecting the layout of charging stations, principles for layout of charging stations, and related optimization models and algorithms.

A. Factors Affecting the Layout of Charging Stations.

Mode of energy supply for electric vehicles. At present, there are three modes of energy supply for electric vehicles, including the conventional charging, the fast charging, and the ground charging. The conventional charging is equivalent to low current charging. Rapid charging is to realize the rapid charging of electric steam vehicle by high current. Charging on the ground is to recharge the electric vehicle by replacing the battery [26].

Charging time. Different charging time requirements will affect the operation mode of electric vehicles, and then affect the layout of charging stations. In the case of no demand for charging time, it can be charged at night when the electric vehicles are out of the operation. Rapid charging or battery replacement may be used for emergency charging [27].

Characteristics of dynamic battery. Different types of power batteries determine the charge and discharge efficiency of electric vehicles. At present, power batteries are generally stored in the characteristics of low charge efficiency and less energy storage. This is also one of the main factors restricting the development of electric vehicles, and plays an important role in planning the number of charging stations and the capacity of charging stations [28].

B. Principles for the Layout of Charging Stations.

The planning principle of charging station should consider the "charging demand" [30] and the "feasibility of charging station construction" [31] [32]. The main factors affecting charging demand are the number of electric vehicles and the radius of charging service. The main factors that affecting the feasibility of charging stations construction process are the road network structures, the power allocation, environmental protection, and some other external factors. Therefore, the

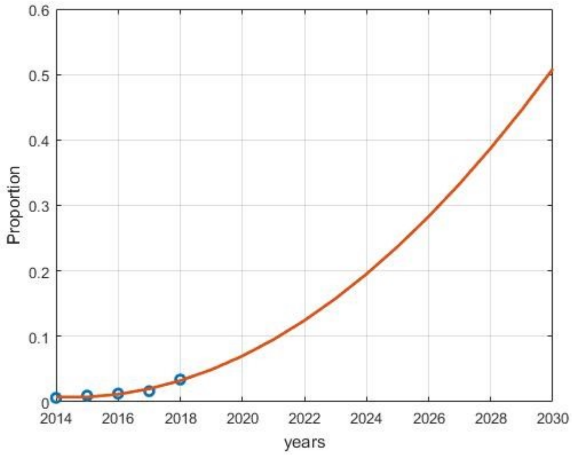

Fig. 1. Tesla electric vehicle market share trend and its change trend in the future. Circles and curve represent actual statistics and prediction values, respectively.

principles of planning and layout of charging stations include the following five points [29] [58]:

(1) The layout of charging stations should be consistent with overall distribution of electric cars and the distribution of charging demand points as far as possible.

(2) The layout of the charging stations should satisfy the distance between the service radius of charging station and the point of charge demand.

(3) The construction of the charging stations should be coordinated with urban master planning and road network planning.

(4) The capacity of the charging stations should be less than the capacity limit of the transmission and distribution network in the region, and the pressure on the local power network should be avoided during the charging peak period.

(5) The charging planning should be forward-looking and take full account of the future development trend of electric vehicles.

C. Related Optimization Models and Algorithms.

In recent years, some preliminary studies on the layout and location of charging stations for electric vehicles have been carried out at home and abroad [33] [34] [35] [59].

The first two classical optimization models for the charging stations' location problem are the P-median model [41] and P-center model [42], where the goal of the P-median model is to minimize the sum of the weighted distances from the total demand point to the service equipment, and the goal of the P-center model is to locate the site under the limitation of the number of service devices, so that the maximum distance from any demand points to the nearest devices is minimized. Toregas [43] first proposed that the set coverage problem SCLM (Set Covering Location Model), which can minimize the construction cost or the amount of construction under the constraints of satisfying all the requirements. Church [44] first put forward the maximum overlay location model MCLM (M aximum Covering Location Mode1), the purpose of which is to cover the most needed points under the limited number of service facilities. In the paper [45], a limited capacity location model was established, which alleviated the unreasonable assumptions of the range and simultaneous service capacity in the FCLM model. It is pointed out in [46] that understanding the behavior of fuel supplementation helps to clarify the role of supply station layout structure in promoting the promotion of new energy cars, and that travelers are usually refueling near the beginning or end of the trip, where the starting point is more common; Refueling is usually completed on the way through the journey, and less oil is used as a single purpose, and the traveler is sensitive to the time economy of the fuel supply station.

The influencing factors of layout planning of the charging stations are analyzed, and the principle suggestions of layout planning are put forward in [36]. A two-stage optimization model for charging stations planning of electric vehicles is presented in [37], and the corresponding algorithm is studied. In paper [38], the traffic flow at the junction node is used to represent the traffic flow in the road network, the weight is used to reflect the influence of the vehicle flow density on the service range of the charging station, and the location is based on the minimum loss cost of the user during the charging journey. In the paper [39], an improved tree structure based coding single parent genetic algorithm with elite strategy is adopted to optimize the location and capacity of the charging stations of electric cars while planning distribution network. In the paper [40], though considering the factors of power network and transportation network, the location and capacity model of the centralized charging station was established in view of the power network planning problem of centralized charging station.

III. Electric Vehicle Charging Station Optimization Model

A. Fully Electrified Forecasting

Full electrification means that the number of EVs accounts for more than 90% of the total number of vehicles. If this standard is met, the area will be fully electrified. For Tesla electric vehicle, we predict the annual number of pure electric vehicles and the ratio of the total number of American cars over time to determine whether Tesla can completely electrify the US. When the ratio is greater than 0.9, the United States can now be considered fully electrified. Fig. 1 is shown based on the ratio of the forecast curve. It can be seen from the curve that it is difficult for Tesla to temporarily electrify the United States. But the curve is based on Tesla's current sales forecast, which has the following limitations. If the Tesla carries out technical reforms, the price of electric vehicle will be reduced. On the other hand, with policy interventions, such as banning the use of fuel vehicles, raising fuel prices, and subsidizing electric vehicle users, more and more people are inclined to buy electric cars. Therefore, Tesla electric vehicle also may in the future completely electrify the US.

B. The Model of the Charging Station Demand

If all the private cars in the United States become electric vehicles, then we have to consider how many filling stations we need. In response to this problem, our goal is to minimize the number of charging stations, and to take the coverage of charging stations and user demand as a limiting factor. The appropriate number of charging stations can be solved by multi-objective programming model.

