Team Control Number

80386

For office use only	Problem Chosen	For office use only
T1________________	D	F1________________
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T4 ________________		F4 ________________

2018
MCM/ICM
Summary Sheet

As the tail of the heavy Falcon rocket dissipated in the atmosphere, Tesla should know that it is more difficult to hand over a reliable production to consumers than sending a car into outer space. How should Tesla find the development plan to meet the needs of customers and deliver Tesla electric cars to every family?

To solve the task 1, we make a regression analysis to the number of American cars and found that we need at least 1,463,222 charging stations after 15 years. Then, discuss the number of the charging stations by regression analysis. After calculating, we can easily know that it is impossible for Tesla to complete the switch to all-electricity in the US, even in 2030. Finally, in order to set up the charging pile more reasonably, we give the suburban space a definition. According to the research, we divide the data into three ratios of urban, suburban and rural area as 27.7%, 56.48% and 15.82%.

As for task 2, we choose South Korea as the research object and generalization of the first question model. We can calculate that they need at least 124,798 charging stations in 2018 and the distribution of urban, suburban and rural area. Then the optimal layout model of the charging station is established by using the maximum cover model and the central ground theory. The development plan of the layout for the charging station is set up at the same time. The key factor affecting the development model of our charging station is the charging demand in the future regions, which will directly determine the layout of the future charging station.

In the part of 2b, our conclusion is to build the charging stations in a balanced construction in each region, and the amount of construction is slightly larger than the demand.

When solving the problem 2c, we set up an competitive exclusion model for automobile and electric vehicle. The numerical solution of the equation is obtained by using the ode45 of Matlab. From the value, we can easily know that it takes about 13 years, 16 years, 18 years and 55 years for South Korea's electric car to reach the required percentages. The key factor that affect our competition model is the competitive advantage of the car to electric vehicles. By making sensitive analysis on these two parameters, we found that the inherent growth rate has little impact on the process of all-electricity and the competitive advantage of the automobile to electric vehicle has significant influence on the process of all-electricity.

The problem get a great change when it comes to task 3. The standard deviation elliptical method is used to get the index of population distribution equilibrium and Gini coefficient to measure the uneven distribution of wealth in countries. Discriminant analysis realizes the classification of equilibrium country and gives the criterion.

In task 4, through the calculation progress, we can find that when the fast replacement station replaced all the existing slow charging stations, the number of charging piles will be 97% less than before. So we think that the fast changing technology will significantly reduce the number of required charging stations

In the end, we write a handout for the leaders all over the world and hope to help them to determine the most suitable strategy for the successful completion of the electrification for their country.

Key Words: Balanced Development; Queuing Theory; Logistic Population Competition; Standard Deviation Ellipse; Discriminant Analysis

Content

1 Introduction

1.1 Background

The modern way of life and the way of production are proud of human beings, and we have to face the reality of resource scarcity and ecological imbalance. The serious energy and environmental crisis caused by this situation is universal in all countries of the world. Therefore, governments are attaching more and more importance to the development of electric vehicles to effectively alleviate the energy crisis and promote social and economic development.

With the continuous development and progress of electric vehicles, it is necessary to consider the planning and construction of the charging station, and its right place to be built in the city.

2 Problem Restatement

The problems that we need to solve in this paper are:

To study the two different types of tesla charging stations in the United States, and determine that whether electric vehicles can have a full implementation in US. How many charging stations should be built to meet the needs, and try to find the best strategy to distribute them between urban, suburban, and other places.

Determine an optimal quantity and distribution for the charging station and choose the best place to build them if the cars in South Korea can all changed into electric vehicles. Give some advice for South Korea to invest the chargers, and work out whether should build the charger in city first, or doing the project both together. To install the charger first or it is better to buy a car before build up the charge station. Find out the key point that effect the plan most. Have a plan for the full evolution to electric vehicles in South Korea. Describe the timeline, and how the timeline will be changed by the key factors.

Is the plan still work in different countries with dissimilar conditions? Discover the key factors that stimulate the network become more consummate. Then discuss the practicability to set up a classification system in group.

Explain how do the new transportations and new science affect the analysis of the increasing Purchase and use of electric vehicles.

Write a page of guided paper which include the key factors that should be considered by the leaders from different countries who are attending an international energy summit.

3 General Assumptions

- Each charging station has 8 charging piles.
- Electric cars are equal to traditional cars when they reach the saturation.
- The idea of an electric car growth plan does not consider the political, military, and other effects of force majeure

4 Model Parameters

Symbol	Definition	Unit
N	Total number of cars in a country	-
S_b	Available driving mileage once every charging	miles
S_d	Average annual mileage per car.	miles
T	The number of driving days per year.	-
μ_1	Supercharger service efficiency	cars/h
μ_2	Destination charger service efficiency	cars/h
B_0	The number of daily charging demand in a country	-
N_{cp}	Total Demand of charging piles	-
T_w	Average daily service time	hours
D_m	The maximum number of cars that a station can serves every day	-
r_1	The inherent growth rate of electric vehicles	-
r_2	The inherent growth rate of traditional cars	-
α	The competitive advantage of traditional cars over electric vehicles	-
β	The competitive advantage of electric vehicles over traditional cars	-
N_1	The maximum number of electric vehicles allowed in a country	-
N_2	The maximum number of traditional cars allowed in a country	-
x_1	Evenness index of population distribution	-
x_2	Gini index	-

4 Model Construction

4.1 Installation of Charging Station Model

4.1.1 Total Number of Charging Station

We assumed that every charging station have 8 chargers. Based on the population data of the years in the United States, we made a linear regression analysis of the population. Under the assumption that the US auto ownership rate has not changed considerably in the next 15 years, the total number of cars in the United States in 2030 is calculated. We supposed that the ownership in United States per capita passenger cars are 0.766, then we can easily calculate that the United States will have 271,561,340 cars in 2030.

Then we are going to get the data of the charging demand per day:

$$B_0 = N \cdot \frac{1}{S_b} \cdot \frac{S_y}{T} \tag{5.1.1}$$

Where:

- B_0 : The number of daily charging demand in a country
- N: The total number of cars
- S_b : Available driving mileage once every charging concerning the

current technical level. It valued as 170 miles.

