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Increasing Charging Electricity Demands and Reducing the Cost in Public Places

Summary

The frequent use of electronic devices has led to an increasing demand for charging in public areas. As the convenience of charging method, we need to properly analyze the expenditure and the allocation of the cost. Mathematical models should be established to describe charging facilities, charging demand and equipment cost.

In part 1, in order to analyze the changes of charging electricity in the public area of the United States, electric vehicles (large devices) and mobile phones (small devices) were taken into considered. Then we collected data on the number of electric vehicles and mobile phones, battery capacity, charging times, and charging frequency in 8 years. Finally, considering the energy loss and the proportion of public charging, we calculated the actual electricity consumption in the public area every year in the US. According to the population of charging groups in recent years, the Bass model was used to predict the continuous changes in the future of electricity consumption. The results are consistent with the predictions of well-known institutions.

In part 2, different kinds of costs were taken into the economic cost model. We divided the cost of large charging facilities into three parts: the land cost in economics, the capital of production tools, and the variable cost. Because the construction cost of a small charging socket is relatively low, we do not take into account land consumption. One part of the costs is fixed cost; the other part is variable cost. In addition, the economic costs of time-cost conversion are discussed in our model.

In part 3, for the four common public areas, we took Starbucks in New York, New York Airport, Stanford University and Macy Supermarket as typical examples. The costs of charging small devices in three areas are distributed to each cup of coffee, airline ticket, and seller, correspondingly. The cost of charging big devices are paid by each user. But for café, there is no large charging facility in the café, so only the loss of the small charging device is calculated. School is relatively special, because it bears all the charging cost, including both big and small devices.

In part 4, to reduce the cost of public charging devices, we listed eight options that can change parameters from the political and economic point of view. Through parameter sensitivity analysis, we estimated the effect of the recommendation in four different occasions

Key words: Prediction of electricity; Bass model; Cost of public charging; Electric vehicle; Mobile phone

Contents

1 Introduction

1.1 Background

In recent years, with the continuous development of technology, people not only use more and more electronic products, but also need more and more timely charging in public places. Free charging sockets and car charging piles are also used in cafes, airports, schools, shopping malls, and other occasions. It is one of the most important problems to analyze the impact of this phenomenon and the requirements for the corresponding occasions. The existing charging facilities will cause certain consumption and impact. For example, Tesla electric vehicle charging pile provides power for users through the power system connecting the parking lot, but it has certain requirements for the compatibility and the aging degree of power supply system. The distribution of electric charge payment of public charging pile has become one of the problems to be solved. Therefore, what we need to do is to analyze the relevant models and optimize them so that this power supply system can adapt to more environments and make the distribution of payment more reasonable.

As the convenience and liquidity of this charging method will also cause higher consumption, we need to properly analyze the expenditure and the allocation of the cost of this part, so as to minimize capital consumption and make it most acceptable to consumers and suppliers. Since there is a certain amount of charging facilities in public places, we need to analyze the consumption and payment of facilities and electricity.

1.2 Problem Restatement

Question 1: We need to find out how the energy consumed by the public free charging mode has changed in recent years, and predict the future changing trend. We need to find out the positive and negative impacts of this growing energy and charging demand on the public environment providing charging and what changes need to be made in the public environment in order to sustain this growth.

Question 2: Use the impact in the first question and the requirements for the public environment to make this "cost model" for the growing energy consumption and demand of electricity and discuss the different forms of cost spending and how these costs are caused.

Question 3: Discuss the changes of "cost model" parameters in the previous question when they are applicable to different locations (such as schools, coffee shops, airports, shopping malls, etc.).

Question 4: Find out the measures that can reduce the cost of increasing power consumption., How will the parameters in the "cost model" change after these measures are implemented.

2 Problem analysis

A schematic overview of the scope of this study is shown in Figure 1. Models will be built to sovlve these four quesitons above.

Question 1: We need to make statistical analysis of the change of the electric energy required by this public charging mode in recent years, and predict the changing trend in the future. At the same time, we need to identify the positive and negative impact of this growing energy and charging demand on the public environment that provides charging. Besides, we divide the public charging consumption into two categories according to the level of energy needed, and build a model from two aspects of mobile phone and electric vehicle charging consumption.

Question 2: We need to use the impact of this charging mode mentioned in question 1, and meet the requirements of this charging mode for the public environment to make a cost model that should be able to adapt to the growing energy consumption and demand. We also need to discuss the different forms of cost spending and what aspects of costs are made up of. In this regard, we are going to start from two aspects: electric vehicle and mobile phone charging cost, whichinclude investment cost and time cost. While investment cost can be further divided into land cost, construction cost and operation cost., time cost is the time cost for queuing

Question 3: We need to discuss how the cost model constructed in question 2 can adapt to different situations, such as airports, coffee shops, department stores, and schools. According to the equation already found in the second question, we will use the cumulative addition to find out the investment and time cost of mobile phones and electric vehicles in different situations.

Question 4: We need to find ways to reduce the increasing cost of increasing power consumption due to the popularity of charging among people and analyze how to change the parameters in the cost model to reduce the cost most effectively.

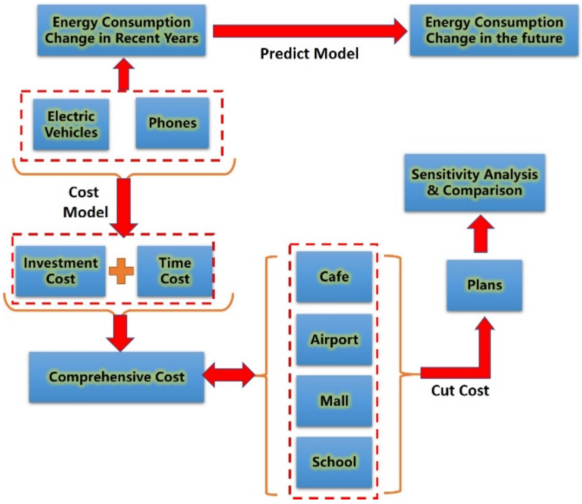

Figure 1 A schematic overview of the scope of this study

3 Assumptions

Assumption 1: we select the United States as the analysis area. Since the United States is a developed country, its charging infrastructure is relatively developed, with the largest free charging market and the largest scale of free charging equipment. Additionally, the existing data is relatively abundant, which makes the data for recent years for statistical analysis accessible to propose and test the theoretical model.

Assumption 2: charging will bring energy loss. Acccording to the principle of physics, during the charging process, a small part of energy will not be converted into electric energy, but will be converted into thermal energy to be emitted. We use it in the title to show the charge loss efficiency.

Assumption 3: the power consumption of hybrid charging vehicle is not covered. Hybrid vehicles can consume both fuel and electricity. The problem only needs us to analyze the power consumption, but not the fuel consumption. It is difficult to judge the specific situation in which hybrid vehicles will consume fuel and electricity, so the power consumption of hybrid vehicles is difficult to estimate.

Assumption 4: the number of charging piles of electric vehicles can exactly meet the charging demand. The number of charging piles must meet the charging demand of electric vehicles, otherwise it will not maintain a charging market with continuous growth of demand.

Assumption 5: mobile phone and electric vehicle users will only charge after using all the electricity, and will be fully charged at one time. In order to do better quantitative calculation, we exclude the situation that the user starts to charge before the battery power is fully consumed and stops charging before the battery is fully charged, and assume that all mobile phone and electric vehicle users will charge after the battery is completely consumed and will be fully charged each time.

Assumption 6: the cost of electricity generated by charging mobile phones in public places is entirely borne by the operator. In order to attract customers, operators (e.g. coffee shops, restaurants, etc.) usually set up free charging plugs for customers to use. Although this part of the cost will ultimately be allocated to customers' consumption, it is the operators who perform this operation. So we classify this part of the cost into the operators' operating cost.

Assumption 7: laptops are not included among the electrical appliances involved in the calculation. People do use laptops to charge in public. But the frequency is low. So the electricity consumption caused by laptops should be neglected.

4 Calculation of public charging demand (Problem 1)

4.1 Description

In order to analyze the change of charging demand in public areas in the United States, we analyze all charging capacity in public areas in recent years, such as schools, public charging piles, airports, coffee shops, etc., and establish a model to predict the change trend of charging capacity in public areas in the next few years. Considering the type of charging in public areas, there are many kinds of charging equipment such as electric vehicles, e-books, and smart phones [1]. There are remarkable differences according to the electricity demand. Therefore, the charging equipment is mainly divided into large equipment and small equipment. We mainly consider electric vehicles $E_{vehicle}$ for large equipment and smart phones E_{phone} for small equipment. Next, we will carry out statistical analysis on the charging capacity of electric vehicles and smart phones in public areas, and establish a prediction model. Our modeling scheme is shown in Figure 2.