Multi-objective programming model:

(1) Charging station service coverage.

Coverage is a function of the number of charging stations,

TABLE II. THE EVALUATION INDEXES AND GUIDELINES LAYER WEIGHTS

Target layer	Guidelines layer	Guidelines layer weights	Indicator layer	Weights
Charging station construction volume	User needs	0.3462	Number of cars	0.2226
			Population density	0.1236
	Regional status	0.2692	Road network density	0.1514
			Area	0.1178
	Level of economic development	0.1923	Regional GDP	0.1202
			Engel's coefficient	0.0721
	Environmental conditions	0.1923	Geographical environment	0.1082
			social policy	0.0841

the service area of a single charging station, and the total area of the zone. The charging station service coverage (*CORT*) of a zone is shown in equation (1) and (2) below.

$$CORT=\frac{S_{sv}\times(N_1+N_2)}{S_c} \quad (1)$$

$$S_{sv}=\pi(30\%\times L)^2 \quad (2)$$

where *CORT* means the charging station coverage, S_{sv} is the service area of a charging station, S_c denotes the total area of the zone, N_1 is the number of the super charging stations, N_2 is the number of the destination charging stations, L represents the electric car can be used normally. The worst battery loss is, the distance it can travel.

(2) The number of vehicle charging needs in the zone.

The total number of the vehicle charging requests N_t is a function that related to the total number of vehicles and the average daily number of vehicles charged, as shown in the equation (3).

$$N_t=\eta\times N_c\times\sum_{i=0}^{f_q}(k\times p_k) \quad (3)$$

where η represents the proportion of the using car, N_c is the total number of regional cars, f_q is the maximum number of charging times, k is the charging times, p_k is the probability of charging k times.

Through the data analysis of the charging process of the American Tesla car, and according to the charging time of the day, we can determine the number of charges per day. And according to statistics and analysis, only slowly charged Tesla vehicles exist with probability of 48%-52%, while the speed and slow charge time are twice or more times a day, which is not the same as that of the cars.

For the proportion of using the car, it is given as the equation (4).

$$\eta=\frac{\sum_{i=1}^{365}N_i}{N_s} \quad (4)$$

where N_i represents the total number of Tesla electric vehicles traveling on the i-th day, and N_s is the total number of days in a year (*i.e.*, 365).

(3) The charging time that charging stations can provide.

The charging time that the charging stations can provide are related with the number of the fast charging stations and the slow charging stations, as given by

$$Z=NCH_1\times N_1\times n_1+NCH_2\times N_2\times n_2 \quad (5)$$

where NCH_1 is the number of fast charging stations, NCH_2 is the number of slow charging stations, N_1 is the charging pile number in the fast charging station, N_2 is the charging pile number in the slow charging station, n_1 denotes the number of vehicles that can be served by a quick-charge charging pile per day, n_2 denotes the number of vehicles that can be served by a slow -charge charging pile per day.

(4) In summary, the number of charging station model can be given by

$$MIN=MCH_1+MCH_2 \quad (6)$$

which is subject to $CORT\geq 95\%$ and $Z\geq N_t$.

The total number of charging stations in the United States can be obtained by inserting the data of the United States into the above model, which includes a total of 2968800 charging stations.

C. Distribution Model Based on Asymmetric Nash Negotiation

First of all, we establish the evaluation index system of the charging station construction, determine the weight of each index by AHP, and fully reflect the difference of each region. Then, we use the existed asymmetric Nash negotiation model to determine the distribution ratio of charging stations in each region.

Charging station construction evaluation index system and weight. The purpose of the system construction is to fully reflect the needs of users, the level of economic development, traffic conditions, and environmental conditions, which can fully reflect the regional differences. Through various factors to consider the charging station demand factors, fully refined evaluation indicators. The specific weights of each index are obtained by the AHP software. Then we present the indicator system and weights, as shown in Table II.

Specific indicators are described as the following:

➢ User needs.

Number of cars: the number of cars in each area affects the demand for charging stations in each area. The larger the number of vehicles is, the greater the demand for charging

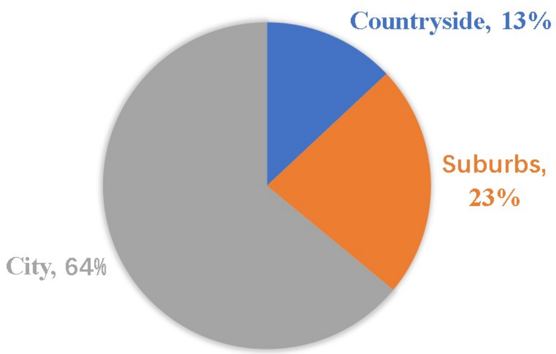

Fig. 2. The distribution programs in urban, suburban and rural areas.

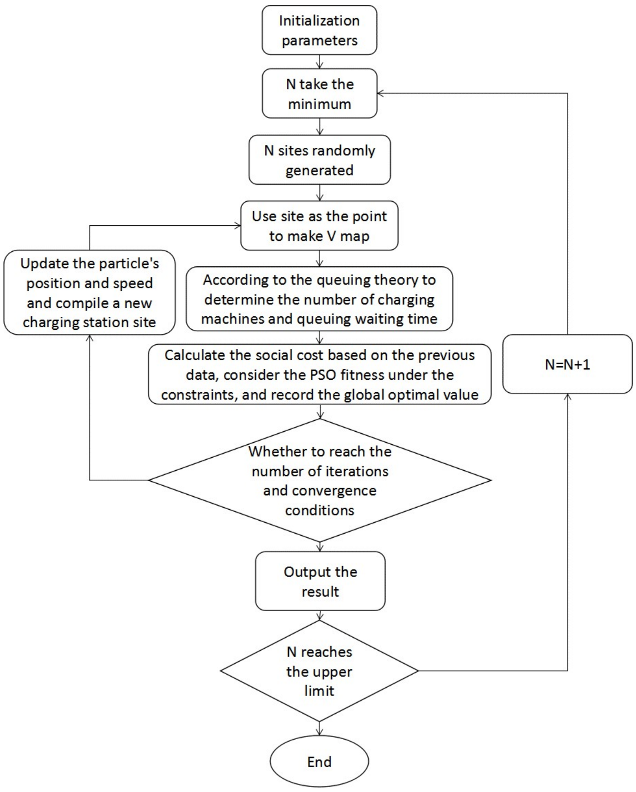

Fig. 3. The flow chart of optimization process.

stations will be.