- S_y : Average annual mileage per car.
- T : The number of driving days per year.
- $\frac{S_y}{T}$: The daily mileage of a car.

From the data of distance driven per person and the number of cars and each car needs to charge every 170 miles, we can get the total daily charge in the United

States: $B_0 = 51{,}676{,}526$ times.

The supercharging serves as $\mu_1 = 2\ cars/h$, the destination charging serves as $\mu_2 = \frac{37}{170} cars/h$. And according to the data we investigated $\alpha = 0.2907$.

According to the model of M/M/1/∞/∞ in Queuing theory:

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)} \le t_w \quad (5.1.2)$$

$$\lambda = \frac{B_0 \cdot k_1}{N_{cp} \cdot T_w} \quad (5.1.3)$$

Where:

- k_1 is the proportion of non-vacancy service vehicles accounted of service throughout the day. $k_1 = 0.9$ (The charging station is not in a busy state all the time, and there will be a certain period of demurrage in the service desk. The time of waiting for a customer to arrive at a service stage, including an invalid service time)
- N_{cp} is the number of charging piles.
- T_w is the longest time that the charging pile can run.

From ***(5.1.2)*** and ***(5.1.3)*** we can get:

$$N_{cp} \ge \left\lceil \frac{B_0 k_1}{T_w\, \mu}\left(\frac{1}{\mu t_w}\right) + 1 \right\rceil \quad (5.1.4)$$

Considering that we have two kinds of charging piles, we can rewrite the formula ***(5.1.4)*** as:

$$N_{cpi} \ge \left\lceil \frac{B_i k_1}{T_w\, \mu_i}\left(\frac{1}{\mu_i t_{wi}}\right) + 1 \right\rceil, i = 1,2 \quad (5.1.5)$$

Set as:

$$u_i = \frac{k_1}{\mu_i T_w}\left(\frac{1}{\mu_i t_w}\right) + 1 \quad (5.1.6)$$

$$N_{cpi} = B_i u_i \quad (5.1.7)$$

According to the equation ***(5.1.7)*** we can get:

$$B_i = \frac{B_0}{1 + \frac{u_1 \rho_2}{u_2 \rho_1}} \quad (5.1.8)$$

Where $_1$ is the proportion of supercharging, $_2$ is the proportion of destination charging piles. Then we get:

$$N_{cp} = \sum_{i=1}^{2} N_{cpi}\ , i = 1,2 \qquad (5.1.9)$$

Then we get the data of $_1$. According to $_1$, we can calculate the whole number of charging piles by equation ***(5.1.7)*** and ***(5.1.9)***.

Thus, N_{cp} =11,705,777, so the number of the charging station is 1,463,222.

4.1.2 Charging stations in urban, suburban, and rural areas

Because in most cases the definition of urban, suburban and rural areas is not very clear. We developed a standard definition of suburban that reflects what residents experience.

A suburb is a mixed-use or residential area, existing either as part of a city or urban area or as a separate residential community within commuting distance of a city. In most English-speaking countries, suburban areas are defined in contrast to central or inner-city areas, but in Australian English and South African English, suburb has become largely synonymous with what is called a "neighborhood" in other countries and the term extends to inner-city areas. In some areas, such as Australia, China, New Zealand, the United Kingdom, and a few U.S. states, new suburbs are routinely annexed by adjacent cities. In others, such as Saudi Arabia, Canada, France, and much of the United States, many suburbs remain separate municipalities or are governed as part of a larger local government area such as a county.

It turns out that many cities' legal boundaries line up poorly with what local residents perceive as urban. Nationally, 26 percent of Americans described where they live as urban, 53 percent said suburban and 21 percent said rural. (This comes close to the census estimate that 81 percent of the population is urban if "urban" is understood to include suburban areas.) [2]

Once we know the rural population, we can calculate the other two parts' population by the proportion above. (suburban population: rural population=53:21)

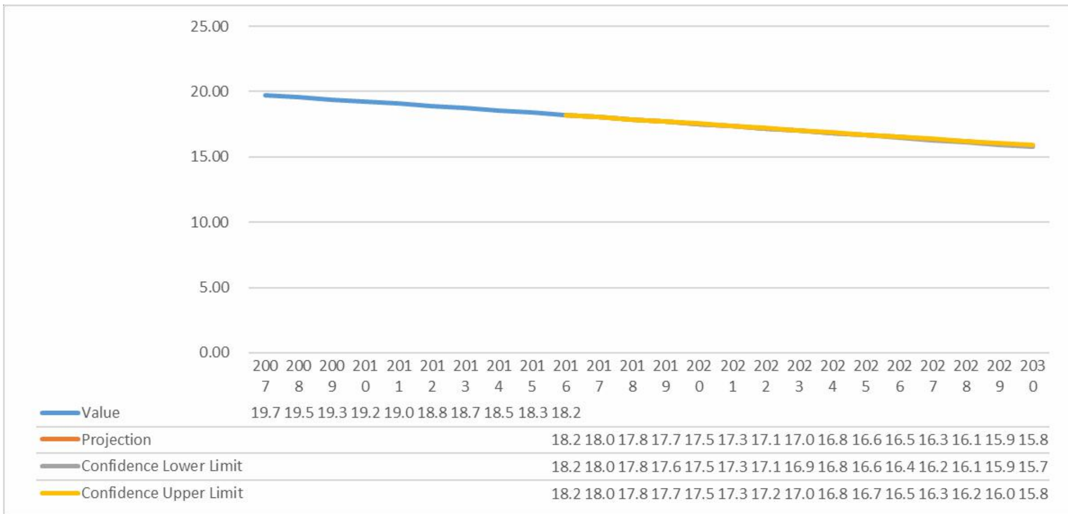


Figure1: Rural population forecast in the United States

From figure 1, we can know the United States' population in 2030, and work out the population of suburb and city. The result as follows:

Population ratio of the United States in 2030: Urban: 27.70%; Suburban: 56.48%; Rural: 15.82%.

Based on the ratio of the United States in 2030, we can get the number of charging piles that required in each region as follows:

Urban: 3,243,085; Suburban: 6,610,905; Rural: 1,851,787.