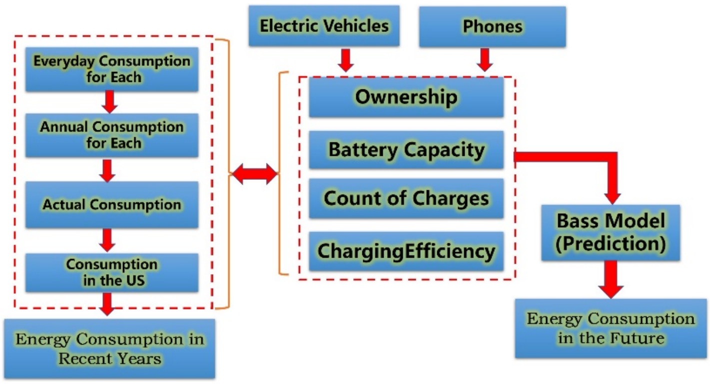

Figure 2 A schematic overview of calculation of public charging demand

4.2 Calculation of public charge calculation model

4.2.1 Calculation model of public charging capacity of electric vehicle

At present, electric vehicles (EVs) in the United States include electric buses, electric taxis, special EVs, business EVs, and electric private cars, of which the proportion of electric private cars is more than 90%. Hybrid cars are usually charged at home at night and can be refueled in most cases. It is assumed that after the hybrid vehicle is charged at home at night, and the part of the external power is exhausted outside, oil and gas are used to generate power, and it will not be charged in public places, so the power consumption of the hybrid vehicle is not considered. Therefore, only the charging of electric private cars in the public area is considered in the analysis of this problem.

First of all, we need to calculate the power consumption of a single electric vehicle every day. Different kinds of vehicles have different driving mileage corresponding to their energy consumption per kilometer. According to the analysis above, we can get the electricity consumption equation of a single electric vehicle in a day:

$$e_{vehicle-day} = \frac{q}{100} \times d \tag{1}$$

Among them, q is the electric energy consumed for every 100km of driving, d is the driving mileage of this type of electric vehicle in a day, and $e_{vehicle-day}$ is the power consumption of a pure electric vehicle in a day. To calculate the total charge, we can sum it up and multiply it by the number of days 365, so the capacity consumed by a single pure electric vehicle in a year is

$$e_{vehicle-year} = 365 \times e_{day} \tag{2}$$

In the course of one year's driving, part of the electric vehicle is charged at home and part of it is charged in public. Assuming that the ratio of the times of charging in public to the total times is $\alpha_{vehicle}$, the result of charging pure electric vehicle in public is $\alpha_{vehicle} e_{vehicle-year}$. Finally, considering that the electric vehicle will have a very large loss in the charging process, assume that the charging loss rate is $\phi_{vehicle}$, then the actual power consumption of each electric vehicle in the public environment is:

$$e_{vehicle} = \frac{\alpha e_{vehicle-year}}{1-\phi_{vehicle}} \tag{3}$$

The number of electric vehicles is in a dynamic change process. Assuming the number of pure electric vehicles in the United States every year is $n_{vehicle}$, then the annual energy consumption of charging in the United States is:

$$E_{vehicle} = n_{vehicle} \times e_{vehicle} \tag{4}$$

Substituting the above Eq. (1) - (3) into Eq. (4), and finally get the equation:

$$E_{vehicle} = \frac{3.65 \times n_{vehicle} \times \alpha_{vehicle} \times q \times d}{1-\phi_{vehicle}} \tag{5}$$

Here, $n_{vehicle}$ represents the total amount of pure electric vehicles in the United States every year, $\alpha_{vehicle}$ is the ratio of times of charging for public occasions to the total times, q is the electric energy consumed for every 100km driving, d is the driving mileage of this type of electric vehicle in a day, and $\phi_{vehicle}$ is the charging loss rate.

4.2.2 Calculation model of public charging capacity of mobile phone

There is a large amount of mobile phone users in the United States. Because the majority of users of Apple mobile phone and there is not a significant difference among current mainstream mobile phone brands, products, and battery capacity , we use Apple mobile phone as our research goal. Power of a single cell phone w:

$$w = C \times V \tag{6}$$

Where C is the battery capacity, V is the standard voltage. Compared with electric cars, mobile phones require more times of charging every day. The daily charge of mobile phone is:

$$w_{phone-day} = w \times n_{day} \tag{7}$$

Among these variables, w is the electric energy of a single cell phone battery, and n_{day} is the number of charges per day. If we want to get total charging capacity of a mobile phone in a year, we can sum it and multiply it by 365 days, then the capacity consumed by a single mobile phone in a year is:

$$w_{phone-year} = 365 \times w_{phone-day} \tag{8}$$

In one year's use of mobile phones, part of them are recharged at home and part of them are recharged in public. Assuming that the ratio of the times of charging in public to the total times is α_{phone}, the charging result of mobile phones in public is $\alpha_{phone} w_{phone-year}$. Finally, considering that there will be a certain amount of energy consumption when charging the mobile phone, assuming that the charge loss rate is ϕ_{phone}, then the actual power consumption of each mobile phone is:

$$w_{phone} = \frac{\alpha_{phone} w_{phone-year}}{1-\phi_{phone}} \tag{9}$$

Assuming that the number of mobile phones is n_{phone} and the number of smart phones in the United States changes dynamically every year, the energy consumption of charging in the United States is:

$$E_{phone} = n_{phone} \times w_{phone} \tag{10}$$

Substituting the above Eq. (6) - (9) into Eq. (10), and finally get the equation:

$$E_{phone} = \frac{365 \times n_{phone} \times \alpha_{phone} \times w \times n_{day}}{1-\phi_{phone}} \tag{11}$$

Among them, w is the electric energy of a single cell phone battery , n_{phone} is the number of cell phones in the United States every year, n_{day} is the number of charges per day, α_{phone} is the ratio of the number of charges in public places to the total number of charges, and ϕ_{phone} indicates the charge loss rate of cell phones.

4.2.3 Calculation model of total amount of public charging

Based on the above model, the total amount of charging in public areas is mainly composed of the power consumption required by electric vehicles - large equipment $E_{vehicle}$and smart phones - small equipmentE_{phone}. Therefore, the total charging capacity in the public area in one year:

$$E_{all} = E_{vehicle} + E_{phone}. \tag{12}$$

4.3 Data Collection and Processing

We find the ownership of new energy electric vehicles (including hybrid vehicles, etc.) and the market share of BEV in the United States from 2011 to 2018 , as shown in the table below [2].

Table 1 Electric vehicle ownership in the United States

	2011	2012	2013	2014	2015	2016	2017	2018
Electric vehicle ownership	22000	75000	170000	290000	400000	550000	740000	1080000
Proportion of pure electric vehicles	0.52	0.55	0.54	0.57	0.62	0.64	0.53	0.66

From the above table, we can get the ownership of pure electric vehicles in the United States, as shown in Figure 3.

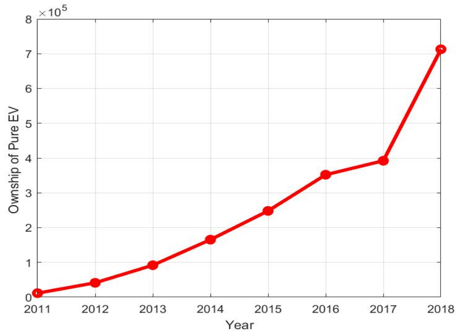

Figure 3 Data of pure electric vehicles in the United States

In 2017, pure electric vehicles accounted for 53% and plug-in hybrid vehicles accounted for 47%. In 2018, the market share of pure electric vehicles (Bev) was the largest, accounting for 66%, and the proportion increased. In order to solve the results above, we found that only about 7% was charged in public, so the ratio of times of charging in public places to total times was set to 7% [2]. q refers to the electric energy consumed for every 100km driving and the driving mileage of this type of electric vehicle in a day. The actual charge loss rate is $\phi_{vehicle}$. In terms of technical parameters of pure electric vehicle, we take the average value of technical parameters of "micro bus" and "Zotye Zhidou" with large number of users as the parameters of pure electric vehicle. The daily mileage of electric vehicle is 50km, and the electric energy consumed for every 100km is 18 kWh (an electricity demand based planning of electric vehicle charging infrastructure). Thus, the total power consumption can be calculated. The literature shows that the actual charge rate of loss of electric vehicles is between 0.07-0.12. We choose 0.1 as the rate of loss of vehicle charging.