Population density: the greater the population density is, the greater the demand for charging stations will be.

➢ Regional status.

Road network density: in areas with high road network density, there is a large number of vehicles that are aggregated, and the risk of a dead battery is relatively large, thus requiring more charging stations.

Area: the area also restricts the construction of charging stations, so we also take the area as an indicator.

➢ The level of economic development.

Regional GDP: the level of economic development in a region is closely related to GDP. Areas with large GDP can be seen as an increase in the number of electric vehicles and an increase in the amount of money that can be spent on building charging stations.

Engel's coefficient: the Engel's coefficient can reflect the wealth of a family. The lower the Engel's coefficient is, the better the family's economic situation will be. If the family economic conditions are different, the ownership and usage of vehicles are different, thus affecting the demand for regional charging stations.

➢ Environmental conditions.

Geographical environment: due to the geographical reason, it may not be possible to build a charging station in some areas, so the geographical environment is also a factor affecting the charging station. For example, it may result in less suitable for building charging stations in mountainous areas. Therefore, depending on whether geographical environments are suitable for the establishment of charging stations, they will be divided into five levels, the corresponding values shown in the Fig. 2 and Table III.

Social policy: due to the environmental friendliness of pure electric vehicles, the government may have relevant policies to support them in the future development. So it will affect the construction of charging stations. Here we define that if there is policy support, it is 1, and if not, it is 0.

Charging station distribution method for asymmetric nash negotiation model. Based on the construction system of fast and slow charging stations, we introduce the asymmetric Nash negotiation model, which is the negotiation process in each region. A regional reference evaluation indicator is to set the proportion of charging stations in other areas of the region and other regions, which strengthens the communication and communication among different regions. At the same time, it can also enhance the fairness of the regional distribution. The construction of this indicator is divided into the following two steps, *i.e.*, the regional difference allocation and the regional negotiation.

(1) Determination of regional differences in distribution programs.

First of all, according to the indicator system of regional charging station construction evaluation, we must give full consideration to the regional differences and determine the evaluation factors of the number of charging stations in each region, as given by

$$k_j = \sum_{i=1}^{m} \omega_i x_i' \tag{7}$$

where m is the number of indicators, x_i is the corresponding value of each indicator, x' denotes the standardized value of the indicator, and ω_i represents the weight of each proposed indicator.

In order to avoid the influence of the order of magnitude and unit of different data in the original data, the data should be normalized. Then, we apply the extreme value method, as given by

$$x_i' = \frac{x_i - x_i(\min)}{x_i(\max) - x_i(\min)} \tag{8}$$

Secondly, according to the evaluation factor, we determine the proportion of the number of charging stations in the total number of regions, as given by

$$\alpha_j = \frac{k_j}{\sum_{j=1}^{n} k_j} \tag{9}$$

TABLE III. GEOGRAPHIC ENVIRONMENT RATING

Completely unsuitable	Unsuitable	Suitable	More suitable	Very suitable
0.2	0.4	0.6	0.8	1.0

TABLE IV. THE DISTRIBUTION PROGRAMS IN URBAN, SUBURBAN AND RURAL AREAS.

Index	City	Suburban	Countryside
α_j	0.5846	0.2743	0.1411
γ_j	0.6352	0.2341	0.1307

TABLE V. THE DISTRIBUTION RATIO OF THE CHARGING STATIONS IN SOUTH KOREA

Regions	γ_j	The number of charging stations
Seoul	0.0760	10167
Busan	0.0734	9819
Daegu	0.0695	9297
Incheon	0.0610	8160
Gwangju	0.0642	8588
Daejeon	0.0711	9511
Ulsan	0.0769	10287
Gyeongi-do	0.0642	8588
Gangwon-do	0.0441	5899
Chungbuk North Road	0.0564	7545
Chungnam Road	0.0633	8468
Jeollabuk-do	0.0621	8307
Jeollanam-do	0.0396	5297
Gyeongsangbuk-do	0.0584	7812
Gyeongnam Road	0.0644	8615
Jeju Road	0.0654	8749

where n represents the number of regions.

According to the equation (9), we can get the distribution coefficient $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_n)$ and the following equation:

$$\sum_{i=1}^{n} \alpha_j = 1$$

Use it as a solution to the disparity in different regions and introduce an asymmetric Nash negotiation model to correct the outcome of the negotiation.

(2) Negotiation Proportion allocation plan.

According to the regional differences in the programs, the comprehensive consideration of various evaluation indicators are adopted. Through the negotiation, each region separately proposes its own negotiation scheme with the ratio of other charging stations in some other regions, and the negotiation coefficient for each region can be given by

$$\beta_j = \{\beta_{j1}, \beta_{j2}, \ldots, \beta_{jn}\} \tag{10}$$

where β_j represents the regional distribution programs given by the j-th area.

Finally, we can obtain the best and the most irrational distribution analysis by bringing all the distribution plans β_j together in each region. Assuming the best allocation plan for the j-th region is $\beta^-(j)$, and the worst distribution plan is $\beta^+(j)$, which are given by

$$\beta^-(j) = \min_{i=1\to n}\{\beta_{ji}\}$$

$$\beta^+(j) = \max_{i=1\to n}\{\beta_{ji}\}$$

(3) Calculation of asymmetric Nash negotiation model.

Combined with the expected regional disparity distribution α_j and the distribution programs proposed by each regional negotiation β_j, the distribution ratios of the final charging stations in different regions are calculated according to the asymmetric Nash negotiation model, and the final charging station allocation coefficient is set as the regional distribution coefficient, as given by

$$\gamma_j = \beta^-(j) + (1 - \sum_{j=1}^{n} \beta^-(j)) \frac{\alpha_j \beta^+(j)}{\sum_{j=1}^{n} \alpha_j \beta^+(j)} \tag{11}$$

The distribution of urban areas, suburban areas, and countryside. According to the asymmetric Nash negotiation model, we can calculate how to allocate charging stations in cities, suburbs and rural areas as shown in the Table IV. So we can get the final charging station allocation ratio: 63.52% of the urban areas, 23.41% of the suburban areas, 13.07% of the countryside.