Thus, we can get the number of charging stations in different areas as: Urban: 405,386; Suburban: 826,363; Rural: 231,473.

5.2 Use the Model in South Korea

5.2.1 Test the Model in South Korea

We can use the method mentioned in ***5.1***.Based on the number of current cars, the proportion of the charging piles , and the service strength of the charging pile μ_1, μ_2, we can also use ***(5.1.7)*** and ***(5.1.9)*** to calculate N_{cp}.

We can get that = 419,059, and the charging stations are 52,382 in South Korea.

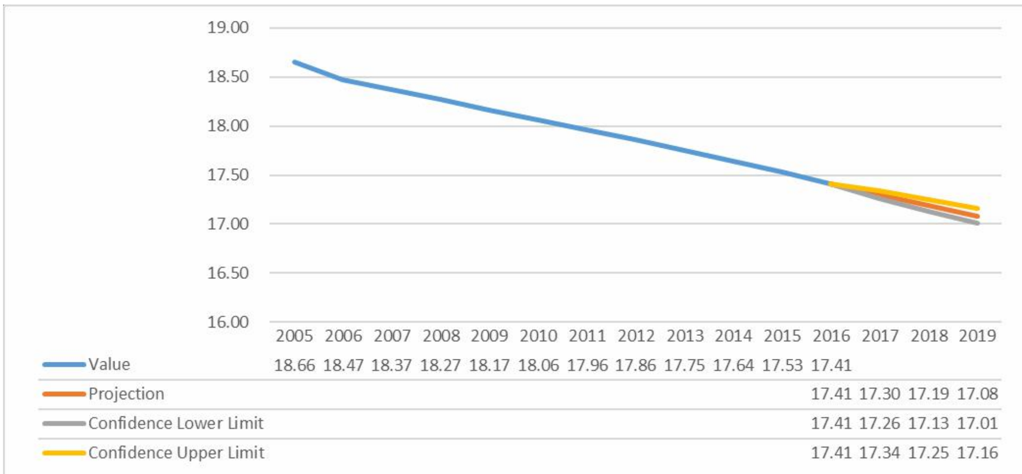


Figure2: Korean Rural population projection

From the figure above, we can get the population of South Korea in 2018, and the proportion of population in each region. Then finally get the needs of charging piles and stations in different areas in the table below:

Table1: The needs of the charging piles and charging stations

	Charging piles	**Charging stations**
The whole country	998,380.01	124,797.50
Urban	272,097.73	34,012.22
Suburban	554,660.76	69,332.59
Rural	171,621.52	21,452.69

5.2.2 Build the General Layout Model of Charging Station

➢ The Maximum Coverage Theory

In order to achieve the maximum coverage in South Korea, we build a Layout

Model of Charging Station. The model form of the theory of the center to divide the service area, the primary site method by gravity in every service area, and we supposed that we have "m" rechargeable charging stations, "n" demand points and going to build "p" stations. Set up the requirement at j as d_j, and take r_{ij} to express the distance from the station i to the demand point j.

Then we set up the decision variables as $X_{ij} = \begin{cases} 1 \\ 0 \end{cases}$

Where 1 indicates that the i alternative is building a charging station and providing service at the j demand point of the charging station. On the contrary, 0 means that build the station at i but do not provide service at the j demand point of the charging station

Then we can get:

$$\sum_{j=1}^{n}\sum_{i=1}^{m} x_{ij} \cdot d_j \tag{5.2.2}$$

Our goal is to work out the formula and get the maximum.

$$\begin{cases} \sum_{j=1}^{n} d_j x_{ij} \le D_m \ (j = 1,2,3, \dots n) \\ \sum_{i=1}^{m} x_{ij} \le 1 \ (i = 1,2,3, \dots m) \\ \sum_{i=1}^{m} \emptyset\left(\sum_{j=1}^{n} x_{ij}\right) \le p \\ r_{ij}\emptyset(x_{ij}) \le r_m \end{cases} \tag{5.2.3}$$

Where:

- D_m is the maximum number of cars that a charging station can serves in one day.
- P is the maximum number of charging stations that can only be built on the alternative address.
- r_m refers to service radius.

In our model, each of the demand point can only serve for one charging station, and the indicative function in the above formula is:

$$\emptyset(x) = \begin{cases} 1, x > 0 \\ 0, x = 0 \end{cases}$$

➢ The Central Ground Theory

The determination of the scope of service is in fact the maximum service radius of the charging station. It should be aimed at the convenience of electric vehicle users charging.

In the initial stage of promoting the use of electric vehicles, the number of pure electric vehicles is relatively small. At this time, the service scope of charging stations is larger, and the number of charging facilities is infrequency. With the increasing number of electric vehicles, the service radius of the charging station will be gradually shortened, and the number of charging stations should be increased to meet the needs of the users. [3]

We assumed that the maximum time for a driver to find a charging station is 10 minutes. When the driver finds that the battery is not enough, he tries to find a charging station near the nearest minute to recharge the vehicle.

Based on the central ground theory, we can get:

$$r_m = \frac{V_{car} \cdot t_f}{\lambda_s} \tag{5.2.5}$$

Where:

- V_{car}: The speed of a vehicle (km/h)
- t_f: The longest searching time that the customers use.
- λ_s: The curvature coefficient of the road. The ratio between the actual traffic distance and the linear distance between two points.

D_m can be calculated in the equation shown below:

$$D_m = 16 \cdot 8 \cdot [\alpha\mu_1 + (1-\alpha)\mu_2] \tag{5.2.6}$$

So, we can get $D_m \approx 94.18$. Thus, the maximum number of cars that a charging station can serves in one day is almost 95.

Figure3: The primary site we choose   Figure4: The development period network

5.2.3 Taking South Korea as an Example to Solve the Model

Our paper starts with the model of network layout theory to divide the service area, and we can choose the service area by this theory. Because the site of the center of gravity method may not be achieved in reality, we need to choose a coordinate near feasible site as an alternative site.

Then calculate the distance matrix of each demand point and each alternative charging station.

We can use the Lingo software to solve the equations ***(5.2.3)*** and ***(5.2.4)***, and get the optimal charging station layout according to the *General Layout Model*.