Table 2 Smartphone ownership and charging power

Year	Parameter source	Quantity of ownership /millions	Capacitance /mAh	Average voltage /V	Charging electric energy /mWh
2011	iphone 4/4s	92.8	1420	3.8	5396
2012	iphone 4s/5	122	1430	3.8	5434
2013	iphone 5/5s	144.5	1500	3.8	5700
2014	iphone 5s/6	171	1685	3.8	6403
2015	iphone 6/6s	190.64	1762.5	3.8	6697.5
2016	iphone 6s/7	208.61	2695	3.8	10241
2017	iphone 8/7/6	246.6	2870.5	3.8	10907.9
2018	iphone 8/x	257.3	3171	3.8	12049.8

For small charging devices, we find the number of mobile phones in the United States from 2011 to 2019 (as shown in Table 2) [3]. Additionally, because the battery capacity of the major

American brands is similar, and the iPhone accounts for the majority, we default the battery capacity of the phone to the battery capacity of the iPhone. In addition, considering the life of mobile phones and the advancement of technology products, in order to ensure relative accuracy, we take the average value of the battery capacity of the latest iPhone and the last cell phone as the battery capacity in each year. The lithium battery voltage of mobile phone fluctuates between 3.7 and 4.2V, we take 3.8V approximately. Multiplying the battery capacity by the voltage obtains the electric energy consumed by the mobile phone when charging once [4]. However, there will be energy consumption in the charger and mobile phone when charging. We all calculate 39%, and then multiply the energy by the retention to calculate the total energy consumption [5]. According to the data, about 51% of the mobile phone's charging power is charged in the public environment, so multiplying the calculated total power by 51% gets the power consumed by our final small device (mobile phone) every year. The charging capacity of mobile phone is charged in the public environment, so the total power calculated before is multiplied by 51% to get the power consumed by our final small devices (mobile phone) every year.

4.4 Mathematical Model

To statistically analyze and speculate on how the demand for electric vehicles and cell phones in public will continue to change in the future, we can first count and analyze the overall number of PEV and phones in the future. After research and comparison, we decided to adopt the Bass model proposed by Frank Bass of the United States, which can be used to predict the quantity of electric vehicles and mobile phones. The pre-assumption of the Bass model is that the growth rate of the market for electric vehicles and mobile phones in the market mainly comes from two aspects. On the one hand, it comes from advertising, marketing and other business activities. On the other hand, it comes from the promotion of existing users. That is, there are already behaviors such as the user's influence on the potential users. In the Bass model, the source of new users of electric vehicles and mobile phones is divided into two types. One is to receive innovative users for marketing and promotion, and the other is to imitate users through old users. Definition p is the innovation coefficient, which is the growth rate of innovative users of EV and cell phones. The specific range is [0, 1]. The larger the value, the stronger the awareness of innovative users to purchase goods. The definition q is the imitation coefficient, and the q value indicates the speed at which the old users of EV and phones promote the product. The value range is also [0, 1]. The larger the value, the easier it is for the old users of EV and phones to promote their potential users. The equation for the Bass model is shown below:

$$N_t=N_{t-1}+p(m-N_{t-1})+q\frac{N_{t-1}}{m}(m-N_{t-1}) \tag{12}$$

where Nt and Nt – 1 represents the quantity of consumers of EV or phones at the time of t and t – 1, respectively, while m represents the total quantity of consumers of EV or phones (aka maximal market potential).

Eq. (12) can be mathematically transformed into high order equation,

$$I(t)=N_t-N_{t-1}=pm+(q-p)N_{t-1}-\frac{q}{m}N_{t-1}^2 \tag{13}$$

And finally we obtain:

$$I(t)=x+yN_{t-1}+zN_{t-1}^2 \tag{14}$$

This paper imports the Bass model to predict the quantity of electric vehicles and mobile phone market, so as to accurately estimate the charging demand of electric vehicles and mobile phones under certain conditions. The Bass model was chosen because it has higher versatility, lower requirements for hardware equipment and technology, simple model calculation, and more reasonable methods than other models in the industry. The Bass model can better estimate the charging demand for each time period and each area. When the number of EV in the area changes to a large extent, after adjusting the parameters, it can still be accurately estimated [Reference 1].

4.5 Statistical Analysis

Based on the above data, we use the Bass model to analyze the electric vehicle (pure EV) data from 2011 to 2018. Therefore, the model is:

$$I(t)=5985.1+0.678N_{t-1}+0.0000018621N_{t-1}^2 \tag{15}$$

The fitted curves in terms of electric vehicles are shown in Figure 4.

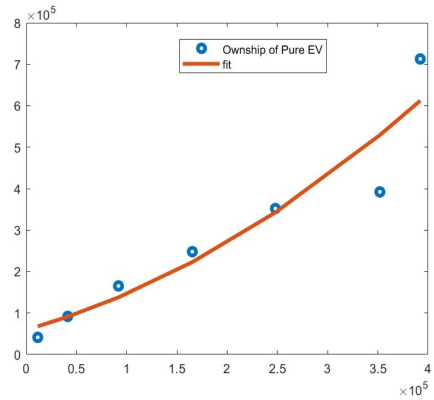

Figure 4 Fitted curves for the ownership of pure EVs

Likewise, based on the above data, we use the Bass model to analyze the cell phone data from 2011 to 2018. Therefore, the model is

$$I(t)=16.8313 + 1.1570N_{t-1} - 0.0006N_{t-1}^{2} \tag{16}$$

The fitted curves in terms of cell phones are shown in Figure 5.

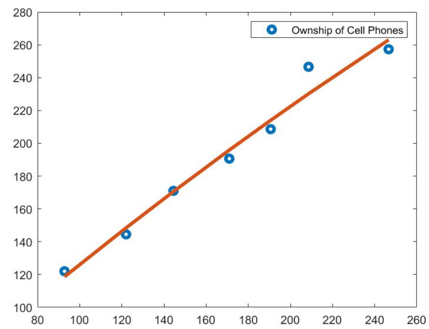

Figure 5 Fitted curves for the ownership of cell phones

4.6 Future prediction

For external prediction, we use the Bass model on basis of the data on the number of electric vehicles and smartphones from 2011 to 2018, based on past data to predict the development of electricity consumption in the next few years [6]. In addition, for the future changes in mobile phone battery capacity, we calculate the average value of mobile phone battery capacity from 2011 to 2018, and use this value as the future change:

$$C=\frac{\sum_{i=1}^{8}(C_{i+1}-C_i)}{8} \tag{17}$$

where C is the average change of mobile phone battery capacity in recent years, and C_i is the average mobile phone battery capacity taken every year since 2011. The calculated average is approximately 250 mAh per year.

Table 3 Prediction of battery capacities

Year	Capacity (mAh)
2019	3421
2020	3671
2021	3921
2022	4171
2023	4471

Prediction of the average battery capacity of mobile phones in each of the next five years is shown in Table 3. Based on the above predictions, the amount of pure electric vehicles and mobile phones are obtained, thereby the corresponding overall power consumption calculated. Here we predict that the number of pure electric vehicles in the United States will be 3.2 million in 2020, which is consistent with the value, 3.3 million, predicted from relevant institutions [7].

Table 4 Prediction of the ownership and power consumption of electric vehicles and smart phones

Year	Amount of PEVs	Amount of Smart phones (million)	Power consumption (10^9 kWh)
2019	1490 000	271.90	1.14
2020	3200 000	283.81	1.69
2021	5390 000	293.34	2.38
2022	8450 000	300.82	3.30
2023	11500 000	306.61	4.22

4.7 Impacts of increasing electricity demand

(1) Gradual expand of electricity demand

Recent years has witnessed the boosting using rate of electronic products with the development of electronic product technology. The vast majority of people in American society today have pure electric cars and smart phones, so the demand for public free charging is undoubtedly increasing. In addition to traditional electronic products, as electric vehicle manufacturing matures, electric vehicles may become a more realistic alternative to gasoline and diesel fuel vehicles. Many electric car drivers charge mainly at home or at work. However, a wide range of public infrastructure charging facilities are still required for day-off work or when the vehicle is traveling in longer distance. For smartphone users, due to the increase in usage, a large number of users often face the problem of a shortage of charging places and the inability to charge. As people's demand for charging places increases, more free charging stations gradually emerge to benefit the wider group of people. The charging problem is solved, which in turn improves people's average living standards.

Providing more convenient and efficient battery charging conditions in public places, major driving routes, and highways has attracted more visitors to a certain extent. Meeting the needs of more people has led to a lot of construction of charging stations. Therefore, we need to consider the cost of building charging stations and various public charging equipment.

(2) Increasing operation and maintenance costs

In most cases, when installing an electric vehicle charging device, the device of each vehicle must have a dedicated circuit available. Sufficient power capacity is expected to flow from the utility to the distribution panel at the appropriate voltage to meet the power requirements of the electric vehicle's power supply equipment. Meanwhile, deliberate destruction or crossing of wires can cause some damage to these public facilities. It is more common to replace damaged parts or to update the powered equipment of vehicles featured with advanced function or communication. Considering the huge demands and high requirements on equipment, public charging devices need to be continuously updated in large quantities, resulting in a significant increase in the cost of maintenance. Therefore, we need to include the cost of maintaining the charging station.

