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T1 ________________	**75730**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
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2018
MCM/ICM
Summary Sheet

Summary

For environmental,economic reasons,it becomes a trend of electric cars replacing gasoline ones,which governments seek to develop policies to promote. Our paper studies how to determine the final architecture of the charging network in order to adapt to the needs of prompting the development of electric vehicles in different countries.

In task1,we establish Polynomial Curve Fitting Model to get the number of charging stations.Analyse all useful Figures by binaryzation,we find:destination charging stations lie in urban areas while supercharging stations most lie in suburban areas.

In task 2a,we established a multi-objective location model to find the best distribution in city and suburb.Then based on the micro analysis of gas-stations, we find four key-factors affecting charge-stations distribution: population density, traffic road distribution,per capita GDP.In task 2b,we choose to build all city-based chargers first and we will build chargers inresponse to car purchases.Two important factors concluded:the predicted distribution of charging stations and the utilization ratio of charging stations.In task 2c,we compare Korea with the United States and use the polynomial curve fitting model established in task 1 to find that when the total electric vehicle ratio of Korea electric vehicle reaches 10%, 30%, 50% and 100%,the time needed is 3.72,14.48,17.34,20.85 years,respectively. After the analysis,key factors is the national share of charging stations and the number of electric vehicles in use.

In task3,we establish Interpretative Structural Model and select three countries.By using key factors:population density,traffic road distribution,and per capita GDP to test the generality of the model in task2,we make suitable development plan of charging station for each countries and popularize three kinds of general plan which adapts to different situations.

In task 4,after analyzes,we conclude that the progress of innovations are beneficial to the development of electric vehicles.

In task 5,we conclude the key factors that will influence a nation's plan of migrating gas vehicles towards electric ones and setting a gas vehicle-ban date.Then we give a handout that includes these key factors.

Keywords: charging stations;distribution;Polynomial curve fitting model;Multi objective location model

Contents

1 Restatement of the Problem

1.1 Background

With the deterioration of our environment,people attach more importance to reducing the use of fossil fuels,including gasoline for cars. Electric cars are not only friendly to our environment but also beneficial to the development of our economy.For acceptable prices and stable performance,this kind of cars is more widely used in agriculture and industry.For example,Tesla manufactures electric trucks and buses to bring convenience and high-productivity to people's life.[1]

As the result,more and more people incline to drive electric cars.Besides,the announcement of European country oil ban policy also accelerates an increasing number of electric cars.At the same time,the number of charging stations should satisfy social need,such as daily use during long-distance trip.

However,where to build charging stations and how many these stations should be built have confused all the governments.In addition,it is a key point that we need to take the updating and development of charging stations into consideration.

So,we hope to build the appropriate models to solve above problems in order to satisfy the need of consumers and promote the development of electric cars.

1.2 An Overview of the problem

For environmental and economic reasons,the whole world inclines to reduce the use of fossil fuels,including gasoline for cars.Consumers are starting to choose electric cars.As a result,A few countries plane to build the charging stations for these cars.A key part of the plan is distribution and number of the charging stations.

There are major problems in the process of building charging stations:

- where to build charging stations,how many charging stations and super-charging ones should be built
- Decide the distribution of charging stations for your chosen country and define the key factors of transition from gasoline vehicles to electric ones
- Present a proposal how to install chargers for your chosen country and identify the important elements of shaping the plan
- Establish your timeline for the full evolution to electric vehicles in your country and analyse what affects your timeline

- Test proposal plan whether applies to given countries and define the significant factors of selecting different approaches to develop the network of chargers
- Comment on how technologies such as car-share and ride-share services, self-driving cars impact analyses of the increasing use of electric vehicles

2 Model Assumptions and Notations

2.1 Assumptions and Justifications

In order to simplify the course of modeling and draw some reasonable conclusions from our model, we make assumptions as follows:

- To simply the model,we only consider the public chargers,not taking private chargers into account.
- Assume that no matter in the cities or in the rural area,the charging stations are along the road.
- We suppose that the chargers installed in whole areas work well without any fault after implementing plan of building the charging stations.
- It costs some time(>30min) to charge electric cars at charging piles.
- The service capacity of charging stations in different areas is approximately identical.Only normal charging stations and supercharging stations differ in charging time.

2.2 Notations

Here we list the symbols and notations used in this paper,as shown in Table 1. Some of them will be defined later in the following sections.

3 The Solutions to the Problems

3.1 Task1

3.1.1 The analysis of the Problem

We should figure out how charging stations can be distributed between urban,suburban,and rural areas.The key point is that we should make sure the location and number of charging stations.

Table 1: Notations

Symbol	Description
p_i(i=1,2,3)	corresponding coefficient of x_i(i=1,2,3)
R-square	the value of R square
λ	transformation factor
α	endurance capacity of gasoline vehicles
β	endurance capacity of electric vehicles
N_1	the number of charging stations
N_2	the number of gas stations
y_i(i=1,2,3,4)	the number of charging stations (percentage =10%,30%,50%,100%)
x_i(i=1,2,3,4)	the time(percentage is 10%,30%,50%,100%)
I_i(i=1,2,...,n)	the index of the cities
J_i(i=1,2,...,nch)	the index of the charge stations
M	the index of the charge stations
Loc(i)	the relative coordinate of the i_{th} city
Loct(j)	the relative coordinate of the j_{th} charge station
road(I_1,I_2)	the road between the $i1_{th}$ city and the $i2_{th}$ city
d(i,j)	the distance from the i_{th} city to the j_{th} charge station
d(j,m)	the distance from the j_{th} charge station to the m_{th} charge station
r_i	density of population of the i_{th} city
s_i	per capita GDP of the i_{th} city
N_{ch}	optimal number of objective charge stations
N_{gas}	origin number of exisited gas stations
μ	electric car occupancy
Droad(j,road(I_1,I_2))	the distance from the j-th charge station to the nearst road(I_1,I_2)

According to the description of the passage,charging stations are the result of gasoline vehicles switching to all-electric in US.In the end,all the charging stations will take place of the oil stations,so we can make use of the number of existing oil ones to ascertain the quantity of charging stations.No matter it's a gas station or a charging station,it's essentially a solution to the energy supply of people's travel tools.Therefore,we can find the relationship between oil stations and charging ones according to the proportion of endurance capacity of gasoline vehicles and electric ones.

Besides,in fact,there are differences in economic development in different regions.The more prosperous the area is,the better the electric cars perform as well as the endurance capacity.Consequently,the economic development of the region will affect to the construction of the relationship between the number of the existing gas stations and the planned charging stations.We can find a reasonable range of floating proportions by consulting relevant literature.

As for the distribution of the charging stations,we plan to compare the existing distribution of two kinds of charging stations with that of population density and traffic routes and consult relative literature to draw a conclusion.