5.2.4 Commercial Model of Electric Vehicle Charging Station

Due to the short range of electric vehicles and the lack of charging stations, it is difficult for consumers to use electric vehicles to complete all their travel needs and this make them feel nervous and generate anxiety.

According to the literature"The Commercial Model of Electric Vehicle Charging Station", we can get the anxiety $\lambda(t)$ as:

$$\lambda(t) = \frac{t}{d_c}\lambda \qquad (5.2.7)$$

Where:

- λ: is an exogenous parameter that represents the initial anxiety of the consumer.
- d_c is the length of a linear city.
- t: is the average distance between two charging stations

Then we can get the consumer purchase benefit:

$$[1-\lambda(t)]\theta - p + b \qquad (5.2.8)$$

Where:

- θ: A random variable. A consumer can get a value if he uses an electric car to complete all his travel needs.
- p: The sale price of an electric car.
- b: Government subsidies

We can know from the above equations that build the charging station first can reduce people's anxiety effectively.

Without the charging station: $t = d_c$, $\lambda(t) = \lambda$

Have a charging station: $t = \frac{1}{2}d_c$, $\lambda(t) = \frac{1}{2}\lambda$. Then it lowers the anxiety of people and raises the enthusiasm to by the electric vehicles of consumers.

In summary, the economically developed areas government or companies should build more charging stations according to the amount of car purchases by consumers. This is mainly because that the relatively high economic level of the users who with their own garage value the convenience of products more than the costs of small, pure electric cars.

5.2.4 The Competitive Exclusion Model of Biological Groups

Choosing the competitive exclusion model of biological groups to simulate the market competition of electric vehicles and traditional automobiles. We assumed $x_1(\ )$ as the number of electric vehicles on the change of time variable t, and $x_2(\ )$ as the traditional automobiles on the change of time variable t.

Then we can write the competitive exclusion model of electric vehicles and traditional automobiles:

$$\begin{cases} \frac{dx_1}{dt} = r_1 x_1\left(1 - \frac{x_1}{N_1} - \frac{\alpha x_2}{N_1}\right) \\ \frac{dx_2}{dt} = r_2 x_2\left(1 - \frac{x_2}{N_2} - \frac{\beta x_1}{N_2}\right) \end{cases} \qquad (5.2.9)$$

Where:

- r_1: The inherent growth rate of electric vehicles

•r_2: The inherent growth rate of traditional cars.

•N_1: The maximum number of electric vehicles allowed in the country.

•N_2: The maximum number of traditional cars allowed in the country.

•β: The competitive advantage of electric vehicles over traditional cars.

•α: The competitive advantage of traditional cars over electric vehicles.

To make electric cars completely replace traditional cars, we need to let the autonomous equation above to reach the balance point $P_1(N_1, 0)$. According to the equilibrium stability criterion of the autonomous equation, if and only if $N_1 > \frac{N_2}{\beta}$ and $N_2 < \frac{N_1}{\alpha}$ established, we assumed that $N_1 = N_2$. Then we get:

$$\beta > 1, \alpha < 1 \quad (5.2.10)$$

So, we can rewrite the formula (5.2.4.2) as: > 1 > , and only when the data turned into this, can electric vehicles replace the traditional automobiles.

Because of the autonomous equation above is very hard to work out, we make use of numerical solution function Ode45 in MATLAB to solve the problem. Where the inherent growth rate in the model $r_1 = 0.3$, $r_2 = 4.7$. We hope the value that r be obtained can calculated and has a very small error with the historical data.

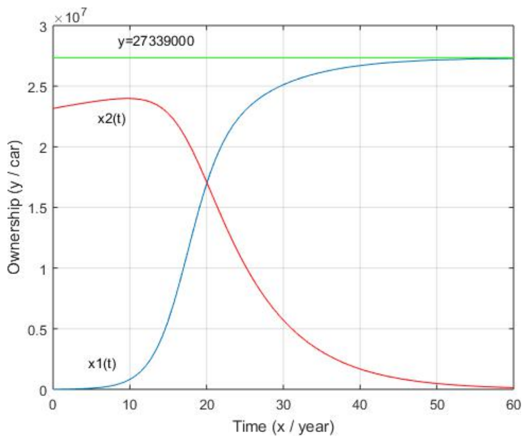


Figure5: The electric vehicles and traditional cars' quantitative changing trend in South Korea from 2018

Where the red line is for the traditional cars, the blue line is for the electric vehicles, and the green line is the peak value that the cars can get. When the blue line reach the green line, it means that everyone switched to all-electric vehicles in the country.

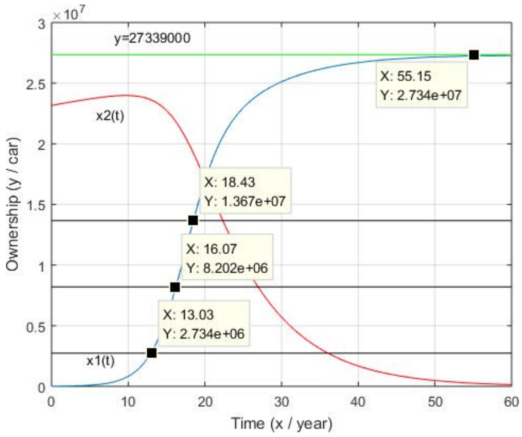


Figure6: Data analysis of the figure X.

From the first point we can know that it needs 13.03 years to turn cars to be 10% electric vehicles. The second point tells that getting 30% electric vehicles needs 16.07 years. Third point means that we need 18.43 years to get 50% electric vehicles.

5.3 Consideration of regional differences

We established a model to find out the regional difference coefficient of each country, and based on this coefficient, we analyzed the different countries.

5.3.1 Use the Gini Coefficient to measure the degree of distribution imbalance.

According to the data given by the World Regional Wealth Statistics Bureau, we can get the two types of countries' Gini coefficient.