(3) The cost of required electricity

Advocates of electric vehicles list the feasibility of public charging stations as the primary factor and prerequisite for people to become interested in electric vehicles, because the charging station provides drivers with a wider choice and flexibility in traveling. With the advent of public charging stations, consumers will be more interested in the electric vehicle industry.

For builders, however, the operation costs of electric vehicle power supply equipment include electricity bills and vehicle costs. In addition to the electricity bill based on energy consumption, many commercial and industrial facilities may be charged for power control from utility companies due to the additional power consumption.

(4) Land cost

Many people charge their devices at home, but the charging station can be found in many places, from the home of the PEV owner to the workplace, to the parking lot of restaurants, malls and airports. Therefore, the construction of the charging station occupies a large amount of land resources, the cost of which needs to be considered.

(5) Queue time cost

With the increasing demand for public charging stations, more and more people are facing the competition for limited resources. The most prominent problem is the queuing. When the demand for charging stations reaches a certain amount, people will face a situation of shortage of supply. We want to create a solution that can be globally optimized to properly allocate charging stations and limit the amount of time each person uses.

5 Cost of charging in public (Problem 2)

Charging equipment mainly includes AC slow charging, AC fast charging and DC fast charging [8]. Among them, the AC leve12 charging facilities, which have established a certain scale and relatively complete charging network, have the largest number of installations and the widest distribution area; the DC fast charger charging facilities, which are mainly located on intercity and interstate highways, provide fast power supply services for long-distance driving electric vehicles. The layout of electric vehicle charging station is mainly combined with indoor or outdoor parking lot to provide charging service while parking. The charging equipment in the United States is mainly operated by operators. By 2018, the number of electric vehicle charging stations in the United States has reached 72150, an increase of 22.5% [3]. A schematic overview of calculation of charging in public is shown in Figure 6.

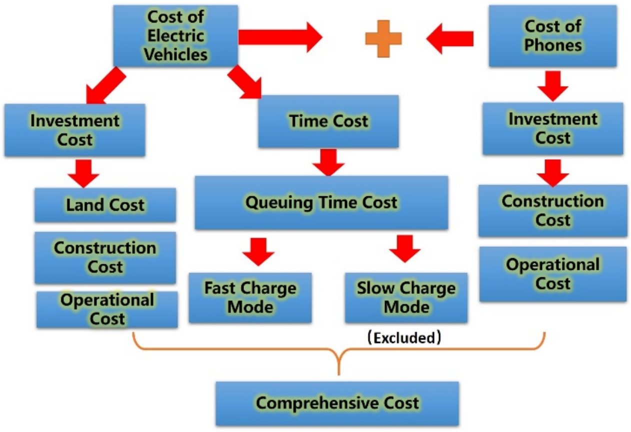

Figure 6 A schematic overview of calculation of charging in public

5.1 Electric vehicle charging cost

The charging cost of electric vehicle is considered from two dimensions: Builder and user, builder and operation cost [9]. Users consider their time input cost. Investment cost mainly includes land cost, station construction cost and operation cost. The land cost is mainly related to the location of the charging station and the floor area, because the price of land in different locations is different, and the larger the floor area, the higher the cost. The cost of building a charging station is related to the cost of infrastructure and the number of stations. The higher the price of infrastructure, the higher the cost of building a station, and the higher the number of stations. The operation cost is closely related to the wages of workers, maintenance costs, number of charging stations and operation years. The time input cost of users is mainly reflected in queuing. If the electric vehicle station in the public area is not set properly, users will spend a lot of time in queuing. The user's capital input cost is mainly reflected in the payment of electricity charges. The cost of this part can be converted with the operation cost of the charging station, so it will not be discussed here.

Based on this, this paper not only considers the investment cost of the builder, but also considers the queuing time cost of the user.

(1) Investment cost: land cost

Electric vehicles belong to new energy vehicles. Compared with traditional vehicles, they are more environmentally friendly. Cities that can promote new energy vehicles generally have developed economy and relatively precious soil resources. Therefore, in the process of considering the investment cost of charging station construction, we should first consider the cost of land. The equation of land cost of single charging station is as follows:

$$C_1 = c_{area} S \tag{17}$$

Here, $C_l$represents the land cost of a single charging station (10000$), c_{area}represents land cost per unit area of single charging station (10000 \$ $/m^2$), S represents the floor area of a single charging station (m^2)

(2) Investment cost: construction cost

The construction cost mainly refers to the input cost of charging piles and their supporting facilities, which is related to the number of charging piles. The more charging piles in a single charging station, the higher the cost of a single charging station. The specific calculation equation is as follows:

$$C_2 = c_{charge} n_c \tag{18}$$

where, C_2 represents the construction cost of a single charging station (ten thousand yuan); c_{charge} is the price of a single charging point; n_c indicates the number of charging posts in a single charging station.

(3) Investment cost: operation cost

The operation cost of the charging pile equipment itself mainly includes the labor cost, the loss of supporting facilities, and the cost of daily maintenance, etc., which is generally proportional to the construction cost. In addition, part of the operating cost is the electric charge generated by the daily charging of the electric vehicle, and the sum of these two parts can get the operating cost of a single electric vehicle charging station for 365 days a year:

$$C_3 = E_{vehicle} c_{vehicle} + n_c(f_e + f_l)\beta_c \tag{19}$$

Here, $c_{vehicle}$ represents the unit price of electric vehicle charge in this area; f_e is the cost of maintenance equipment; f_l is the wage paid to the worker when repairing the equipment; β_c is the maintenance frequency.

(4) Time cost: queuing time cost

The time cost of users is mainly the time cost of waiting for charging. At present, the charging mode of electric vehicles is generally divided into fast charging and slow charging. Fast charging takes 0.5-2h, and slow charging takes 7-8h. For users who need to charge in the public area, they usually choose fast charging. Therefore, this paper mainly considers the waiting time of users in the process of fast charging. In a single charging station, each fast charging point can be regarded as a time cost consuming unit. Based on this, the equation of the total waiting time cost per day for a single charging station can be obtained,

$$C_w = T_w n_{vehicle} c_t \tag{20}$$

Here, T_w refers to the total waiting time of users in a single charging station every day (H). $N_{vevicle}$ refers to the number of electric vehicles per day at a single charging station(Vehicle). C_T represents the travel cost per unit time of the user (10000 \$ / h).

The cost model of a single EV charging station can be established by combining the investment cost and time cost. Considering that the double objective functions in this paper are all cost, and the units are the same, then we use the cumulative addition to merge directly. Combining the land cost, construction cost, operation cost and the time cost of users waiting for charging, the cost model of 365 day electric vehicle fast charging station in a year is obtained. The constraints are as follows:

$$F_c = C_1 + C_2 + C_3 + T_w$$
$$= c_{area} s + c_{charge} n_c + \left(E_{vehicle} c_{vehicle} + n_c(f_e + f_l)\beta_c \right) + 365 T_w n_{vehicle} c_t \tag{21}$$

The annual cost of a single charging station is shared equally on each electric vehicle it charges, and the shared cost model is as follows:

$$A_c = \frac{min\, F_c}{365 w_c}$$
$$= \frac{c_{area} s + c_{charge} n_c + \left(E_{vehicle} c_{vehicle} + n_c(f_e + f_l)\beta_c \right) + 365 T_w n_{vehicle} c_t}{365\, n_{vehicle} \times \alpha_{vehicle}} \tag{22}$$

5.2 Mobile phone charging cost

The charging cost of mobile phone is analyzed from the same two dimensions, builder and user. The builder considers its construction cost and operation cost. However, if the mobile phone users cannot find the charging socket in the public area, few people will wait for others to charge their hands, so the queuing time cost will not be considered in the mobile phone charging cost.

To sum up, the main cost of mobile phone charging in public areas includes construction cost and operation cost. Mobile phone charging mainly depends on hardware facilities such as charging socket and charging line. Because of the different models of mobile phones, mobile phone users usually bring their own charging lines, so we mainly consider the cost of charging sockets in public places. Its cost is related to the cost of wiring and the number of charging sockets. The cost of wiring and the number of charging sockets can be understood as the infrastructure cost of charging sockets. The operation cost of the charging socket is mainly related to the electricity fee (hypothesis 6), maintenance cost (including the facility maintenance and labor for maintenance, but because these two parts are paid together most of the time, we will calculate them together) and the service life of the charging socket and other factors.