3.1.2 The Model of Polynomial Curve Fitting

We obtain the amount of charging stations and electric cars in Teslaś annual report[3][4][5] from 2012 to 2018.By drawing scatter diagram of electric cars and charging stations,we find the fact that as the number of electric cars increases,the number of charging stations increases.Through using curve fitting tool cabinet of matlab, we fit a curve with quadratic polynomial and get an ideal result.The curve is shown in Figure 1.The model is shown in equation 1.

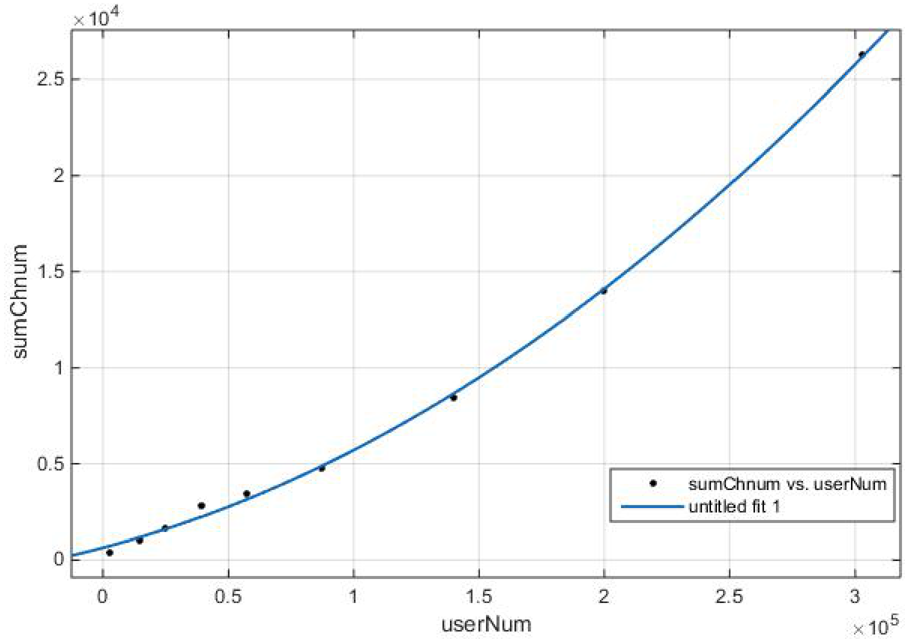


Figure 1: relationship between the number of charging stations and consumers

$$f(x) = p_1 * x^2 + p_2 * x + p_3 \tag{1}$$

p_1=1.653e-07(1.325e-07,1.981e-07), p_2=0.03427(0.0243,0.04424), p_3=638.7(142.4,1135)

Abscissa represents the number of consumers and ordinate represents the amount of charging stations.$R - square = 0.9989$.

The more closer to 1 the value of R- square obtained by the fitting curve is,the better the fitting curve is It shows that the number of consumers of electric cars increases,it is necessary to increase the number of charging stations to meet consumers' needs.In the figure,the number of electric stations is constantly increasing and will increase significantly in the coming years.

However,the number of electric cars increases as the autos are replaced for the price because most people buy electric cars for replacing original autos. The development of electric cars is in the early stage at present so the amount of charging stations increases as the number of consumers increases.Nevertheless,the replacement of the original cars won't last forever.When it increases to a certain value,it will be in a saturated state. According to the relevant data[4][5][6]which shows the changes of the total amount of the vehicles in North American,a curve graph of vehicle amounts varying with time could be drawn (abscissa represents the time while ordinate represents the amount of cars),as shown in Figure 2.

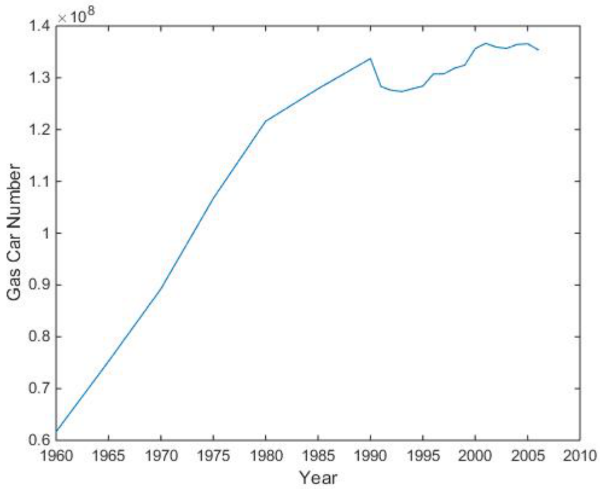


Figure 2: relationship between time and the number of cars

It can be observed that the amount of vehicles increases rapidly in the early stage,while the growth rate decreases significantly since 2000 and soon reaches a saturation status.According to the Law of supply and demand and other relevant literature, the amount of gas stations is positively associated with the amount of vehicles.The number of gas stations tends to be saturating while the number of vehicles also becomes saturated.We can draw an analogy between the development of electric cars and gasoline vehicles.Considering the actual situation where the gasoline ones are gradually replaced by the electric ones and the total amount of household vehicle is stable at present,the amount of electric vehicles can approximately equal the amount of the gasoline ones.As electric vehicles take place of the gasoline ones,gas stations will gradually be replaced by charging stations. Because a significant gap still exists in the endurance capacity between gasoline vehicles and electric ones,gas stations and charging stations can't be directly converted. Both of them ensure people's normal driving and are related to the endurance capacity.Therefore,we introduce a transformation factor λ during their transformation according to the definition of the endurance capacity of autos α and electric cars β:

$$\lambda = \alpha/\beta \tag{2}$$

Through consulting relative information about cars,we know model s series of tesla electric cars that are popular among the people can run a long distance between 400 km and 470 km,while the autos that has the same price compared to the electric cars can run a distance between 700 km and 900 km.We can obtain the conversion factor$\lambda = 2+_0.25$ by calculating the proportion of the endurance capacity of these kinds of cars.Considering the actual situation,due to the existence of economic differentiation in different regions,λ is related to the development of area.The more developed the area is,the endurance of electric cars is better.So λnimumly values 1.75 in the prosperous area.

In order to know the distribution of two kinds of charging stations in urban, suburban and subsuburban areas,we scanned the distribution of existing charging piles in Tesla website.[7][8]The overall distribution of the charging stations on the map of North America can be extracted as feature points.We obtain 22032(108*204) matrices to record the density of charging stations on the map.We compare these maps with the map of population density and the map of North American roads,as shown in the Figure 3.It was found that the distribution of normal charging stations is similar to that of population density.The distribution of supercharging stations and traffic routes has the same rule.It can be seen that in densely populated areas, there are many destination charging to meet the needs of most people.Along the highway, there are more supercharging stations, which offers fast charging in the suburbs.