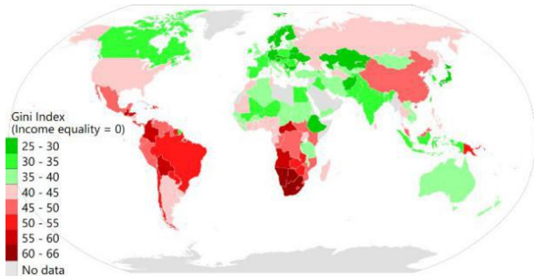


Figure7: The Gini Index of the world

5.3.2 Standard Deviation Ellipse Algorithm

If the data of the country is hard to know well, we can build another model to solve this problem. We assumed that x_1 is the proportion of the land area that contains 50% population account to the whole country's. The land area is set up as S_W. We can get the two kinds of country's population distribution by standard deviation ellipse algorithm.

According to the equation of standard deviation ellipse:

$$\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2 = s \qquad (5.3.6)$$

Because one point on a plane can be expressed by only 2 coordinates, we can use the determined confidence coefficient, such as 95%, and search the chi square distribution table with 2 freedom degrees to calculate equation ***(5.3.5)*** to get the value of S.

The standard equation after converting to an ellipse:

$$\frac{x^2}{s\sigma_x^2}+\frac{y^2}{s\sigma_y^2}=1 \tag{5.3.7}$$

As we know that the data of the major axis semidiameter “a” and minor axis semidiameter “b” of the ellipse is:

$$a=\sqrt{s}\sigma_x\,,b=\sqrt{s}\sigma_y \tag{5.3.8}$$

Finally, we get the data about the standard deviation ellipse:

$$S_c=\pi ab=\pi s\sigma_x\sigma_y \tag{5.3.9}$$

Where S_c is the population concentrative area in coordinate.

$$S_r=\eta^2\cdot\pi\cdot s\sigma_x\sigma_y \tag{5.3.10}$$

Where S_r is the real value of the area, and η is the map scale. From the map we researched that η equals 100.

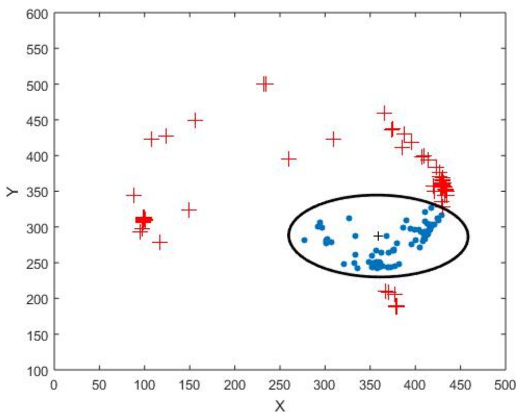
Thus, we can calculate x_1:

$$x_1=\frac{S_r}{S_w} \tag{5.3.11}$$

Then we get the evenness index x_1

Select some typical countries as test samples. According to fisher discriminant method and distance discrimination, we can use the software R to analysis the test sample. Then use the data we analyzed from R to check the return accuracy and draw some intuitionistic figures for people to have a clear visual perception.

Unbalanced country:



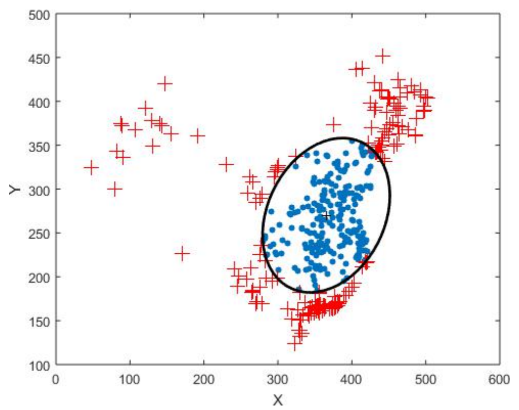


Figure8: The population distribution of Australia Figure9: The population distribution of China

The red cross in the figure is not in the 50% circle, and the blue point have the opposite meaning. You can see in the figure above that there are some areas in the ellipse that are not in the land of Australia, it do have some error in the calculation of the index $_1$. But considering that the area of this part accounts for a small percentage of the total area of Australia, it can be ignored when doing analysis.

Balanced Country：

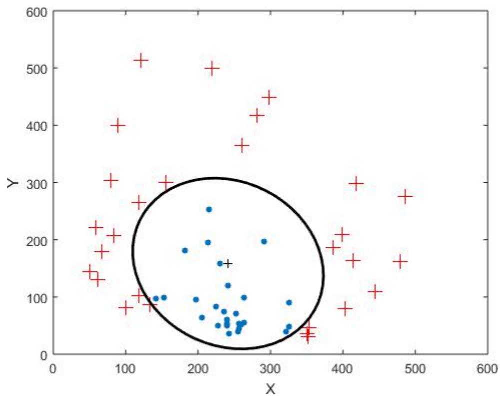


Figure10: The population distribution of Uruguay

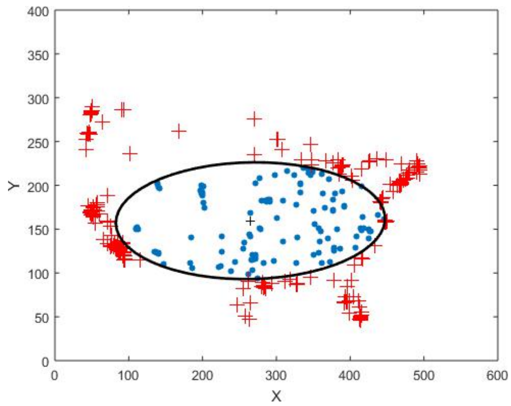


Figure11: The population distribution of US

5.3.3 Discriminant Model

Because of the large regional differences in different countries, we assumed x_1 as evenness index of population distribution. Based on the population density from high to low, we can get x_1 from the proportion of the population concentrated area accounted for the proportion of land in the country. The smaller the x_1, the more concentrated the population.

Next, we consider about the distribution of wealth and ordered the province from high to low. Then we can get x_2 as the proportion of 90% place that concentrate on wealth with the land area. The smaller the x_2, the more concentrated the wealth.

Finally, we can get the regional difference coefficient:

$$P_i(x_1, x_2)\ , i = 1,2,3 \dots n \tag{5.3.1}$$

Where i means the number of countries.