(1) Investment cost: construction cost

The construction cost mainly refers to the wiring cost of the socket and the number of charging sockets. Theoretically, the wiring cost of the socket is also positively related to the number of sockets. The more charging sockets in a single public area, the greater the charging cost of mobile phones in the public area. The specific calculation equation is as follows:

$$P_1 = (p_c + p_w)n_{phone} \tag{23}$$

Here, $\boldsymbol{P_1}$ Represents the construction cost of a single public area (10000$); P_C represents the price of a single charging plug; P_W represents the price of the cable corresponding to a single charging plug; N_{phone} refers to the number of charging sockets in a single public area.

(2) Investment cost: operation cost

The operation cost of infrastructure mainly includes electricity cost (assumption 6), maintenance cost, maintenance worker cost, loss of charging socket (due to the long service life of charging socket, we do not consider the cost consumption here), which is generally proportional to the construction cost. Therefore, the calculation equation of operation cost is as follows

$$P_2 = E_{phone}\, c_{phone} + p_l \beta_{phone} n_{phone} \tag{24}$$

Here, $\boldsymbol{P_2}$ presents the operation cost of mobile phone charging socket in a single public area (10000$); c_{Phone} represents the unit price of electricity used for smart phone charging in the region.P_l means the combination of the price of the equipment and the price of the workers in the repair order (since the appearance is not high, we sum them here). β_{phone} indicates the maintenance frequency of the mobile phone socket;

Based on the comprehensive construction cost and operation cost, the cost model of mobile phone charging socket can be established for 365 days a year.

$$F_p = P_1 + P_2 = (p_c + p_w)n_{phone} + E_{phone}\, c_{phone} + p_l \beta_{phone} n_{phone} \tag{25}$$

$$= (p_c + p_w)n_{phone} + \frac{365 \times n_{phone} \times \alpha_{phone} \times w \times n_{day}}{1 - \phi_{phone}} c_{phone} + p_l \beta_{phone} n_{phone} \tag{26}$$

If the cost is allocated to each mobile phone, the cost model of charging socket allocated to each mobile phone 365 days a year is as follows:

$$A_p = \frac{P_1 + P_2}{365 w_{phone}}$$

$$= \frac{(p_c + p_w)n_{phone} + \dfrac{365 \times n_{phone} \times \alpha_{phone} \times w \times n_{day}}{1 - \phi_{phone}} w_{phone} + p_l \beta_{phone} n_{phone}}{365\, n_{vehicle} \times \alpha_{vehicle}} \tag{27}$$

5.3 comprehensive charging cost

Most of the public places include mobile phone charging socket and electric vehicle charging pile, so we can use sum to calculate the comprehensive charging cost as follows:

$$F_{total} = F_c + F_p = (C_1 + C_2 + C_3 + T_w) + (P_1 + P_2)$$
$$= \left[c_{area} s + c_{charge} n_c + \left(E_{vehicle}\, c_{vehicle} + n_c (f_e + f_l) \beta_c \right) + 365 T_w n_{vehicle} c_t \right] +$$
$$[(p_c + p_w)n_{phone} + E_{phone}\, c_{phone} + p_l \beta_{phone} n_{phone}] \tag{28}$$

6 Analysis in different scenarios (Problem 3)

Many factors are considered in the cost model of increasing demand and the use of energy in public places such as local price, land price, electricity fee, etc., as well as the problems of labor cost and maintenance in operation [10-12]. In order to analyze, the model needs to be combined with the actual scenario. In this paper, we analyze and discuss four specific examples: New York Kennedy Airport, New York Starbucks cafe, New York King's Plaza Shopping Center, and Stanford University. According to the analysis, we discovered that there will be no time cost for users in the different environments analyzed below, so we set the time-cost value of electric vehicle charging consumption in all the following scenarios as 0.

We also evaluate how the charging service provider makes up the cost. We find that the charging cost of all the charging vehicles will be made up in the form of parking fee. For the charging cost of mobile phones, the school can hardly make up for it; coffee shops will include this part of the cost in the price of coffee; airports will include this part of the cost in the price of boarding pass; shopping malls will include this part of the cost in the price of goods. The way of solving problems is mainly represented in Figure 7.

Figure 7 A schematic overview of charging in public in different scenarios

6.1 Cafe

6.1.1 Mathematic model

As for the café, there is no electricity consumption of the electric vehicle charging pole since most coffee shops will not pay the corresponding cost for the shopping mall where they are located, or the coffee shop may exist independently. Therefore, we assume that the electricity consumption cost of the coffee shop is only the cost of the mobile phone charging sockets.

Thus JC = 0, jphone = 1 the equation as follows:

$$F_{cafe} = F_p = P_1 + P_2 = (p_c + p_w)n_{phone} + E_{cafe-phone}c_{phone} + p_l\beta_{phone}n_{phone}$$

Among these variables, F_{cafe} represents the total operating cost of a single coffee shop in a year; as there are many parameters in the equation, other parameters refer to the parameters in 5.2 mobile phone charging cost (the same below).

Since we have got the annual operating cost of the coffee shop, we can obtain the allocated operating cost of each customer's consumption by dividing the annual flow of customers of the coffee shop, as shown below:

$$F_{personal(cafe)} = \frac{F_{cafe}}{365R_{phone}} = \frac{(p_c+p_w)n_{phone}+E_{cafe-phone}c_{phone}+p_l\beta_{phone}n_{phone}}{365R_{airport.phone}}$$

Among them, $F_{personal(cafe)}$ refers to the allocated operating cost of each person's consumption in the café, and $R_{cafe.phone}$ represents the number of daily customer visits / cups of coffee sold in a café per day.

6.1.2 Sample data and results

We use Amazon's mobile phone charging sockets as representative. The price is 12 dollars.According to the comparison with Amazon's price, we estimate that the cable price is $20. Therefore, P_1 is calculated by:

$$P_1 = 12 \times 1 \times (1 \times 8 + 12 \times 1) = 240$$

First of all, we take Starbucks as the baseline of coffee shop. Since Starbucks can be either with two floors and one floor, we take the average value, with each coffee shop of 1.5 floors. There are high tables and low tables in Starbucks. A high table averagely corresponds to eight sockets while a low table averagely corresponds to one socket. And we assume that there are one high table and 12 low tables in a single floor.

Therefore, the equation to calculate n_{phone} can be expressed by:

$$n_{phone} = 1.5(1 \times 8 + 12 \times 1) = 30$$

Assuming that the coffee shop operates for 17 hours, the utilization rate of the socket is 80%, and the output power of the charging socket is 5W, we take New York City as the representative, through the data survey, in 2018, the electricity charge of New York City is 19.3 $/ kWh; β phone, we assume that the damage frequency of each mobile phone charging socket is once a year.

Therefore, P2 is calculated as:

$$P_2 = 17 \times 30 \times 80\% \times 5w \times 365 \times 19.3 \times 10^{-3} + (12 + 20) \times 30$$
$$= 14370 + 1920 = 16290$$

Since F_{cafe} = P1 + P2 = 16290 + 240 = 16530$. According to the market situation, we estimate that Starbucks can sell 500 drinks or food within a day

If we share our electricity bill among all the goods sold in a year, we can get:

$$f_{personal(cafe)} = \frac{16530}{500 \times 365} = 0.091$$

6.2 Airport

6.2.1 Mathematical model

As for airports, car and mobile phone charging exist at the same time.Therefore, $j_c = 1$, $j_{phone} =1$. Since the electric vehicles are all paid by consumers, and there is a sharing problem in the charging of mobile phone socket, we will separate the two costs. For the charging cost of electric vehicles, the equation is shown below:

$$F_{airport.vehicle} =$$
$$C_1 + C_2 + C_3 = c_{area}s + c_{charge}n_c + \ (E_{airport-vehicle}c_{vehicle} + n_c(f_e + f_l)\beta_c)$$

Further calculation can obtain the loss shared by each visitor in each visit to the airport:

$$F_{personal(airport.phone)} = \frac{F_{airport.phone}}{365R_{ariport.phone}}$$
$$= \frac{(p_c + p_w)n_{phone} + E_{airport-phone}c_{phone} + p_l\beta_{phone}n_{phone}}{365R_{ariport.phone}}$$

Among them, $F_{airport.c}$ represents the annual cost of airport electric vehicle charging; $F_{airport.phone}$ represents the annual cost of airport mobile phone charging; $F_{personal(airport.phone)}$ refers to the cost allocated to each customer after the annual cost of airport mobile phone charging, and $R_{airport.phone}$ represents the number of people using airport mobile phone charging every day.

6.2.2 sample data and results

C_{area} assumes that JFK Airport has 1000 parking spaces with charging piles, and one parking space is 15m^2; S is the price per unit area of JFK airport of \$2400/m^2. So C_1 is expressed as:

$$C_1 = 1000 \times 15 \times 2400 = 36000000$$

The price of charge is set at \$650; Therefore C_2 is expressed as:

$$C_2 = 1000 \times 650 = 650000$$

Assume that the charging pile of JFK Airport works 12 hours a day and the output power is 7KW; f_e assumes that the cost of each maintenance of charging pile is 1 / 3 of the cost of charging pile; f_l assumes that the cost of each maintenance of single charging pile for workers is \$15; β_c assumes that the maintenance frequency of each charging pile is once a year.