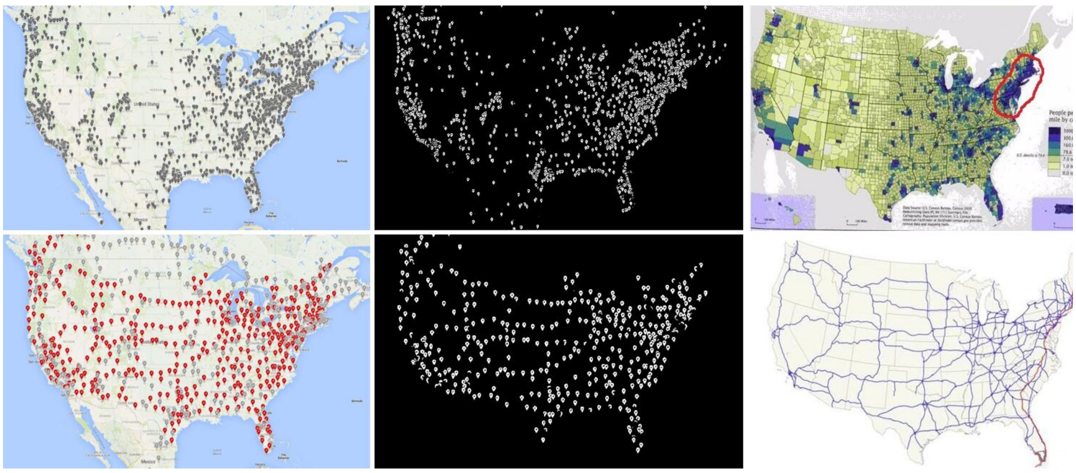


Figure 3: Comparison the distribution

3.1.3 Calculating

Through consulting the statistics of Us Transportation,we know there are $1.87 * 10^5$gas stations in US.The equation of calculating the number of charging stations N1 by using the number of gas ones N2 is as follows:

$$N1 = \lambda * N2 \tag{3}$$

It is common that changing the cars in US.Considering the endurance capacity of original cars,λ values 2.0.So we get the number of charging stations: $3.75 * 10^5$.

3.1.4 Conclusions

As more and more government announce the ban on the use of gasoline and diesel cars and Tesla produces more and more practical electrical cars, people will be willing to use electric cars as their travel tool.So we can know Tesla is on track to allow a complete switch to all-electric in the US.In the future,the electric cars will completely replace of the autos.Through above equation of the relationship between oil stations and charging stations,the number of charging stations when reaching saturation point will be around $3.74 * 10^5$.Supercharging stations enable electric cars to be fully charged in short time compared to normal charging stations,which is beneficial to the people when driving for a long distance.From 3 ,normal charging stations lie in densely populated areas,such as downtown area,while supercharging stations are built along the highways.

3.2 Task2

3.2.1 Analysis of the Problem

2a: We should know how to build charging stations to meet consumers'needs when chosen country popularizes electric cars.The number of charging stations should be determined,and from macro aspects we can establish a model to simulate the macroscopic distribution of charging stations throughout the country for meeting different needs in cities and rural areas.[3]At the same time,the key elements of the model should also be needed.

By using established Polynomial Curve Fitting,utilizing the total number of original gas stations and cars in a certain area,and analyzing the local situation to choose appropriate replacement factor lambda.Finally the number of charging stations when electric cars completely replace gasoline ones can be obtained.We plan to establish Multi-objective Location Model and use genetic algorithms[2] to solve the problem of macroscopical allocation of charging stations in cities and suburbs.There are two goals,namely improving the capacity of charging stations to meet people's needs and increasing the utilization rate of charging stations.

From micro aspects,we analyze the distribution of gas stations in two different regions in order to find out their distribution rules.Then from macro aspects,we can further analyze the factors that influence the distribution of charging stations.

2b: The task asks us to put forward a plan to build the network of domestic charging stations starting from scratch in the country that we choose,Korea.We need to figure out where we should build the charging stations first,whether our motivation is to promote people to buy electric cars or satisfy the need of charging,and what influences our plan.

It is meaningful to make full use of the conclusion in 2a where we construct a model to design the distribution of the network of charging stations in Korea in the future to build the charging stations.We know that the distribution ratio which is more than 70% in urban of charging station is larger than that in rural areas.As a result,in the early stage of building the charging stations,Korea should build all city-based chargers first to increase coefficient of utilization of charging stations.In usually,the city has a large population,a prosperous economy,where people have strong purchasing power,so we build chargers in response to car purchases.

As for key factors,we can find them according to the coefficient of utilization of charging stations and the predicted distribution of charging stations in urban and rural area.

2c: The task needs us to propose a timeline for the full evolution to electric vehicles in Korea based on our growth plan in 2b.This timeline includes the time when electric vehicles respectively account for 10%,30%,50%,100%of the total personal passenger vehicles.And in the end,we should know what are the key factors of timeline.

It is obvious that the larger the proportion of electric vehicles in domestic vehicles,the more charging stations will have to be built. In other words,we can calculate the time when charging stations occupy 10,30,50 and 100 percent of the total charging stations and gas stations in the whole country respectively.The time that we obtain equals the time when electric vehicles respectively account for 10%,30%,50%,100% of the total personal passenger vehicles.

3.2.2 The model of Multi-objective Location

We compare the distribution of charging stations needed when Korean electric vehicles are popularized to that of gas stations in same situation.Then we build macroscopic model based on microscopic analysis to determine how to arrange a certain number of charging stations to meet consumers'needs.

Ten cities, including Seoul and Incheon, are important transportation hubs in Korea as well as developed cities with a larger population density and a higher per capita GDP. In order to simulate the best distribution of gas stations in the country,we select relative information of these representative cities,as shown in Table 2. Based on the relative position coordinates of the cities,the location of some important cities and main road between cities are simulated.We take the population as the main indicator,define the levels of these cities, and use Equation 13 to visualize the images in circles.So we obtain the scope of the city,as shown in Figure 4 .

$$R_i = k_i * \ln(k_2 * r_i) \tag{4}$$

i is the city serial number,and R_i is the city area(radius) and r_i is city population (millions)

On this basis,we begin to build a multi-objective location model:

Table 2: information about cities

city	relative longitude	relative latitude	per cipita GDP(k$)	population(MM)
Seoul	45	148	31.23	9.85
Incheon	28	140	19.3	3.61
Shizong	49	110	40.9	2.3
Daeju	56	87	20.16	1.54
Guangzhou	28	26	23.97	1.21
Daegu	100	67	17.36	2.47
Pusan	119	29	20.3	3.45
Ulsan	128	48	52.53	1.17
Suwon	98	130	23.65	1.52
Chun-ju	96	154	25.44	1.61