We can use formula (5.3.1) to calculate the coefficient of regional difference in some typical countries:

Table 3:Regional difference coefficient of typical countries

	Country	Evenness Index of Population Distribution	Gini Coefficient
1	China	0.2991	0.422
2	Indonesia	0.2541	0.395
3	Australia	0.2268	0.349
4	Saudi Arabia	0.3633	0.459
5	Singapore	0.3808	0.464
6	Russia	0.0967	0.377
7	United States	0.3409	0.41
8	South Korea	0.4248	0.313
9	Ireland	0.2475	0.319
10	Uruguay	0.4002	0.417
11	Japan	0.2922	0.321
12	German	0.3205	0.314

First of all, China, Indonesia, Australia, Saudi Arabia, Singapore and Russia are regarded as unbalanced countries. United States, South Korea, Ireland, Uruguay, Japan, German are on the contrary. According to the national development balance standard, this classification is reasonable.

The countries above will be represented by Numbers 1~12. In order to test the accuracy of our discriminant model, Australia and Saudi Arabia, are randomly selected from the sample function of the R software, and select Ireland as a test sample of the balanced country, the rest were used as training samples.

The discriminant result:

Table4: The result of equilibrium country discriminant

Unbalanced Country	Balanced Country
China	South Korea
Indonesia	Ireland
Australia	Uruguay
Saudi Arabia	Japan
Singapore	German
Russia	
United States	

It was found that three randomly selected samples were all correct, and the rest of the training samples are correct except for the United States, and the total correct rate is greater than 91%.

Thus, according to the Evenness Index of Population Distribution and Gini coefficient, the distance discrimination can be used to judge whether a country is balanced. But the United States, which was supposed to be a balanced country, was identified as an unbalanced country. To go further study, comparing the two indicators of United States, Evenness Index of Population Distribution and Gini coefficient with unbalanced countries, it is found that the two indicators of United States are indeed close to the mean of unbalanced countries. In particular, the Gini coefficient of 0.41 has exceeded the "warning line" of income distribution gap and the relative error is less than 3% with the Gini coefficient in unbalanced countries. This may be that our model does not consider more balanced indicators. If we have more time, we will further select the appropriate indicators to better measure the balance of the country.

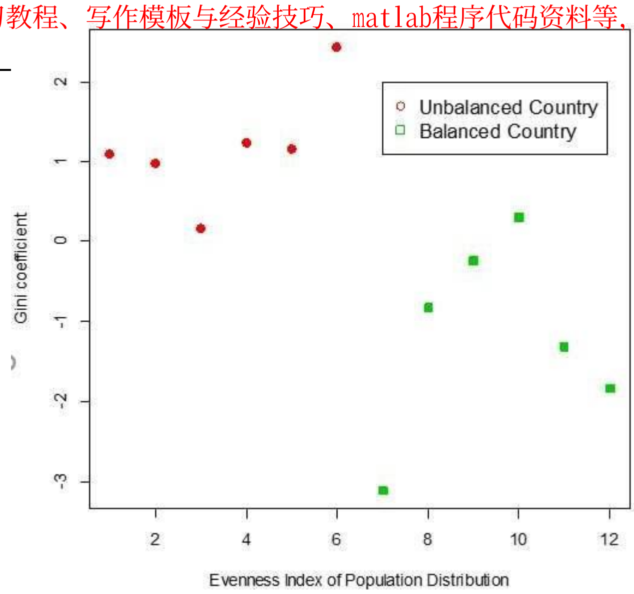


Figure12: The discriminant graph of equilibrium state and unbalanced country

Through the above image, it can be seen more intuitively that the two indexes, the Evenness Index of Population Distribution and the Gini coefficient, can be used for discriminant analysis, and will effectively classify balanced and unbalanced countries.

In summary, martensite distance can be used to distinguish whether any country is a state of equilibrium or not, and the criteria are as follows:

$$R_1 = \{x|d^2(x,X_1) \le d^2(x,X_2)\} \\ R_2 = \{x|d^2(x,X_1) > d^2(x,X_2)\} \quad (5.3.2)$$

Where d is the distance and can be calculated:

$$d(x,X) = \sqrt{(x-\mu)^T \Sigma^{-1}(x-\mu)} \quad (5.3.3)$$

Where Σ is the covariance matrix. $\Sigma > 0$

Then we can get:

$$w(x) = (x-\mu)^T \Sigma^{-1}(\overline{X_1} - \overline{X_2}) \quad (5.3.4)$$

w(x) is the distance discrimination function for two objects, then we can rewrite ***(5.3.2)*** as:

$$R_1 = \{x|w(x) \ge 0\} \\ R_2 = \{x|w(x) < 0\} \quad (5.3.5)$$

According to the regional difference coefficient table of each typical country, the mean vector of the two types of equilibrium countries and unbalanced countries can be calculated by ***(5.3.5)***:

$\overline{X_1} = (0.270132, 0.411)$, $\overline{X_2} = (0.337678, 0.349)$

Observe the Gini coefficient of the two types of country, the equilibrium countries' income is relatively reasonable and unbalanced countries' income gap are large. This is further proved that our discriminant method is effective.

In summary, we can calculate the regional difference coefficient *x* by the formula ***(5.3.1)***, and ***(5.3.5)*** can be used to determine whether the country is a state of equilibrium.

5.3.4 The Classification System

The classification system is established according to the two types that we described before. Then we can discuss the two different ways in those countries.

- Overall growth model

The overall growth model is being used in the first group. The countries in first group are all facing the same problems: Uneven population distribution and unequal distribution of wealth.

We can divide the people from first group by have the charging conditions or not. The purchase intention of small pure electric vehicles with rechargeable conditions is most affected by the convenience of charging and maintenance services. This is mainly due to the fact that the users of their own garage have relatively high economic level. The convenience of their products is more important than the cost of electric vehicles. Therefore, the corresponding countermeasures are taken to improve the convenience of the pure electric vehicle, which can improve the consumer's willingness to buy electric vehicles.

On the contrary, the other part of people do not have charging conditions, their purchase intention of pure electric vehicles is most affected by economic and policy preferences. Therefore, on the basis of establishing and perfecting the charging conditions of electric vehicles, reducing the cost of buying and using electric vehicles can effectively improve the purchase intention of these consumers.