IV. LAYOUT AND OPTIMIZATION PROGRAM OF CHARGING STATIONS IN SOUTH KOREA

A. The Analysis of Charging Station Needs in South Korea

In this section, we present the layout and optimization program of charging stations in South Kora. The overall idea of the optimization model is as shown in Fig. 3. Through the charging station demand model in part *B* of section III, we can calculate that the best number of charging stations in Korea is 137770.

B. Layout and Optimization Model of Charging Stations

Charging stations distribution plan in South Korea. In fact, South Korea can be divided into 16 regions. Through the asymmetric Nash negotiation model in part *C* of section III, we can calculate the distribution plan for the charging stations in these 16 regions. The specific results obtained are shown in the Table V.

Finally, through the software of ArcGIS, we can get the distribution of charging stations in various regions, as shown in Fig. 4.

Further optimization for the regional layout. In the planning stage and construction of charging station, the basic investment cost and social benefit of charging station should be both considered. Therefore, the consideration of the fixed investment costs, operation and maintenance costs, the time costs of taxi to charging station, the service costs of waiting time in charging station, and the costs of finding passengers are necessary. Finally, we take the minimum total social costs as the final plan.

(1) Optimized configuration of the charging stations based on queuing theory.

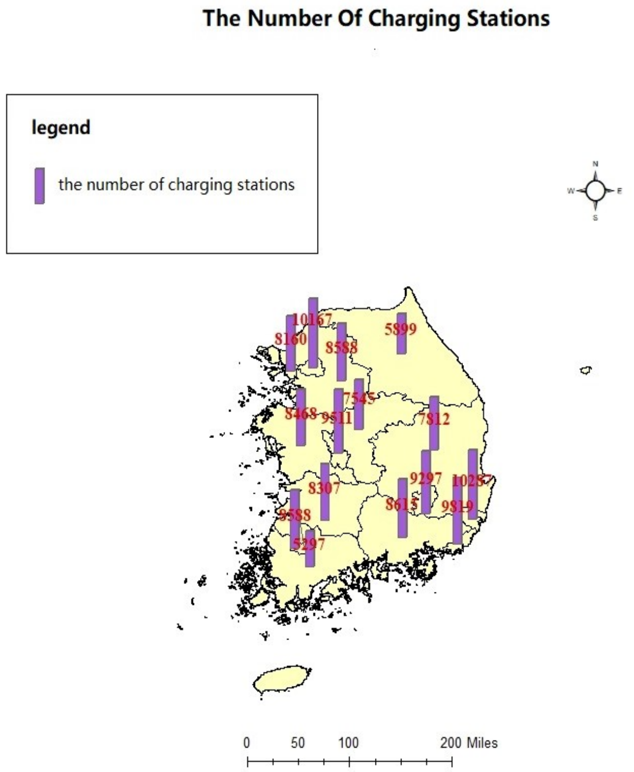

Fig. 4. The distribution of charging stations in South Korea.

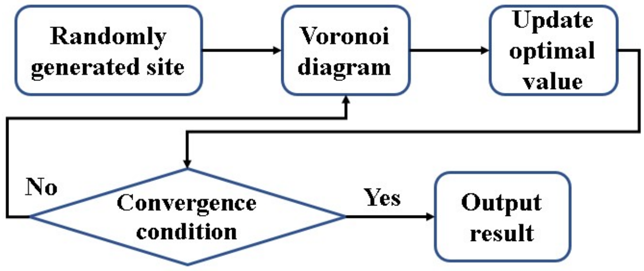

Fig. 5. The solution process.

Electricity demand for electric vehicles should be mostly filled by slow enough, while a small number of slow charging public refueling stations are considered. Taking into account the rapid charging process of electric vehicles for randomness and mobility, the electric vehicles can be charged to the fast charging station based on the M / M / s queuing theory model. Under the normal circumstances, the vehicles driving into the charging stations mainly concerned about the queue waiting time. In the case of a certain number of vehicles, the waiting time of the line decreases with the increase of the charger, and the configuration of the charging stations should conform to the expected waiting time.

If the number of electric vehicles within a charging station is n_{cv}, the probability of a single quick charge per day is p, the number of charging piles that provide fast charge service is N_{ch}, and the period of the electric car using the fast charge is t_s. Then according to the queuing theory M / M / s model, the expected waiting time for electric vehicles in line can be given by

$$W_q = \frac{N_{ch}\rho^{N_{ch}+1} p_z}{\lambda N_{ch}!(N_{ch}-\rho)^2} \tag{12}$$

$$p_z = \left[\sum_{k=0}^{N_{ch}-1} \frac{\rho^k}{k!} + \frac{N_{ch}\rho^{N_{ch}}}{N_{ch}!(N_{ch}-\rho)} \right]^{-1} \tag{13}$$

where

$$\rho = \lambda / \mu$$
$$\lambda = n_{cv} p / t_c$$
$$\mu = 1 / t_s$$

where p_z denotes the probability of all chargers idle, ρ is the charging service intensity, λ is the number of EVs that reach the charging station within a unit of time following Poisson flow, and μ is charger average service speed.

Then we set a maximum queue waiting time W_{q_max} as a constraint. By increasing N_{ch}, we can obtain $W_{q\_max} < W_{q\_max}$. In this case, N_{ch} represents the number of chargers that meet the requirements.

(2) Charging station site optimization

We first discuss the charging station and charger related to the basic investment costs. The fixed cost is a function related to the number of chargers N_{ch}. Then the construction costs in a year can be obtained by

$$C_{1i} = \sum_{j=1}^{m} (P_r + C_l + L_d) N_{ch} \frac{r_0 + (1+r_0)^z}{(1+r_0)^z - 1} \tag{14}$$

where r_0 is the discount rate, and z represents the depreciation period.