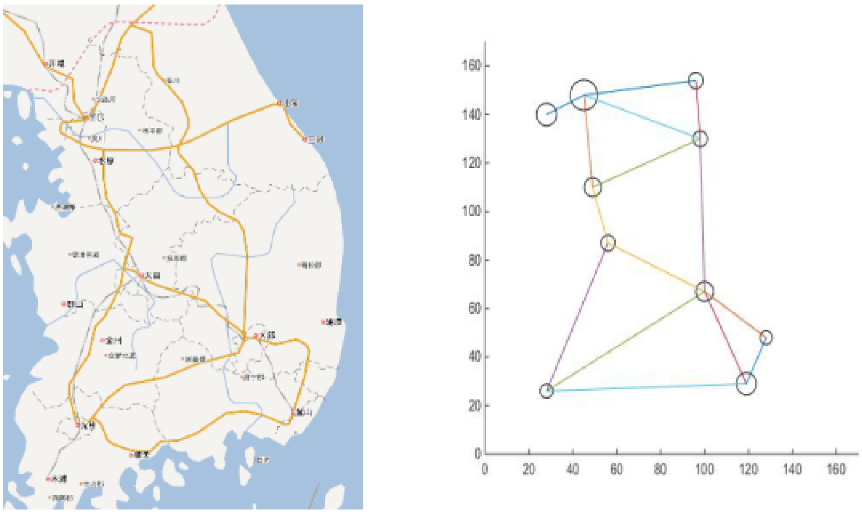


Figure 4: traffic network of cities

- **Objective 1:** Satisfy the most consumers' needs

The purpose of building charging stations in cities or suburbs is to meet users' demand for electric vehicles.Because differences in density of population,the needs between cities are different.The city with a larger population and better development has bigger demand,so charging stations center on them.The same is true on roads,and the longer the roads are, the more they need charging stations.Then:

$$max \sum_{i=1}^{Nch} r_i * s_i * d(i,j) \tag{5}$$

$$max \sum_{j=1}^{N} (r_{i1} + r_{i2})/2 * (s_{i1} + s_{i2})/2 * Droad(j, road(I_1, I_2)) \tag{6}$$

- **Objective 2:** Avoid the crowded distribution

When charging stations gather,the resources of the two charging stations will not be fully utilized due to competition.The charging stations should be dispersed as far as possible on the premise that the majority of users are satisfied.So we should enlarge the distance between the charging stations,especially those nearest charging stations.

$$max \sum_{m=1}^{Nch} d(j,m) \tag{7}$$

- **Restriction:**

Considering actual situation,the distance between the two suburban charging stations can not be too small.Controlling the distance is a necessary factor to improve the utilization of the existing resources.

$$D_{min} < d(j,m) \tag{8}$$

The charging station can't be too far away from the highway.If not,it will be very difficult for the charging stations to have vehicles passing by and waste the existing resources.

$$D_{road} < D_{rmax} \tag{9}$$

The number of charging stations is certain.According to the demand of each city and each road,a certain number of charging stations should be allocated.The sum of these components should be equal to the total amount of charging stations calculated before.

$$\sum N_{city} + \sum N_road = N_{charge} \tag{10}$$

3.2.3 Calculating

2a: If the country owns a 100% share of electric vehicles,it means that the country has a large demand of electric vehicle implements such as charging stations.Compared to the development of electric vehicles in three countries,we choose Korea.Since 2010,the amount of gas stations in Korea decreased year by year which reflects decreasing of gasoline demands. As the number of electric vehicles increases,the demand of charging stations also increase.Meanwhile,the government has also put forward some policies to promote the electric cars to replace gasoline vehicles[10].Therefore the amount of domestic charging stations steadily increases in the coming years and a lower conversion index is used to represent a higher conversion quality of electric vehicles,λ=1.75.

With existing conversion equations in task1 and the amount of gas stations counted by the RTA of South Korean,we can get a reasonable number of charging stations needed when gasoline vehicles completely are replaced.

$$N_{ch} = \lambda * N_{gas} = 21000 \tag{11}$$

Genetic algorithm is used to simulate the distribution of charging station population,whose number is 200.After 60 iterations,the value of fitness in function has reached a stable state.Table 3 shows the proportion of charging stations in cities and out of cities after simulating.Thus it can be known that the proportion of urban charging stations is higher, which means that when the electric vehicles are fully popularized,the demand in the cities is greater than that in the suburbs.Then by making full use of Multi-objective Location Model,we get ideal distribution of charging stations,as shown in Figure 5.

Table 3: stimulating of the charging stations in cities

N	total number	proportion
1	148	0.74
2	147	0.735
3	155	0.775

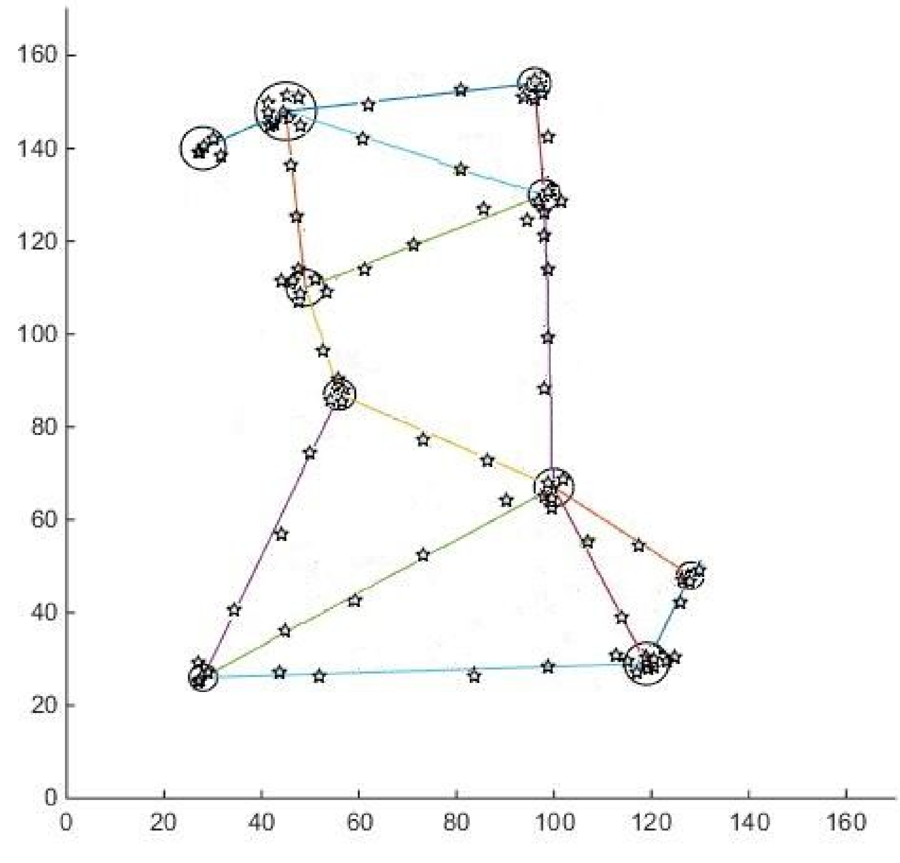
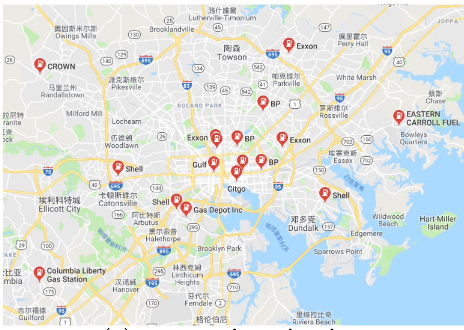