Therefore, C3 can be expressed as:

$$C_3 = 1000 \times 12 \times 7 \times 365 + \left(\frac{650}{3} + 15\right) \times 1 \times 1000 = 30660000 + 231660 =$$
30891660. According to:

$$F_{airport.vehicle} = C_1 + C_2 + C_3$$

We can obtain:

$$F_{airport.vehicle} = 36000000 + 650000 + 30891660 = 67541660$$

For the calculation of mobile phone charging socket, we also divide it into P_1 and P_2;

The number of n_{phone} sockets can be calculated by using the number of boarding gates. JFK has 112 boarding gates in total, with each gate corresponding to 7 rows of seats, and each row of seats has 6 sockets. Therefore, the number of charging sockets in JFK Airport is calculated as follows:

$$n_{phone} = 112 \times 7 \times 6 = 4700$$

Since we assume that the price of cable and charging socket is fixed, we can maintain the data in **6.1.1**. The equation P1 can be obtained as follows:

$$P_1 = (12 + 20)4700 = 150400$$

It is assumed that the operation time of mobile phone charging socket in the airport is 24 hours; the utilization rate of mobile phone charging socket in airport is 30%; the output power of charging socket is 5kWh. As represented by JFK Airport, the data is the same as that in 6.1.1. In 2018, the electricity charge in New York City was \$19.3/ kWh. P_l considers the annual price growth (inflation). We assume that the maintenance cost of each charging plug is equal to its total damage;

Therefore, P2 is calculated as follows:

$$P_2 = 5w \times 24h \times 30\% \times 365 \times 4700 \times 19.3\$ \times 10^{-3} + (12+20) \times 4700$$
$$= 1191929.4 + 150400 = 1342329.4\$$$

$F_{airport.phone}$ is the sum of P1 and P2. Thus:

$$F_{airportphone} = P_1 + P_2 = 150400\$ + 1342329.4\$ = 31492729.4\$$$

In order to obtain the share of electricity cost of each airport visitor in the ticket, we set the parameter $F_{personal(airport.phone)}$

According to the survey, we get that $365R_{airport.phone}$ = 80000000 people;

Therefore, the calculation equation of $F_{personal(airport.phone)}$ is as follows:

$$F_{personnal(airport.phone)} = \frac{F_{airport.phone}}{365R_{airport.phone}} = \frac{31492729.4\$}{80000000\ capita} = 0.394\$/capita$$

6.3 Mall

6.3.1 Mathematical model

As for mall, car and mobile phone charging exist at the same time. Therefore, $j_c = 1$ $j_{phone} = 1$. Mall's consumption calculation method is different from the previous ones since the cost of electric vehicles of mall is borne by consumers, while the charging of mobile phones is entirely borne by the mall. Similarly, we separate them.

For electric vehicles, the equation of cost per charge in mall is as follows:

$$F_{mall.vehicle} = \frac{C_1 + C_2 + C_3}{365R_{mall.car}} = \frac{c_{area}s + c_{charge}n_c + \ \ (E_{mall-vehicle}c_{vehicle} + n_c(f_e + f_l)\beta_c)}{365R_{mall.vehicle}}$$

The charging cost of mobile phone borne by mall throughout the year is as follows:

$$F_{mall.phone} = F_p = P_1 + P_2 = (p_c + p_w)n_{phone} + c_{phone} + p_l\beta_{phone}n_{phone}$$

Among them, $F_{mall.vehicle}$ represents the cost of electric vehicle charging each time in the mall; $R_{mall.vehicle}$ refers to the number of vehicles visiting the mall every day; $F_{mall.phone}$ represents the cost of mobile phone charging undertaken by mall throughout the year.

6.3.2 Sample data and results

As for the mall, it is relatively complex to consider the payment of electric vehicle charging, so we first analyze the cost of mobile phone charging socket.

First of all, we use Kings Plaza Shopping Center as the representative of all shopping malls since it's also located in New York City. Therefore, we maintain the electricity fee of \$19.3/kWh and other corresponding costs in 6.2.

According to the survey, the Kings Plaza Shopping Center covers an area of 309m × 256M. It is assumed that there is a socket every 10m, and the number of sockets on the single floor is: $F_1 = (30 + 25) \times 2 = 110$

There are four floors in Kings Plaza Shopping Center: $F_4 = 110 \times 4 = 440$

Assume that the operation time of the shopping mall is 12 hours. The utilization rate of charging socket is 20%. It is known that there are 440 charging sockets for mobile phones, which can be obtained as follows:

$$F_{mall.phone} = (12\$ + 20\$) \times 440 + (12\$ + 20\$) \times 440$$
$$+ 20\% \times 12h \times 5w \times 440 \times 365 \times 19.3\$ \times 10^{-3}$$
$$= 28160\$ + 148{,}779{,}840\$ = 148{,}816{,}240\$$$

We cannot get the accurate data of the number of charging piles due to the fast update of charging piles, so we assume that there are 80 charging piles for electric vehicles. According to the previous assumption, C_{car} has 80 charging posts corresponding to 80 parking spaces, each of which is known to be $15m^2$. According to the survey, the land price of Kings Plaza Shopping Center is 5344 \$/m^2; electric vehicle charging point price maintains the data in 6.1, 650 \$; the data required for the calculation of C_3 shall be maintained from the data related to charging point electricity charge in 6.2. Assuming that the charging post in Kings Plaza Shopping Center operates for 14 hours, the probability of use is 40%. Therefore, the calculation is as follows:

$$F_{mall.vehicle} = \frac{80 \times 15m^2 \times \frac{5344\$}{m^2} + 650\$ \times 80 + 40\% \times 14h \times 365 \times 80 \times 5w \times \frac{19.3\$}{kwh} \times 10^{-3}}{365 \times 51278}$$
$$= \frac{6{,}412{,}800\$ + 52000\$ + 22{,}091{,}552\$}{365 \times 51278} = \frac{28556352\$}{365 \times 51278} = 0.007\$$$

6.4 School

6.4.1 Mathematical model

The calculation of the school's electric energy consumption will be relatively complex. First, we can calculate the total annual consumption equation of electric vehicles. But for the calculation of the mobile phone charging plug consumption, we can calculate the school's mobile phone charging consumption by multiplying the number of middle buildings, floors, and classrooms of the mobile phone university with the number of charging sockets in each classroom. Finally, we can calculate the total consumption of the school by summing up. The equation is as follows:

$$F_{school} = F_c + F_p = (C_1 + C_2 + C_3 + T_w) + (P_1 + P_2)$$
$$= \left[c_{area}s + c_{charge}n_c + \left(E_{school-vehicle}c_{vehicle} + n_c(f_e + f_l)\beta_c\right)\right] + \left[(p_c + p_w)n_{phone} + E_{school-phone}c_{phone} + p_l\beta_{phone}n_{phone}\right]$$

Among them, F_{school} represents the average annual total electricity consumption of the school; B refers to the number of buildings in the school; C represents the number of classrooms; G represents the average number of charging plugs in each classroom;

6.4.2 Sample data and results

For the equipment data in P1, inherits the data in 6.1. According to the survey, there are 600 classrooms in Stanford University and 20 sockets in each classroom, so n_{phone} = 12000. This is different from the previous calculation method. We use 18643 mobile phones, multiplied by 0.68 times / day of charging times of mobile phones in public every day, and assume that each charging is charged fully, and the cell phone battery capacity is 12049.8mwh. Therefore, we should multiply 10^{-6} at the end of the equation. We obtain:

$$F_p = (12\$ + 20\$) \times 12000 + 51\% \times 18643 \times 0.68 \times 12049.8mwh \times 365 \times \frac{19.3\$}{kwh} \times 10^{-6}$$
$$= 384{,}000\$ + 548812.9\$ = 932812.9\$$$

Since we can't get the specific data, in order to calculate the number of charging piles in Stanford University, we assume that the number of Stanford University is equal to the number of mobile phones, with 3% of them own electric vehicles in the University. So the n_c value is 550. According to the survey, the land cost of Stanford is 10100 \$/ m^2. It is assumed that the use time of charging post in Stanford University is 8h. As each vehicle corresponds to a charging pile, there is no low utilization rate, and the utilization rate is 100%. Other data inherit the data in **6.2**. We obtain:

$$F_c = 550 \times 15m^2 \times \frac{10100\$}{m^2} + 550 \times 650\$ + 365 \times 8h \times 550 \times 7kwh \times \frac{19.3\$}{kwh}$$
$$= 83{,}407{,}500\$ + 357{,}500\$ + 216{,}970{,}600\$ = 300{,}735{,}600\$$$

As for the school, the total consumption is entirely borne by the school, therefore:

$$F_{school} = F_c + F_{phone} = 932812.9\$ + 300735600\$ = 301668412.9\$$$

6.5 Analysis and discussion

According to the above analysis results, we summarize the results of itemized cost and total cost in each case, as well as how much money per capita needs to pay, so as to facilitate the pricing of merchants.