Next, we analyze the annual operating costs for charging stations. The annual operating and maintenance costs include staff salaries and equipment depreciation costs. Since they cannot be an exact and clear values, according to the initial investment cost, the annual operation and maintenance costs can be given according to

$$C_{2i} = \sum_{j=1}^{N_{ch}} N_{ch} \eta (P_r + C_l + L_d) \tag{15}$$

The third one is the costs of charging service time. Electric vehicles drive into the charging station for charging, but you need to wait in line if there is no spare charger at this time. Therefore, the less chargers the charging station is, the greater the probability of queuing and the longer the waiting time will be. However, if the allocations are excessive, they will lead to the waste of resources and increase the maintenance cost to some extent. Therefore, the configuration of charging station capacity will affect the waiting time. Finally, we can calculate the costs of time according to

$$C_{3i} = 365 \rho' q \sum_{k \in M} \sum_{i \in A_k} n_i^b W_k \tag{16}$$

where ρ represents the probability of charging, q is the cost coefficient of drivers, n_i is the number of vacated cars that traveled from i to k, W_k represents the waiting time, M denotes the charging site set, and A_k is the collection of transportation nodes within the service area of charging station k.

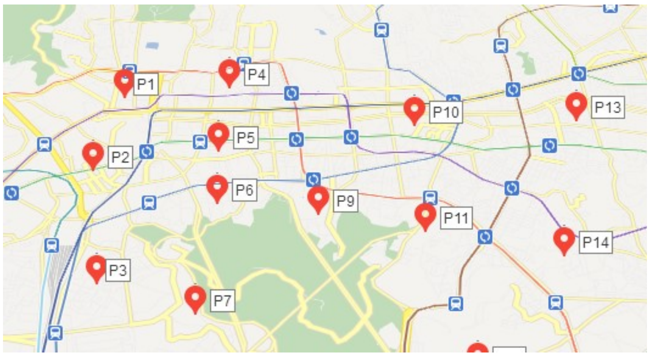

Fig. 6. The distribution of ground-truth parking and charging stations in the area.

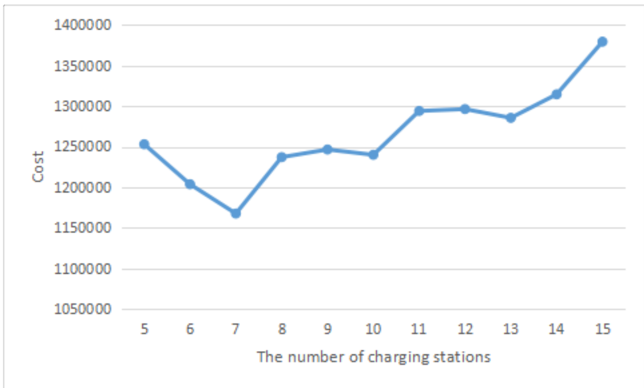

Fig. 7. The relationship between costs and the number of charging stations.

It can be clearly seen that this is a costly and laborious way of charging. The annual cost of charging the station from the time the electric vehicle generates the charging demand can be obtained by

$$C_{4i} = 365\rho' q \sum_{k\in M}\sum_{i\in A_k} n_i^b t_{ik} \tag{17}$$

where t_{ik} represents the times of a car driving to the charging stations.

In summary, the total social costs of charging station site C is:

$$C = \sum_{i=1}^{N}(C_{1i} + C_{2i} + C_{3i} + C_{4i}) \tag{18}$$

And the optimization model of charging station location is:

$$\min C = \sum_{i=1}^{N}(C_{1i} + C_{2i} + C_{3i} + C_{4i}) \tag{19}$$

which is subject to the service radius constraint of charging station:

$$D_k \le 2D_s$$

and the charging station capacity constraints:

$$\sum_{i\in I_j} P_i \le S_k e(S_k)\cos\varphi$$

where D_k represents the distance of straight line between two charging stations, and D_s represents the service radius of the charging station, S_k denotes the capacity of the k-th charging station, $e(S_k)$ denotes the charging station with a loading rate k, and $\cos(\varphi)$ is the power factor.

(3) Solution.

The problem involved in the introduced electric vehicles charging station optimization model is complicated, while the traditional optimization algorithms are not easy to solve it. Therefore, we propose to use the combination of the Voronoi diagram and particle swarm optimization algorithm to solve the problem.

The distance between the inner point of each polygon in the Voronoi diagram and the generator is shorter than the distance between the point and the other generators. This attribute corresponds to the concept of charging station service. So, the site set of EV charging station can be taken as the discrete set of points on the plane and then the Voronoi diagram can be made. The determined polygons are the service range of each charging station. The charging distance of electric vehicles in service area is less than that of other charging stations, which saves the time and cost of charging. After dividing the area, we determine the number of vehicles to be charged according to the needs of the area. Based on the knowledge of queuing theory, we can calculate the number of chargers deployed in the field through the traffic flow and population density in this area. Particle swarm optimization algorithm [54] can be used to calculate the location scheme of charging station layout and output the scheme corresponding to the lowest social cost. Finally, we present the final settlement process, as shown in Fig. 5.

C. *Model Example Solution*

In this section, let us take Jong-wu district in Seoul as an example. Jongno is located in the middle of Seoul, which is a special city in the Republic of Korea (west of Dongdaemun). It is the heart of Seoul and has the special long history, which covers an area of 23.92 square kilometers, has a total number of 69668 residents and 188733 people. The region has 2125 vehicles. According to the requirement of optimization model, the cars all turn to pure electric vehicles. As can be seen from the statistical data distribution, the quick-charging period of electric vehicles mainly lies in the afternoon of 13:00 to 18:00, the exit rate is about 95%, and the fast charging probability is 0.41. From the road network density and traffic distribution, we can roughly determine the following charging demand point, as shown in Fig. 6. Moreover, the coordinates for each point are given in the appendix.

(1) Through understanding the statistical analysis, we can obtain the following values: the service radius of a built charging station D_s is 5km. Furthermore, the unit cost of the charger P_r is \$ 31732, the average cost factor of the charging station construction C_r is \$ 87264, the average cost factor of the land lease for the charger L_d is \$ 23799, the discount rate r_0 is 0.08, the depreciation period z of the charging station is 10. The conversion ratio parameter η is 0.1 and the wait-up cost factor q is \$ 8 per hour.

(2) According to the formula of quantitative model, we can calculate the number of charging stations in the region in the range, *i.e.*, 5-15.