Figure 5: distribution of charging stations in Korea in the future

The pentagram symbol represents charging station and the size circle represents the area of city,and connecting line between the circles is the highway.Abscissa is the longitude,an ordinate is the latitude.

The distribution of gas stations around a city with standard radial ring roads indicates different demand of gas stations in different areas.From micro aspect,we analyze the distribution of gas stations in two different regions to find the rules for analysing reasonable distribution of charging stations.Figure 1 is a road map of a city in the eastern US with red marks representing the location of charging stations while Figure 2 is a small town in the central US,located on Interstate 80.



(a) gas stations in city

(b) gas stations in town

Figure 6: gas stations in US

As can be seen from Figure a,gas stations are densely distributed on the circular roads in the city, and most of them are located on the main roads or intersections of the roads.In the outskirts,there are a few gas stations.After measuring the distance from the nearest gas stations out of city to the city center in outskirt on Google Maps,we obtain following data ,as shown in Table 4.

Table 4: distance between gas stations

Baltimore City		Dallas City	
gas station	distance	gas station	distance
Columbia Liberty	11.8 miles	Exxon	19.9 miles
Eastern Carroll Fue	13.1milies	Costco Lewisville	18.1miles
Crown	13.7miles	Tom Thumb Fuel	10.9miles
Exxon	9.68miles	Race Thumb Fuel	14.6miles

With regard to the distribution of the gas stations on the urban fringe,we can see it is a circular distribution at a distance from the city.The radius of distribution range is relevant with the size of city,density of the population.Large cities with a dense population have a wide range of radiation.In places with high traffic such as highways,road intersections etc,the demand of gas stations is also large and these places gather gas stations.

From Figure b,gas stations gather in the town,distributing separately by a certain distance on the main road,which is related to people's needs.Vehicles traveling on the road are mobile,and they only stop to refuel when they need.In other words,there is less demand in this region.Therefore we can know:it is impossible to cause an intensive distribution of gas stations though there is high traffic on the road.

Gasoline vehicles have a 97% almost 100% share of the market at present.[12]Observing the microscopic distribution of gas stations,four main factors could be concluded as population density, road conditions, per cipita GDP and the amount of vehicles.

2b: According to the conclusion in 2a:most of the charging stations in Korea will lie in cities,as shown in Figure 5.So we choose first plan:build all city-based chargers first.

In usually,the city has a large population,a prosperous economy,where people have strong purchasing power,so we build chargers in response to car purchases when we choose first plan.

2c: To obtain the time when electric stations respectively account for 10%,30%,50% ,100% of the total personal passenger vehicles,we decide to utilize the model of polynomial curve fitting(abscissa represents the number of charging stations in Korea and ordinate represents time).As the number of charging stations in Korea increases,we can get the value of x which is the time we need by making full use of the curve. Due to lack of data on the total number of domestic charging stations in Korea in previous years,we decide to refer to the development curve of charging stations in the United States.Korea and the United States belong to the developed countries(United Nations recognized developed countries are mainly Canada,the United States,Japan, Korea,Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK, Australia, New Zealand, etc. [8]There are many similarities between the two countries in terms of economic development and social construction.As a result,It is feasible for us to refer to the development curve of charging stations in the United States.

Through searching relative information,we can know that there were 12633 gas stations in Korea in 2016.[9]South Korea's domestic gas station market is saturated and stable,and the number of gas stations will not increase by a large margin,so it is obvious that when South Korea completely stops using gasoline vehicles to drive electric vehicles, there will be 12633 charging stations.We use y_4=12633 represents the number of charging stations when there are no gas station in Korea.Then:

$$y_3 = y_4 * 50\% = 6317 \tag{12}$$

$$y_2 = y_4 * 30\% = 3790 \tag{13}$$

$$y_1 = y_4 * 10\% = 1263 \tag{14}$$

We define y_1,y_2,y_3 respectively represents the number of charging stations When it account for 50%,30%,10% of the total number of gas stations and charging stations.The values of correspond with the value of ordinate,so we can get the corresponding valus of x_i(i=1,2,3,4) from the polynomial fitting curves established in task1,as shown in Table 5.

Table 5: timeline

proportion	10%	30%	50%	100%
y	y_1=1263	y_2=3790	y_3=6317	y_4=12633
time(year)	x_1=3.72	x_2=14.48	x_3=17.34	x_4=20.82

3.2.4 Conclusions

2a: Through referring to the relevant literature,we get the number of gas stations in Korea.By using Replacement Model established in task1,we calculate that the total number of charging stations to be built when Korean cars are completely replaced by electric ones is 21000.On this basis,we determine that one objective is to increase the capacity of charging stations to meet people's needs and another objective is to increase the utilization ratio of charging stations.Then Multi-objective Location Model is established to obtain the optimal distribution of charging stations in Korea,as shown in Figure 5.Genetic algorithm is used to calculate the number and proportion of charging stations in cities and suburbs,as shown in Table 3 and Table 8.Finally we solve the macro distribution problem of charging stations in cities and suburbs of Korea.

Through microcosmic analysis of gas station distribution in two different regions,we find the distribution law of gas stations and four significant factors that influence the macroscopic distribution of charging stations:population density,road conditions,per cipita GDP and the amount of vehicles.

Table 6: coordinate of charging stations

number of charging stations	longitude	latitude
1	1.269277095022282	0.469277095022282
2	0.460463611063090	0.255204919382603
3	1.193880857239356	0.486422368837147
4	1.171279482014901	0.267443986475388
5	0.282420660935959	0.262420660935959
...	...	...

2b: Because most of charging stations will distribute in the cities ,Korea should build all city-based chargers first.The city is prosperous,full of people who have strong purchasing power,so we build chargers in response to car purchases.By referring to the conclusion in 2a,we define the key factors that shaped our proposed charging station plan are the coefficient of utilization of charging stations and the distribution of charging stations in cities and rural areas.