Table 5 cost details of four scenarios

\$	C1	C2	C3	P1	P2
coffee shop				240	16290
airport	36000000	650000	30891660	150400	1342329.4
mall	6412800	52000	22091552	14080	148793920
school	83407500	357500	216970600	384000	548812.9

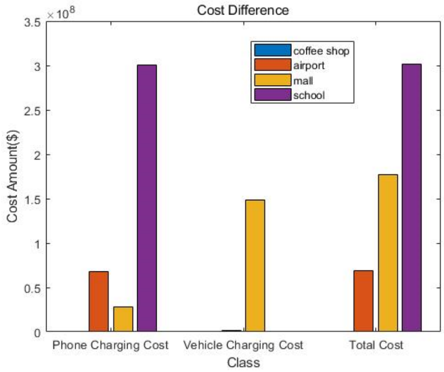

Figure 8 four scenarios charging cost chart

Figure 8 demonstrates the cost demand of establishing public charging equipment in cafes, airports, shopping malls, and schools. In the overall comparison process, it is obvious that the funds needed to build mobile phone charging equipment in a coffee shop are very small compared with those in other cafes. At the same time, the cost of building mobile phone charging equipment required by the school is much, mainly because the school is relatively large and the required charging power supply and cable laying are relatively long, but the rate of electric vehicles used by teachers and students in the school is relatively low. The number of charging Posts needed for electric vehicles will be relatively small. Because shopping malls are located in the center of the city, the electricity price and land price are relatively high, and the total energy cost will be relatively high if the base number is relatively large.

7 Plans of lowering the cost (Problem 4)

Nowadays, the energy consumption in public places is increasing. As demand increases, it is particularly important to reduce energy costs in public places. We first confirmed how to change the charging cost of mobile phones and charging cars in different scenarios - cafes, airports, shopping malls, schools by changing the parameters in the cost model. Later, we further explained the different options that can change these parameters. Next, we established the models of Fc and Fp respectively, and considered how the parameters should change. Finally, we analyzed five parameters (x, y, z, m, n) by sensitivity analysis, and built graphs to compare the cost changes caused by the change of parameters in four different occasions. Finally, judge the sensitivity of these recommendations. The mind map is shown in Figure 9.

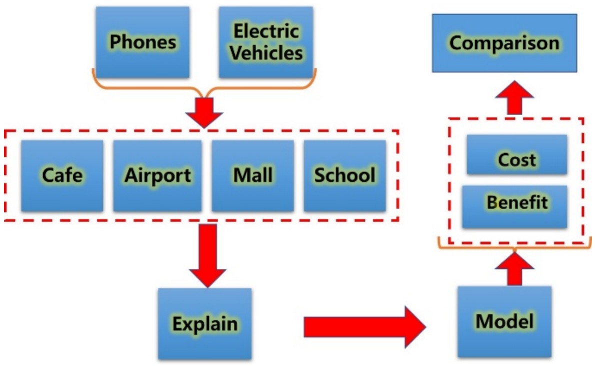

Figure 9 A schematic overview of lowering the cost

In order to lower the extremely increasing rate of the cost of energy consumption, we can use ways listed below to lower the cost.

7.1 Methods

Ways to reduce the cost of charging electric cars and charging phones are shown in Table 6 and Table 7.

Table 6 ways to reduce the cost of charging electric cars

	café	School	Mall	Airport

A1	√	√	√	√
A2			√	√
A3		√		
A4	√	√	√	√
A5	√		√	√
A6		√		

Annotation:
A1: Government tax cuts for pure electric vehicles
A2: Land cost of car charging pile
A3: Installation cost of car charging pile
A4: Operating costs of car charging pile
A5: Give out free parking coupons to promote consumption of electric
A6: Solar panel

Table 7 ways to reduce the cost of charging phones

	Café	**School**	**Mall**	**Airport**
A6		√		
A7		√		
A8	√	√	√	√

Annotation:
A7: Installation cost of socket for phone charging
A8: Operating costs of socket for phone charging

7.2 Description of plans

Electric vehicle charging cost plans:

A1: pure electric vehicles use electric energy sources that can reduce the use of fossil energy and reduce air pollution. Therefore, for large-scale construction of charging piles, the township government can apply for land tax reduction to reduce costs. The policy can contribute to all of the mentioned scenarios.

Building a three-dimensional parking lot is also an effective way.

A2: The three-dimensional parking lot of malls and airports can reduce the land cost. We could construct a three-dimensional underground. The parking space can be lifted and lowered by electric power control to increase the number of vehicles that can be parked as much as possible. The number of parking spaces on each floor of the garage can reach two or three times than before, so do the cars that stop at the parking lot. The number of cars will also increase. As a result, the total amount charged will increase, and effectively making up the high cost of charging.

A3: On the other hand, because the number of charging guns and the number of parking spaces are equal, in the three-dimensional parking lot, the charging pile can be built higher and equipped with more charging guns, so the floor space of the electric car charging pile is also It will reach a minimum to achieve the goal of reducing land costs.

A4: The operating cost of the electric car charging pile can be covered by offering the charge free to people. Mall and airports can increase the number of customers by issuing free parking tickets. As in the assumption of our question, the charging cost of the department store will be spread to the rent of each merchant, and the consumption of the customer can increase the rent, and it can cover more electricity charges. The airport can also give discounts and services to passengers who purchase first class tickets. It can also give free parking coupons and free charging coupons to encourage more people to purchase first class tickets. Because the first-class ticket covers the charging fee, purchasing more first-class tickets means more electricity bills can be covered.

A5: At the same time, free parking coupons can be used to reduce costs indirectly. This scheme is applicable to all the above scenarios: department stores and airports can increase the number of customers by issuing free parking coupons, because merchants must use part of the money earned as rent. Handed over to the mall, the rent includes a portion of the electricity bill, so promoting consumption can increase the profit of the merchant, and by paying more rent, it can cover more electricity bills. Thus, by reducing the total cost C, the total cost can be reduced. The airport can also give discounts and services to passengers who purchase first class tickets. It can also give free parking coupons and free charging coupons to encourage more people to purchase first class tickets.

A6: Since it is difficult for us to reduce the cost of the unit electricity bill, we can consider using solar power that is already very popular. This measure can be applied to various public places. For schools only, we can adopt the method of introducing solar panels, which can reduce the school's demand for electricity purchase, thereby saving a lot of operating costs. Solar panel is mainly used for small equipment ports such as phones. Rich energy will be used to charge electric vehicles. Although this proposal will increase equipment costs (C2, P1), it will be more educational as a new energy source for schools.

A7: In terms of the charging cost of phones, considering the current appearance-oriented sockets on the market, such as invisible sockets, although the overall environment can be made more tidy, the construction cost is much higher and the damage rate is high. Therefore, in order to achieve cost reduction, we can reduce the aesthetic considerations for charging sockets or charging piles, and use ordinary sockets, especially for schools that are more concerned with practicality, and can appropriately abandon the beautiful public places, and A high usage rate such as a coffee shop leads to a vulnerable place.

A8: In terms of future operating costs, the mall can cover the cost by distributing the charging cost to the rent of each merchant. In other places, the airport can be divided equally into the ticket, the coffee shop is evenly distributed to each cup of coffee, and the school can apply for education funds to cover the cost because most of them do not use the charging fee to realize the profit.

7.3 Model modification

For electric cars:

$$F_c = xC_1 + yC_2 + zC_3$$

Where 0 < x , y , z < 1, the case in which the change of land cost is described by the x parameter, the case in which the change of installation cost is described by the y parameter, and the case in which the change of operating cost is described by the z parameter.

A1 is an optimized plan for government tax cuts to change land costs, directly affecting **x**. **A2** is an optimized plan for the land cost of electric cars charging piles, directly affecting **x**. **A3** is an optimized plan for the installation cost of electric cars charging piles, directly affecting **y. A4** is an optimized plan for the operating cost of electric car charging piles, directly affecting **z. A5** is an optimized plan that promotes consumption by giving out free parking coupons to change operating costs, directly affecting **z**. **A6** is an optimized plan for solar panel to reduce land costs, directly affecting **x**. Moreover, **A6** can directly affect **C2**, because the installation cost of building solar panels will be higher than installing charging poles.

For phones:

$$F_p = mP_1 + nP_2$$

Where 0 < m, n < 1, the case in which the change of installation cost is described by the m parameter; the case in which the change of operating cost is described by the n parameter.