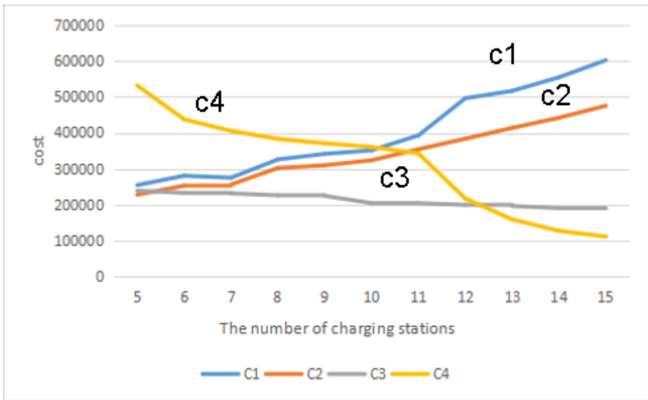

Fig. 8. The relationship between costs and the number of charging stations in four.

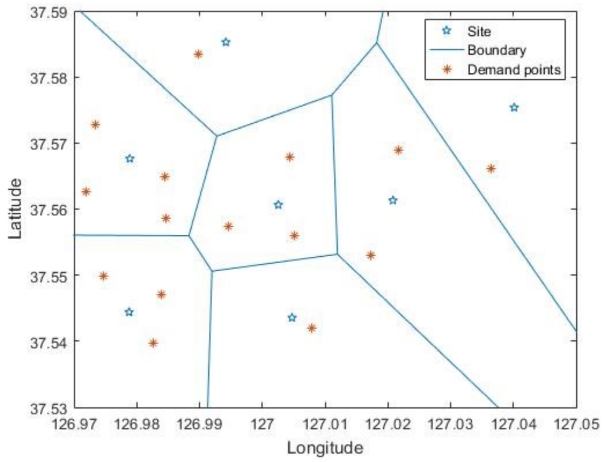

Fig. 9. The final Voronoi graph.

(3) The combination of the Voronoi diagram and particle swarm optimization algorithm is used to solve the problem. Firstly, we set the population size to 15 and the maximum evolutionary generation to 100. According to the calculation that shown in the flow chart, genetic algebra is stable after 25 generations. The output corresponds to the planning scheme of different number (*N*) of charging stations. The social costs corresponding to the different charging stations are shown in the appendix.

From the figure we can see that the optimal cost of charging station layout is 1167774 dollars and the number of charging stations is 7. As shown in Fig. 7 and Fig. 8, with the number of the charging stations increases, it can be seen that the cost of time consuming and waiting for service decrease obviously. Finally, the average cost is therefore reduced. However, with the number of charging stations increases, the construction cost and operation costs increase significantly. Therefore, if the number of charging stations is greater than 7, the cost is gradually increasing. When we are building charging stations, it not as good as possible, but should follow the principle of cost minimization.

When the number of charging stations is 7, the coordinates and capacity of each charging station site are shown in the appendix. According to the site coordinates, the final Voronoi diagram is shown in Fig. 9. It can be seen from the figure that its distribution is more reasonable. The area enclosed by each polygon represents the service area of the charging station. Their distribution on the map as shown below. Red mark shows the demand point *P* and blue flag represents the site, as shown in Fig. 10. Finally, we can refine the distribution of charging stations in Korea as the Fig. 11, in which the white flag stands for charging station.

V. Development Program

A. Direction of Development

According to evaluation factors of the number of charging stations in asymmetric Nash negotiation model, the greater the demand for charging stations in a region is, the greater the demand for charging stations will be. So, we can calculate the evaluation factors of the number of charging stations in major urban and rural areas in South Korea to show the demand level of charging stations in different regions. Eventually, charging stations are built from large to small, depending on the degree of need. Based on the available data, we selected several typical urban and rural areas to compare their needs. The final evaluation values for each area are shown in the appendix.

According to the evaluation factors of each region, we can get the results, as shown in Fig. 12. As can be seen from the figure, the demand for charging stations in cities is generally large, mostly outside the standard values and in rural areas. Therefore, in order to satisfy the demand, we suggest that charging stations be established from the city onwards, and as the number of charging stations increases, the urgency of charging stations in the region will decrease, that is, the evaluation factor will be reduced. Construction of charging stations in urban and rural areas did not begin until most cities fell to near time standards.

In combination with the actual situation, the absence of a charger will lead to a difficult charging problem for electric vehicle users, resulting in a reduced user experience, which will have the significant influence on sales. Therefore, we recommend the first configuration of the charger to address user concerns about charging to stimulate customers to buy electric vehicles.

B. Multiple Regression Analysis and Forecasting

In this section, we consider the impact of national policies to the sales of electric vehicles. Here we propose to use the regression model with dummy variables to solve this problem. Based on the distribution of the number of charging stations in South Korea to electric vehicles, we have decided to use a multivariate conic model with virtual variables. Finally, the multivariate conic model with virtual variables is established according to

$$\begin{aligned} y_j(t) &= \beta_0 + \beta_1 zx_1(t) + \beta_2[zx_2(t) - zx_2(0)]D_j \\ &+ \beta_3 zx_3(t) + \beta_4 zx_3(t)^2 + \beta_5 zx_4(t) + \varepsilon \end{aligned} \tag{20}$$

where D_j represents the virtual variable. And we can get D_j according to

$$D_j = \begin{cases} 0, i < i_0 \\ 1, i \geq i_0 \end{cases} \tag{21}$$

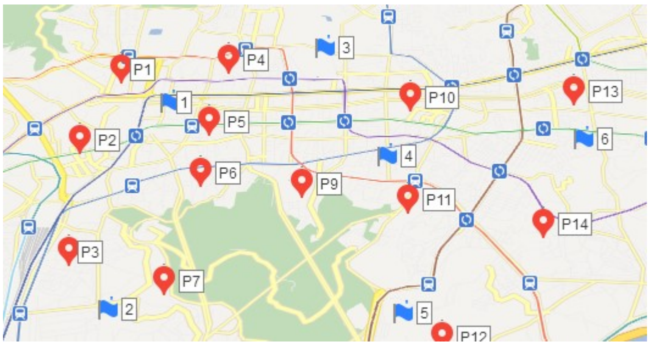

Fig. 10. The distribution of obtained parking and charging stations in the area.