- Service fee dissimilation model

This model is being used in second kinds of countries. The population is evenly distributed and the wealth distributed equally in these countries. We design a service fee dissimilation model to meet the needs of people in different areas.

We assumed that current charge service fees are k dollars per kilowatt-hour. The economic development level and population density of area A to D are decreasing, so we consider that the charge of service fee is consistent with the decline trend of economic development and population density. Then we set up an area C to be the datum point, the charging fee in area C is k, and the change of the floating proportion of each step on both sides of the K element is 20%.

To sum up, based on the partition of the battery charge up service differentiation rate is greater than the current economic benefit brought by the overall charging. This is a great improvement in the shortening of the rechargeable operator's investment recovery period, and also can increase the return on investment. In this model design, it will also greatly increase the investment confidence of charging pile operators and get them to invest more.

6 The Influence of High-tech on Electric Vehicles

With the rapid development of science and technology, our life is becoming more and more inseparable from the support and progress of science and technology. Fossil fuels have been gradually replaced by the new energy sources, and auto sharing and self-driving cars are emerging. Electric vehicles have become the most energy-efficient and environmentally-friendly means of transportation nowadays.

6.1 The influence of new transportation methods on electric vehicles

First, the three technologies of car-share and ride-share services, self-driving cars, and even flying cars are analyzed. They are expected to lead to an increase in daily charging. We take South Korea as an example to recalculate the required number of charging piles for different degrees of daily recharging. The result is shown in figure below:

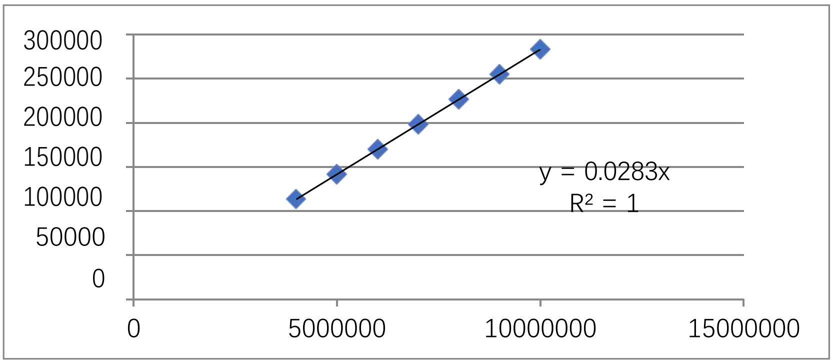


Figure13: The number of charging piles required for daily recharging

These three technologies are considered to lead an increase in the number of charging stations.

Secondly, the number of charging piles is calculated using fast changing technology. When the fast replacement station replaced all the existing slow charging stations, the number of charging piles will be less than 3%. So we think that the fast changing technology will significantly reduce the number of required charging stations.

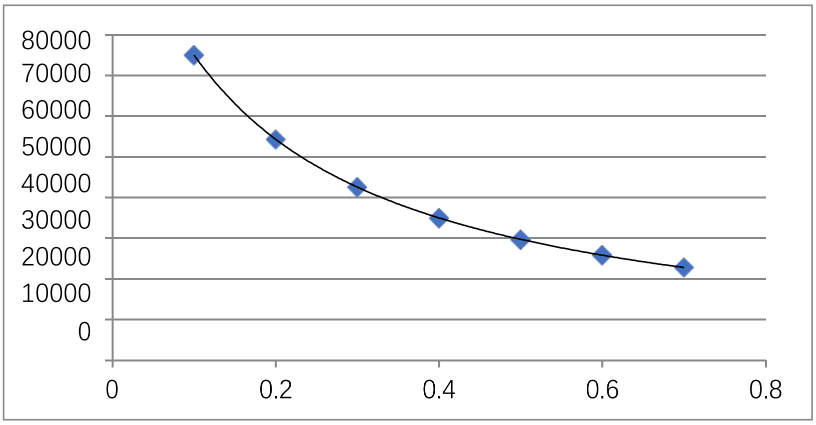


Figure14: The proportion of quick change charging stations and the number of charging stations required.

The influence of new transportation methods on electric vehicles is various:

6.1.1 Car-Share services:

According to formula:

$$(1 + a)B_0 , a \in [0,1] \qquad (6.1.1)$$

Where B_0 is the number of cars that need to be charged. The sharing mode increases the number of cars that need to be charged per day. This makes it possible for people who can't afford to buy a car to spend less money and travel with the service fee per vehicle. This must increase the daily use of electric vehicles and also increase the need for charging.

6.1.2 Self-Driving Cars:

The maturity of technology in self-driving cars field can help people who have no driving skills to get cheap "drivers", this can lower the threshold for people to buy cars. Also, it can raise the need of electric vehicles and the number of B_0.

6.1.3 Flying Cars:

Because it is not restricted by the terrain, road, traffic and other factors, the flying cars will greatly reduce the cost of people's travel. This mode of travel also can raise B_0 because it still requires batteries with rich energy.

Thus, the new transportation methods can raise the number of cars that need to be charged, and encourage people to travel with electric products.

6.2 The influence of new technology on electric vehicles

First of all, the key of a pure electric vehicle is the power battery and the new technology has a significant impact on batteries and charging station. The innovation of battery technology will promote the development of electric vehicles. The new technology can help us to develop batteries with smaller quality, larger capacity, faster charging, and a perfect charging network. It solves the problem that the specific power of the battery is not enough and that it cannot provide enough power in the start, acceleration, overtaking and climbing of the car. Have a battery with great power, the electric vehicles can easily replace the traditional cars.

Second, the new technology can solve the problems that that people think of electric vehicles, such as the continue mileage of the electric cars; safety and reliability; battery's service life and replacement cost; construction of supporting facilities such as charging station and charging pile in cities and so on. The performance of the vehicle itself has been greatly improved. It can reduce people's concerns, and raising the desire for purchase.

Third, the development of new charging piles and fast charging technology is more and more advanced. Fast charging technology helps people to gain enough power to drive long distances in a short period of time. As Tesla CEO said that if there were no charging facilities from home for a long distance, consumers would not gain a good driving experience. Fortunately, encouraged by the government and policies, the construction of this kind of fast charging stations and supercharging piles has exploded.