2c: The key factors that shape our proposed growth plan timeline are the percentage of charging stations in Korea and number of people who use electric vehicles.The reasons can be divided into two aspects:

- The more charging stations are built, the more convenience they bring to people's life, which will encourage people to buy electric vehicles and shorten the time required for popularity of electric vehicles in South Korea.
- The more people use electric cars,the greater the demand for charging stations is and the more charging stations will be built.The number of people who drive electric cars influence the number of charging stations(y) so it indirectly affects time(x).

3.3 Task3

3.3.1 Analysis of the Problem

The task asks us to test whether the model established in task2 has some generality.We discuss the different situations of Australia, China, Indonesia, Saudi Arabia, Singapore and so on.

According to the conclusion in 2a,we find out the key factors that influence the choice of using different methods to grow the network of charging stations: population density,traffic road distribution,per capita GDP.Then we can draw up the development plan of charging stations adapted to their countries on the basis of these key factors and generalize three kinds of charging station development schemes in general which can adapt to different situations after summarizing the characteristics of the three countries.

3.3.2 The model of Interpretative Structural

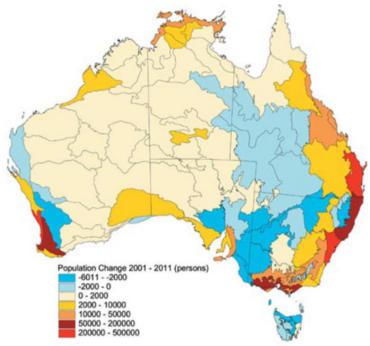
To simplify the model,we chose three of the most distinguished countries to discuss: Australia,Indonesia,Singapore

Table 7: information about Australia,Indonesia,Singapore

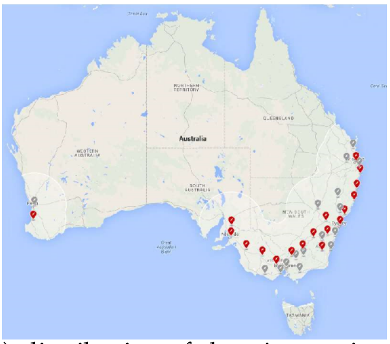
nation	GDP	situation
Australia	52214	developed nation
Indonesia	3570	developing nation
Singapore	52961	developed nation

Australia: Through consulting relative information,[9]we gather useful information of these countries,as shown in Table 7. From these information,as shown in Table 7 and Figure 7 we can know:Australia has a special geographical environment.The most majority of people live in coastal urban areas,while the central part of Australia has large deserts and few people.The country's roads are mainly built in coastal areas.In addition,Australia has high per cipita GDP and strong purchasing power.So with using the model in task 2,Australia should build all city-based chargers first. In the future, charging stations will be mostly distributed in urban areas and a few of them will be in rural areas.

(a) distriution of traffic road



(b) population density

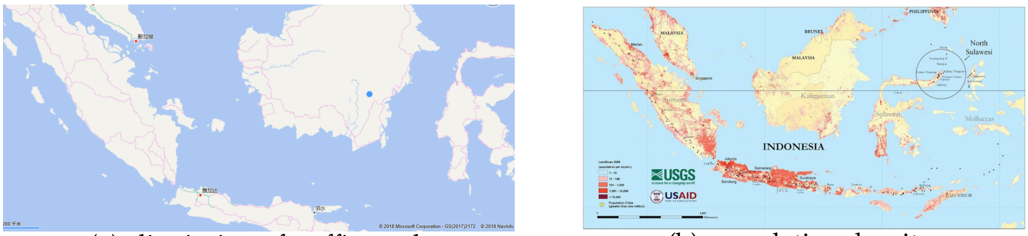


(c) distribution of charging stations

Figure 7: information about Australia

Indonesia:Based on all information(some are as shown in Table 7 and Figure 8),we can draw a conclusion: Indonesia is an island country with small land area.The land of the country is scattered and the population is basically evenly distributed on the island.There is no obvious population aggregation phenomenon. In addition,Indonesia has a very prominent feature that it has low per capita gdp.The quality of highway is low and the construction of super highway remains stagnant .According to the model in task2,the country should build charging stations both in urban and rural areas at the same time.In the future , the proportion of charging stations in urban and rural areas will be substantially the same.

Singapore: To sum up all information (some are as shown in Figure 9), we can know that it



(a) distriution of traffic road (b) population density

Figure 8: information about Indonesia

is an island country, which is characterized by a very small land area,a very high per capita GDP, a high population density and a well-developed traffic path.[10]Based on the model in task2,we know that Singapore should build rural chargers first,in order to encourage people to buy electric cars.Because people are not short of money and the transportation is developed. In the future, the proportion of charging stations in urban and rural areas will be basically the same.

Figure 9: distriution of traffic road

3.3.3 Conclusions

Through analysis of three countries Australia, Indonesia and Singapore that have very different geographies, population density distributions, and wealth distributions,we can conclude that they vary in many ways,such as in land size,geographical environment,population density,population distribution,transportation roads,per capita GDP.In order to create a classification system that can help different countries successfully migrate away from gasoline diesel diesel vehicles to all electric ones,we base our conclusions on model established in task2 to analyse the development plans of charging stations suitable for Australia and Indonesia and Singapore from these aspects:population density,traffic road distribution,per capita GDP.Three general types of charging station development programs adapted to different countries are as follows:

- **A country with a high per capita GDP, a high population density and excellent transportation(Singapore, France, Britain, Germany, etc):**Charging stations should be built from rural areas to attract people to buy electric vehicles.The distribution of charging stations in urban and rural areas in the future is basically the same.
- **A country with a high per capita GDP, a small population density,a high concentration of population in urban,and a poor domestic traffic road(Australia, the United States, etc):** We determine to build the charging stations from urban areas.In the future,most of the charging stations will be located in urban areas,and a few in rural areas.

- **A country with a low per capita GDP,high population density,and not perfect domestic transportation roads(Indonesia, Malaysia, etc):**The country should build charging stations both in urban and rural areas at the same time.In the future,the proportion of charging stations in urban and rural areas will be basically the same.

3.4 Task4

The development of science and technology has greatly promoted the change of people's travel mode, and they are often the cause of the new mode of transportation. The evolution of human transport: from the initial walk to the use of animal power and water power, the mode of transport has not been upgraded, just to let the original people do things with natural power instead.[11] Until the revolution of science and technology, with the birth of the steam engine, the mode of transportation has a big leap forward. Then with the gasoline engine and diesel engine come out, private cars are spread gradually. And This period are all inseparable from the science and technology.

But cars are used at the expense of fossil fuel consumption. Faced with dwindling reserves of fossil fuels, there is an urgent need for another possibility to ensure that human beings do not stagnate in society as a whole when their underground oil is exhausted. At present, cars, ships and planes are using fossil fuels. And electric cars are the first step in opening up this possibility.