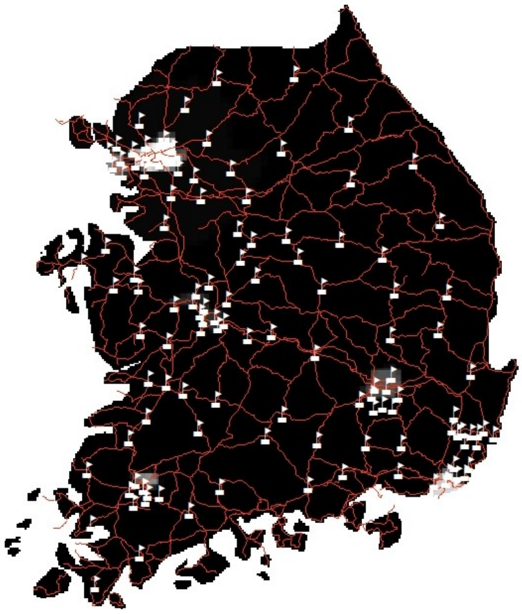

Fig. 11. The final distribution of charging stations in South Korea.

It can be understood that this is a sudden change in sales when the state has issued a policy at the time of i_0. And $y_j(t)$ denotes the percentage of Korean electric vehicles in the total number of vehicles, β_0 represents the constant term, and β_1, β_2, …, β_6 are regression coefficients. $zx_1(t)$, $zx_2(t)$, $zx_3(t)$, and $zx_4(t)$ are the levels of the regional development at the time of t, the implications of national policy at the time of t, the total number of charging stations at the time of t, and the electric vehicle development technology, respectively. And their units are billions of dollars. ε is the sum of the effects of various random factors.

In this paper, we consider the development level of battery. The battery energy density is $zx_4(t)$, which can be described by Wh/kg.

VI. The Suitability of the Optimization Model

Depending on the gap between the rich and the poor, and the density of the population, different countries will have different development patterns. Therefore, we define different development models according to the factors of regional energy reserves and regional development level.

A. Full of Oil Resources (Policy-Driven Model)

Although fewer and fewer oil resources are available in the

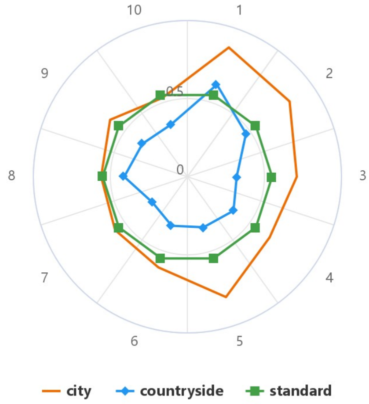

Fig. 12. Regional evaluation factors in three regions, *i.e.*, city, countryside, and standard area.

world and many countries are facing the possibility of oil depletion, a small number of countries still have enough oil resources to fully sustain the country's development needs in the coming few hundred years and beyond. Therefore, the demand for the use of electric vehicles in these areas is not large. The market for electric vehicles is still very small and the rate of development is slow. For long-term consideration, the state has to introduce policies to inject new vitality into the electric car market so that electric cars gradually come into people's lives. For different countries, we introduce a relative index of oil reserves to measure the size of a country's oil reserves, which is defined as

$$I = I_o / I_{\max} \tag{22}$$

where I_o represents the proportion of oil reserved in the world to total reserves, and $I_{\max}$ represents the share of countries with the largest oil reserves(17.73%). Here, we take $I > 0.5$ for oil-full country.

B. Lack of Oil Resources

For countries deprived of petroleum resources, there is no need for state intervention. Due to the tight supply-demand relationship, electric vehicles are bound to lead the trend of the times. For this type of country, we can be subdivided into two categories by the development model:

- City first development model.

For a large number countries, the gap between urban and rural development should not be ignored. In some areas, the rural economy is backward and the hydropower facilities are not perfect, which cannot meet the needs of charging station construction. Therefore, these countries must first develop electric vehicles in cities, and then promote the development of rural electric vehicles.

- Coordinate development mode.

In order to popularize electric vehicles in the whole country, electric vehicles should be developed at the same time in urban and suburban areas to speed up the popularization of electric vehicles.

As for the two development models mentioned above [55], because the urban-rural gap is mainly reflected in the income distribution gap, we consider a country's income distribution index & Gini coefficient, which is defined as

TABLE VI. THE COORDINATES FOR EACH POINT

Country	*k*	*G*	Development model
China	0.0615	0.465	City first development mode
Saudi Arabia	0.8860	0.447	Policy-driven mode
Singapore	Very few	0.464	City first development mode
Indonesia	0.0120	0.39	Coordinated development mode
Australia	0.0133	0.32	Coordinated development mode

TABLE VII. THE SOCIAL COSTS CORRESPONDING TO THE DIFFERENT CHARGING STATIONS

Demand points	Traffic	Longitude	Latitude
P1	340	126.973408	37.572692
P2	375	126.971935	37.562581
P3	310	126.974764	37.549908
P4	333	126.989879	37.5835
P5	343	126.984435	37.564833
P6	281	126.98474	37.558626
P7	220	126.983923	37.547125
P8	221	126.982566	37.539636
P9	238	126.994621	37.557296
P10	325	127.004431	37.567905
P11	237	127.005114	37.556023
P12	221	127.007961	37.542068
P13	238	127.021746	37.568906
P14	240	127.01734	37.552976
P15	342	127.0365	37.566074

$$G = 1 - \frac{1}{n}\left(2\sum_{i=1}^{n-1} W_i + 1\right) \tag{23}$$

The closer the value of G to one is, the bigger the income distribution gap will be. This is mainly reflected in the further widening of the gap between the rich and the poor and the widening of the gap between urban and rural development. If $G > 0.4$, we can conclude that the gap between urban and rural development is very large.

By collecting data and calculating, we get the index values of five countries: China, Saudi Arabia, Singapore, Indonesia, and Australia.