Finally, because of the advances in technology, the automotive industry ushered the biggest change in history. Under the dual pressure of oil energy shortage and environmental pollution, all developed countries in the world regard electric vehicles as the important development direction of automobile industry. With the emergence of electric car charging pile and some countries put forward the corresponding policy, more and more people choose to buy electric vehicles, and this trend has become increasingly apparent.

6.3 Wireless Charging Technology

With the development of batteries, we can predict the use of wireless charging technology on electric vehicles.

If the wireless charging combined with electric vehicles, people can easily supplement the power of the vehicle during the trip. It requires the use of a charging board as the power transmitter to deliver the power, and a charging device, with a built-in receiver, to receive the power. Once the charging board recognizes the valid receiver, the charging begins. Because of the charging mode and conditions are suitable for transportations, so this kind of charging way can reduce people's anxiety about looking for a charging station or a charging pile. It makes charging more convenient and can charge in anywhere and at anytime you want.

With the wireless charging technology, it can encourage people to travel by electric vehicles, and dispel people's concerns about charging. Also, can increase the sales and purchase of electric transportations.

7 The Sensitivity Analysis

The sensitivity analysis of the minimum amount of waiting time that the driver can tolerate in a charging service model for the minimum number of required charging stations

Table5: The longest waiting time with the smallest needs of stations

Waiting time	The needs of the station
0. 5	124797. 5018
0. 4	126269. 6354
0. 3	127840. 4992
0. 2	129520. 3702
0. 1	131321. 0026

It is considered that the longest waiting time has little effect on the number of final charging stations.

In the model of competition between cars and electric cars, we test the sensitivity of the inherent growth rate with the time needed to realize electrification. Set South Korea as an example:

Table6: Electric vehicle ownership of intrinsic rate of growth from 50% to 100%

r_1	t_{50}	t_{100}
0.6	18.5	55
0.8	13.9	55
1	11.1	50
1.2	9.2	50
1.4	8	45

It is found that the inherent growth rate has no significant effect on electrodynamics.

In the model of competition between cars and electric cars, we test the sensitivity of the competitive advantage of automobile to electric vehicle with the time needed to realize electrification

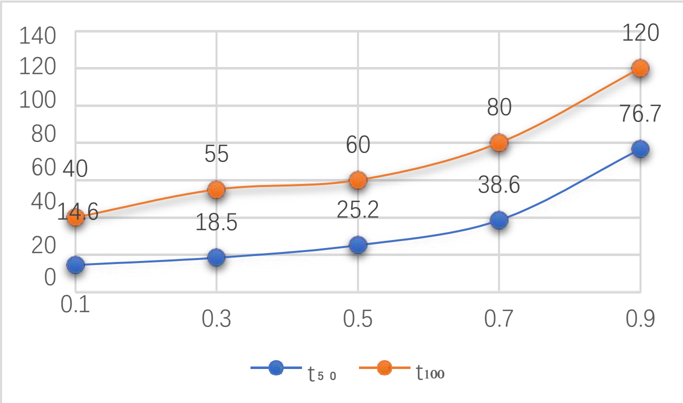


Figure15: The competitive advantage of automobile to electric vehicle and the time diagram to realize electrification

8 Strengths and Weaknesses

8.1 Strengths

- This paper related to engineering, management, statistics, and many other study fields. It covers many knowledge, such as Electric vehicle, Regression analysis of statistics, consumer purchase behavior, population competition and discriminant analysis are typical interdisciplinary frontier research.
- We propose the differentiated charging method but the design scheme of this differential charge is one of our design ideas, and it is still at a very early stage. Research and analysis only make rough plans through observable and available limited data. Its rationality and effectiveness have not been proved in practice, so the scientific of the scheme needs to be discuss.
- A more advanced wireless charging method is envisaged to make the future of electric vehicles more diversified.
- Sensitivity analysis was performed on the parameters that could not be found or estimated correctly in each model to quantify their influence on the result of the model.
- It is an innovative use of the standard deviation ellipse to measure the equilibrium of population distribution.

8.2 Weaknesses

- The sources of data sources are not wide enough so that models are difficult to solve effectively. However, the optimality of the models are always established, in other words, the model always solves the correct optimal result based on the given data. That way, the final solution will be adjusted quickly with data that are more accurate.
- Lack of sufficient support material for building the charging stations in cities, suburbs, and rural areas.

9 The handout for the leaders

Future development initiatives for electric vehicles.

Welcome to this international energy summit, and this page will help you learn more about the future trends of electric vehicles and the key factors that should be considered when you return to your country.

First of all, we hope you can do a classification based on the discriminant analysis in our thesis. According to the national conditions of your country, you can tell whether your country is a balanced country or an unbalanced one. For these two different types, we will give you some suggestions in a more accurate and specific way.

As for the balanced country, the development of electric cars has been in steady progress. In these countries, population distribution and wealth distribution are relatively uniform. Because of this, we need to increase the support of encouraging preferential policies to improve the user's enthusiasm for the use and purchase of electric vehicles. Speed up scientific research on electric vehicle is very important too. Setting a 30 to 45 years’ time to implement the policy of gas vehicle-ban can stimulates people to turn gasoline cars into electric cars.

About the countries with unbalanced national conditions, we’d better to create conditions for the use of electric vehicles for users. This can dispel consumer concerns about electric cars and improve their desire to buy. Then, improve the level of after-sales service. Give consumers a better service and make them feel free to worry about the hidden danger. Raising the subsidies next and support the purchase of electric vehicles in backward areas, so as to promote the conversion of cars to electric vehicles. Also, increasing the investment in infrastructure construction, such as charging stations, power supply networks and so on. This can help to realizing the national equalization of basic electric vehicle services, and gradually narrowing the gap between regions and the gap between urban and rural areas. We suggest that this kind of countries can set up a 60 to 75 years’ time to ban the oil car. People can know more about electric vehicles and gradually discover the benefits of electric cars in this period.

Second, we have three great suggestions for all the countries in the world. One is to set up a district charging system, and the second one is to explore the talents in electric field and develop the charging technology. Third, hold the regular international electric vehicle development and promote the technology exchange.

In the end, hope you enjoy the current international energy summit and bring more useful methods to your country.

Thanks for reading.

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