As technology moves towards diversification, there are many alternative modes of transport, including shared cars. Because most people still can't accept the high price of electric vehicles and fixed pile charging mode, the development of electric vehicle industry is hindered to some extent.[12] To a certain degree, while sharing cars can solve the electric car parking and charging hard problem. More importantly, this is conducive to the promotion of electric vehicles. (As shown in the figure 10a:A reserved share car parking place) According to last year's global market watch, the global car-sharing market is expected to reach $ 2024[13] .In China, Didi has also announced it will create a nationwide charging network for electric vehicles and said it will meet its goal of using 1 million electric vehicles by 2020. In November last year, Didi pointed out that more than 260,000 electric vehicles had already been running on its platform. The influx of large amounts of capital will speed up the construction of tram infrastructure, such as charging stations, while promoting the popularization of electric cars.

On the other hand, the development of self-driving cars has promoted the coverage of electric vehicles and the construction of charging station. Self-driving car is a vehicle that is capable of sensing its environment and navigating without human input. Self-driving cars use a variety of techniques to detect their surroundings, such as radar, laser light, GPS, odometry and computer vision. Some of the modules of the self-driving cars are shown in the figure 10b, which are only some of the structural modules required by the vehicle itself and do not include the road interconnection system. These systems themselves require electric power and network support, particularly the former. So, in terms of self-driving, electric cars are better than traditional fuel vehicles. In fact, companies such as Tesla and Google are actively developing driverless technology, based on electric cars[14](Figure 10c: Google Pod wagon).And the growing maturity of self-driving cars technology will also feedback to stimulate universal coverage of electric vehicles.

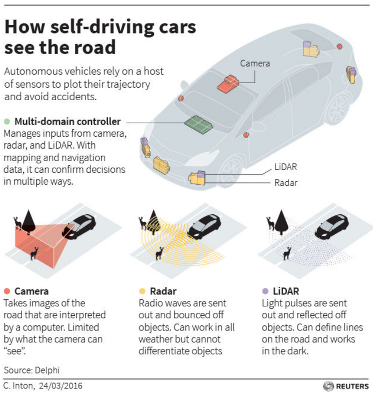
The most important resistance to the development of electric vehicles is the way in which they obtain energy sources - charging is not convenient. It is mainly reflected in two aspects; First, the charging station network construction is not perfect, many areas do not have charging pile; Second, charging is not as fast as refueling, charging takes more time than refueling. For these two aspects, the first aspect of the reasons for many, such as the region's power grid itself is not complete, and charging station needs to consume a lot of electricity, so it is difficult to establish. In addition, the terrain, flow of people, these factors analyzed above will also have a certain impact on the construction of the power station.[15] For the second aspect, technically accelerating the charging of lithium batteries has basically reached its limit, with little room for improvement. While the establishment of the rapid battery-swap stations will effectively solve these two problems. For example, a battery-swap station company could set up replacement stations in the weak suburbs of the power grid to replace fully charged batteries with used-up electric vehicles, and regularly transport the used-up batteries to other developed areas of the power grid for charging. This not only improves the power-up efficiency of electric vehicle users, but also playes a large role in amplification of charging station network. So the technology will also stimulate universal coverage of electric vehicles.

In addition to the above existing technology, flying cars, hyperloop these upcoming technology development will also have a certain impact on the development of electric vehicles. Such as flying cars should take electric vehicles as the carrier, because the general gasoline vehicle engine is very heavy which is not conducive to flight. Due to the imperfect policies and rules, flying cars will not be popular in a short period of time, but with the maturity of its technology, it will promote the development of electric vehicles. Hyperloop is an inter-city high-speed pipeline transportation system proposed by spaceX. In theory, its maximum speed can reach 1200 km/h, more than an ordinary aircraft flight speed. If the hyperloop is well developed, it would be a good choice for long-distance urban traffic.[16]But it will not have too much impact on the current development of electric vehicles. Perhaps as it matures, it will become an option for people to travel like a train or high-speed rail. Figure10d shows the planned hyperloop between Kansas, Colombia and ST Louis on January 31.

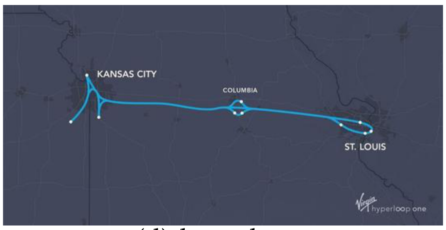
Thus, the development of electric vehicles is an inevitable trend, the current foreseeable development of science and technology will not weaken the momentum of electric vehicles, on the contrary, technology is promoting the development of electric vehicles.

(a) share car parking

(b) pod car



(c) modules of self-driving cars



(d) hyperloop

Figure 10: technologies

3.5 Task5

Handout

Nowadays, all kinds of energies are more and more scarce in the world, and people are paying more and more attention to environmental protection. The ideas of green, energy saving and environmental protection are increasingly advocated by people.

We have found that electric vehicles are more environmental and economic than traditional gasoline and diesel cars. As nations seek to develop policies that promote the migration towards all electric vehicles, they will need to design a plan that works best for their individual country.

In order to create a general growth model for different nations to successfully migrate away from gasoline and diesel vehicles to all electric cars. We build Polynomial curve fitting model and Multi Objective Location Model, use conversion function and genetic algorithm.

If your nation is going to make policies to encourage migration from gasoline and diesel cars to electric vehicles and further accelerate the switch to electric vehicles, there are some key factors that your country should pay attention to.

The key factors are as follow:

1.The population density distribution, Traffic road distribution, and GDP per capita of your nation will directly influence the initial construction plan and the final construction distribution in the future of charging station in your country. We provide a general three charging station development program for different countries for reference.

(1)The country has a high per capita GDP, a large population density and excellent traffic road distribution:the country should build charging stations at rural areas first in order to encourage people buy electric cars. In the future, the proportion of charging station in urban and rural areas will basically be the same.

Countries that conform to this situation: Singapore, France, Britain, Germany, etc.

(2)The country has a high per capita GDP, a small population density and imperfect traffic road distribution. The population is concentrated in rural areas:the country should build charging stations at urban areas first. In the future, the charging stations will mainly distribute in urban areas, minorly distribute in rural areas.

Countries that conform to this situation: Australia, the United States, etc.

(3)The country has a low per capita GDP, a large population density and imperfect traffic road distribution:the country should build charging stations both in urban and rural areas at the same time. In the future, the proportion of charging station in urban and rural areas will basically be the same.

Countries that conform to this situation: Indonesia, Malaysia, etc.

2.The country's current number of gas stations will indirectly affect the total number of future charging stations in the country.