C. Technology Impact

With the continuous advance and progress of technology, the performance of electric vehicles and charging stations is getting better and better. The larger the battery capacity is, the shorter the charging time will be. Technology allows people to use the new refresh energy sources to replace previously non-renewable and polluting resources. On the other hand, due to the environmental friendliness of pure electric vehicles, more and more countries begin to attach importance to the development of electric vehicles, adopt policies to encourage development, increase the charging station infrastructure, and reduce the price of electric cars, which solves longstanding concerns about electric vehicles. Moreover, with the advent of the Internet and the arrival of the times, more and more electric vehicles dominated by shared cars appear in people's eyes. These technologies have accelerated the popularity of electric cars. We believe that electric cars will get more and more attention from all over the world. Finally, as a result of technological advances, it is likely to spread much faster than we expected.

TABLE VIII. THE COORDINATES AND CAPACITY OF EACH CHARGING STATION SITE

N	C1/dollar	C2/dollar	C3/dollar	C4/dollar	C/dollar
5	254433	227554.6	239095.9	531942.5	1253026
6	280366.7	252846.9	232862.8	437740.9	1203817
7	274910.3	256003.1	231387.7	405473.1	1167774
8	325968.3	301950.8	226074.5	383120.4	1237114
9	341528.4	309595.5	224393.3	371016.1	1246533
10	351362.5	323743	204139.5	360751.9	1239997
11	392967	354369.5	203838.2	342777.8	1293953
12	496502.6	383600.3	199333.8	216816	1296253
13	517066.3	413735.1	196018	158642	1285461
14	555132.6	442283.9	190072.1	126913.6	1314402
15	602715.4	475812.8	189541.5	111049.4	1379119

TABLE IX. THE FINAL EVALUATION VALUES FOR EACH AREA

Charging station number	Longitude	Latitude	Charge machine number
1	126.978888	37.567629	10
2	126.97878	37.544414	6
3	126.994213	37.585268	8
4	127.002549	37.560643	7
5	127.004741	37.543567	7
6	127.020812	37.561318	9
7	127.04013	37.575377	6

D. Peak-to-Peak Load Problem

In fact, it takes longer to fully charge an EV than to fuel a gasoline or other hydrocarbon-powered vehicle. Depending on the charge setting level and battery capacity (see the table below), it takes about 1 to 10 hours or more. It is worth noting that EV charging focuses on the number of miles per minute of running, instead of adding a few liters of gasoline. In a broad sense, the EV charging situation is similar in many respects to many aspects of life: how many "servers" do we need to support the expected usage requirements (people and devices).

If there is an event that predicts a storm, then a peak-peak load problem may occur. Then, all of these normal queue assumptions are invalid and must go to another analysis mode: the results will be different. As with all traffic and demand scenarios, a burst point occurs after waiting too long, because only one user can use the system at a time. Similarly, the traffic flow of the vehicle also occurs the same.

Therefore, for EVs, it is not only the number of charging stations, user needs and charging time that are important. Complementary questions are also important: whether the regional "grid" provides sufficient peak power and to what extent it will be a factor limiting peak service.

There are many factors involved in the location of EV charging station. It is necessary to make the comprehensive planning and design according to the technical level, quantity and distribution of electric vehicle, charging mode and other factors. The evaluation of charging station location is an important link in the process of charging station location. There are many factors to be considered in charging station location selection, which brings some difficulties to the evaluation of charging station location.

VII. Conclusion

Nowadays, in order to reduce the pollution of environment and save resources, more and more countries are beginning to promote new energy vehicles. With Japan as a representative, many countries popularize the new energy vehicle based on the hybrid electric vehicle. The US has also developed its own pure electric vehicles based on the Japanese hybrid dynamic, such as Tesla. For different stages of EV development, there should be different charging station location strategies. The construction of charging stations and the popularization and application of electric vehicles are a process of mutual game and promotion.

Although HEVs have shown environmental friendliness, they still have some pollution. We advocate that all countries should do their utmost to develop pure electric vehicles. In this paper, we give the following several factors that should be considered in the process of development. The first one is the infrastructure configuration. One of the important reasons for restricting the development of the electric vehicles is that the number of charging stations is not enough. If it is as dense as the distribution of gas stations, it can solve the problem that people worry about not being able to charge when they go out. If only the electric vehicles are developed, regardless of the construction of ancillary facilities, users will have difficulty in charging. And the customer's experience is also very poor. Slowly, fewer and fewer people buy electric cars. Therefore, electric vehicles and charging stations should be developed at the same time, even we can build a charging station first. And ensure that the establishment of charging station is sufficient to solve the local charging needs.

Then we considered the impact of economic development index. Areas with higher economic growth indicators may be the first to be GM electric vehicles. Therefore, we can focus on good economic areas and establish sufficient charging areas to ensure that users can easily charge. Next, the status quo of electric vehicle technology is also an important factor in the practical application process. One of the main reasons why electric cars are not yet accepted is their poor endurance. Therefore, the state may consider increasing research funds for battery research in electric vehicles, so that the battery capacity is larger and the charging time is shorter. Moreover, the price of electric vehicles plays a key role. Because the production technology of electric vehicles has some difficulty, its price has been high, resulting in the public cannot afford. Therefore, the government can introduce some subsidies for electric vehicles to encourage people to buy electric vehicles. Finally, a date should be set to ban the use of fuel-efficient vehicles and force people to replace electric vehicles, despite the complexity and inconsistency of national circumstances. Here, we propose the global ban on the usage of fuel vehicles in 2045.

The future research direction mainly includes the following key points:

●As one of the main means of transportation at present, automobile has great mobility, with the flow of the car, the demand for charging will change with the change.

●Different places in different time periods attract different traffic volume. Based on this point, it is necessary to consider the time factor and the attraction factor of traffic place to the location problem, and finally establish the dynamic location model.

●In addition to the charging stations mentioned in this paper, the charging facilities of electric vehicles also have a variety of operation modes, such as the charging piles, battery replacement stations, and so on.

●How to build a more perfect charging network for electric vehicles, so that all kinds of charging operation modes can be operated in a coordinated manner. It is another research focus in the future to make full use of charging resources, realize the convenience of charging and obtain the greatest social and economic benefits.

Appendix

In this section, we show the coordinates for each point, the social costs corresponding to the different charging stations, the coordinates and capacity of each charging station site, and the final evaluation values for each area in Table VI, Table VII, Table VIII, and Table IX, respectively.

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