3.The country's charging stations and the number of electric vehicles will affect the country to determine when it will be able to fully disable gasoline and diesel car in the future.

4 Strengths and Weaknesses

4.1 Strengths

- It is simple and easy to carry out,which fits for the situation of most different countries and can give the development plan which has certain rationality.
- Fitting data come from the official, with authenticity and timeliness.
- The fitting result is very good, R^2 is very close to 1, which has the effectiveness of fitting.
- By using the function toolbox, the operation is simple and convenient to use, and the repeatability is strong.

4.2 Weaknesses

- It is difficult to quantify.Only from the macro situation,it can analyse the situation of the country and propose the appropriate charging station development plan.
- the fitting data is not enough,which can not be very accurate to predict the future.
- the fitting function does not fully consider the actual situation, and can only predict the short-term results, rather than long-term prediction.

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[13] `https://electrek.co`

[14] `http://www.evhui.com`

[15] `http://club.ddc.net.cn`

[16] `https://tieba.baidu.com`

Appendices

Appendix A First appendix

Here are Genetic Algorithm we used in our model as follow.

Input matlab source:

```
%% Genetic Algorithm Main Function
clc
clear
warning('off')
%% parameter
load('data');
maxgen = 80;
sizepop = 200;
pcross = [.6];
pmutation = [.01];
lenchrom = [1 1];
bound = [0,140;0,170];

individuals = struct('fitness', zeros(1,sizepop), 'chrom',[]);
avgfitness = [];
bestfitness = [];
bestchrom = [];
for i=1:sizepop
    individuals.chrom(i,:) = code(lenchrom,bound);
    x = individuals.chrom(i,:);
    individuals.fitness(i) = fun3(individuals.chrom,i);
    %individuals.fitness(i) = fun3(x);
end
%find best chrom
[bestfitness bestindex] = min(individuals.fitness);
bestchrom = individuals.chrom(bestindex,:);
avgfitness = sum(individuals.fitness)/sizepop;

trace = [];
%% evolution begin
for i=1:maxgen

    flag=0;
    individuals = select(individuals,sizepop);
    avgfitness = sum(individuals.fitness)/sizepop;
    individuals.chrom = cross...
(pcross,lenchrom,individuals.chrom,sizepop,bound);
    individuals.chrom = mutation(pmutation,lenchrom,...
individuals.chrom,sizepop,[i maxgen],bound);
    %nonlinear programming


    for j=1:sizepop
        x=individuals.chrom(j,:);
        individuals.fitness(j) = fun3(individuals.chrom,j);
```

```
    end

    [newbestfitness,newbestindex] = min(individuals.fitness);

    if bestfitness>newbestfitness
        bestfitness = newbestfitness;
        bestchrom = individuals.chrom(newbestindex,:);
    end
    avgfitness = sum(individuals.fitness)/sizepop;
    trace = [trace; avgfitness bestfitness];
end
% evoution end
%% result view
[r c] = size(trace);
for i=1:size(loc,1)
    hold on
    rectangle('Position',...
[loc(i,1)-r1(i),loc(i,2)-r1(i),2*r1(i),2*r1(i)],'Curvature',[1,1]);
end
xlim([0,170]);
ylim([0,170]);
road=[1 2;1 3;3 4;4 5;5 6;5 7;6 7;7 8;6 8;4 6;6 9;3 9;1 9;9 10;1 10];
for i=1:15
    road(i,3)=dist(loc(road(i,1),:),loc(road(i,2),:)');
    hold on;plot([loc(road(i,1),1),loc(road(i,2),1)],...
[loc(road(i,1),2),loc(road(i,2),2)]);
end
disp('func value(y)                       variables(x)');
disp([num2str(bestfitness) '||' num2str(x)]);
a_402;
a=individuals.chrom;figure(1);plot(a(:,1),a(:,2),'kp');
```

Input matlab source:

```
%% city parameter
close all
loc=[45 148;28 140;49 110;56 87;28 26;100 67;119 29;128 48;98 130;96 154];
s=[31232 19296 40900 20166 23971 17362 20298 52526 23648 25441];
r=[985 361 230 154 121 247 345 117 152 161];
s=s/1000;r=r/20;r1=1.6*log(r);
for i=1:size(loc,1)
    hold on
    rectangle('Position',[loc(i,1)-r1(i),...
loc(i,2)-r1(i),2*r1(i),2*r1(i)],'Curvature',[1,1]);
end
xlim([0,170]);
ylim([0,170]);
road=[1 2;1 3;3 4;4 5;5 6;5 7;6 7;7 8;6 8;4 6;6 9;3 9;1 9;9 10;1 10];
for i=1:15
    road(i,3)=dist(loc(road(i,1),:),loc(road(i,2),:)');
    hold on;plot([loc(road(i,1),1),loc(road(i,2),1)],...
[loc(road(i,1),2),loc(road(i,2),2)]);
end
```

Table 8: coordinate of charging stations

number of charging stations	longitude	latitude
1	1.269277095022282	0.469277095022282
2	0.460463611063090	0.255204919382603
3	1.193880857239356	0.486422368837147
4	1.171279482014901	0.267443986475388
5	0.282420660935959	0.262420660935959
6	1.270978554273420	0.432393282072845
7	1.261979042338767	0.479916194953468
8	1.174569358945904	0.274569358945904
9	0.282420660935959	0.262420660935959
10	1.018782170499572	0.688792320635827
11	0.968132511382376	1.288132511382376
12	1.017438026854687	0.687438026854687
13	0.944811338007243	0.917202972199369
14	0.287783262883777	0.267783262883777
15	0.949841802799148	1.529841802799148
16	0.509240485728765	1.119240485728765
17	1.000382359748601	0.666535326320386
19	0.299816326067744	0.255204919382603
20	1.273146355274195	0.541522085923940
21	1.186867179194315	0.277863544884842
22	0.280649733822103	0.260649733822103
23	1.011834192641908	0.681834192641908
24	1.192884575094085	0.276476958614848
25	0.965323055639477	1.285323055639477
26	1.193043762808991	0.293043762808991
27	0.277732289602148	0.257247583057345
28	1.193880857239356	0.293880857239356
29	0.280649733822103	0.260101537314021
30	1.278233614591987	0.431753203823471
31	1.258161956051570	0.482773362736711
32	0.885676784642155	0.651866140394653
33	0.272999596386422	1.382999596386422
34	1.293710070284337	0.495805450949294
35	0.980852724267133	0.651881131775796
36	0.433452585752661	1.465960040032721
37	1.193880857239356	0.293880857239356
38	0.966860969512201	1.546860969512202
39	0.987787096280034	0.649967096280034
40	0.277247583057345	0.257247583057345
41	1.211736839386968	0.311736839386968
42	1.270978554273420	0.417271842454164