A6 is an optimized plan for solar cells to reduce installation costs, directly affecting m. Moreover, **A6** can directly affect **P1**, because the installation cost of building solar panels will be higher than installing charging poles. **A7** is an optimized plan for the installation cost of mobile phone charging sockets, which directly affects m. **A8** is an optimized plan for the operating cost of mobile phone charging sockets, directly affecting **n**. All in all, **A6** and **A7** affect the parameter m at the same time. **A6** also directly changes **P1. A8** affects the parameter **n**.

7.4 Sensitivity analysis

In response to these suggestions above, we applied sensitivity analysis on different parameters to discuss the impact of different plans on cost. In this process, only the cases that share similarities are compared. For the parameter selection, we got the table below:

Table 8 sensitivity analysis

Plan Number	Variables	Minimum	Maximum	Step
A1	x	0.8	1	0.05
A2	x	0.6	1	0.05
A3	y	0.7	1	0.05

A4	z	0.7	1	0.05
A5	z	0.6	1	0.05
A6	x , m	0	1	1
A7	m	0.5	1	0.05
A8	n	0.7	1	0.05

The results of the sensitivity analysis are in Appendix A. From the analysis of the results, it can be concluded that the advance 1.8 has a great impact on the mall. The advance 3.4.5 has a great impact on the airport. The advance 2.6 has a great impact on the school. The advance 7 has a great impact on the coffee shop.

8 Strength and weakness

In this study, the energy consumption of charging in recent years was statistically analyzed from various data of charging devices of charging cars and mobile phones. We also predicted the energy consumption for the next five years through the Bass model. Taking into account the principles of economics, a cost model for the investment cost and time cost of charging cars and mobile phones was separately established. And based on the big data, specific cost was estimated by taking four scenes of coffee shop, airport, shopping mall and school as examples. In order to reduce the cost brought by the charging device, we give 8 reasonable proposal and propose a modified model. Using the sensitivity analysis method combined with the modified model to discuss our proposal. Therefore, a series of steady consumption predicting models and economic cost models are established to provide theoretical guarantee for the construction of public area charging.

There are also some of the disadvantages for our modeling. In the model we chose the New York city as the typical of our data collection. Because the New York city consuming level is much higher than the other area in the US, so the solution we calculated might bigger than the normal value. Second, because the revolution of electronic charging devices, we cannot collect some of the data, which means our assumptions may render the solutions not so specific. Third, we didn't add the medium size electronic devices like computers which the value is undefined, but proport to the value of smart-phone-charging. Lastly, we did not use the time cost setting in the question two in question three. If these problems are solved, our model will be better.

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News

Charging in Public: not a problem anymore

Do you lose your sense of security when your cell phone is dead? When your electric car is running out of power, do you not panic to find a charging point? For the serious charging problem in public areas, we once again used the method of establishing mathematical model to predict the charging volume of public areas we will use in the future, and also helped you to calculate the demand for mobile phone computer flashlight socket and charging pile, as well as the investment cost needed in airports, shopping malls, cafes and our schools. We hope that our model can let you know the specific situation of the amount of charging required in our public areas.

We have analyzed all the charging capacity of public areas in recent 8 years, such as schools, public charging piles, airports, coffee shops, etc., and established Bass model to predict the change trend of charging capacity in public areas in the next few years. The results are consistent with those of famous institutions.

In the economic cost model, the economic loss is added. The large-scale charging facilities are divided into three parts: land cost, capital cost and variable cost. We can summarize the construction and operation consumption of large-scale charging facilities and establish corresponding models. The cost of small-scale charging facilities is divided into two parts: the construction cost of small-scale charging socket is relatively low and land consumption is not considered, so it is classified as fixed cost; the other part is variable cost. Besides, the economic cost of time cost transformation is discussed in our model.

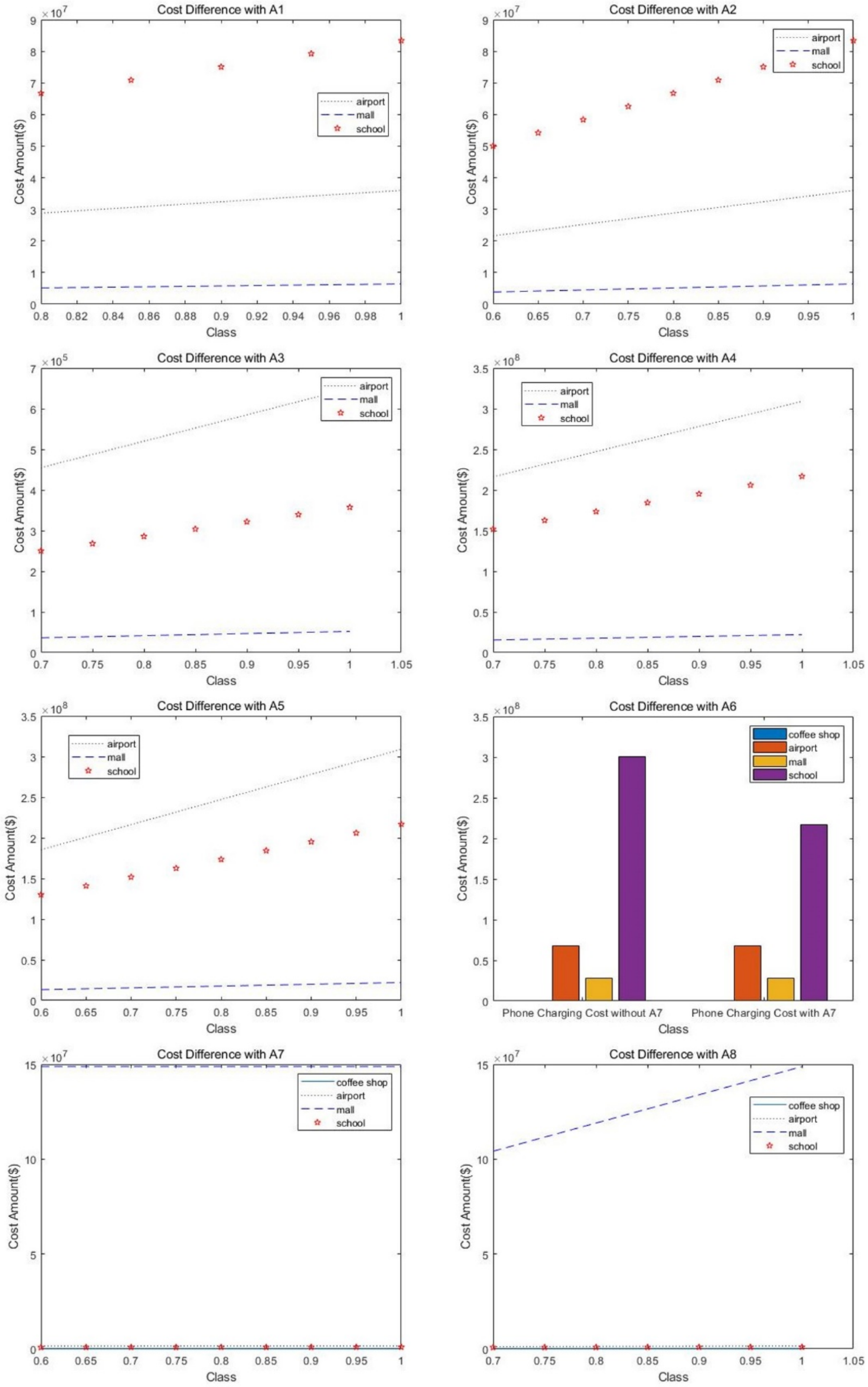
For the four common public occasions, we choose Starbucks in New York City, airport of New York City, Stanford University, Macy supermarket and other landmark buildings and collect data. The cost of charging equipment is calculated and analyzed.

Because it really needs a lot of capital investment to establish a perfect public charging system, here we put forward some ways to reduce costs and share them with you. Firstly, because pure electric vehicles use environmental friendly new energy, which can reduce air pollution, when building charging piles in large scale, we can apply to the government for local tax relief to reduce costs. Secondly, establishing a three-dimensional parking lot in the department store and airport, thus increasing the number of parking spaces and charging guns on each floor can reduce the cost of land. Thirdly, we suggest using ordinary sockets in places where the beauty can be properly discarded, especially in schools and cafes. Free parking coupons and charging coupons will be issued in department stores to increase the profit of businesses by promoting consumption and cover the electricity charge; free parking coupons will be issued in airports to encourage more people to buy first-class tickets to cover more electricity charge and reduce the total cost. Fourthly, department stores and airports can increase the number of customers by issuing free parking tickets, because businesses must pay a part of the money they earn as rent to the stores, which includes a part of the electricity fee, so promoting consumption can increase the profits of businesses, and then pay more rent, which can also cover more electricity fee.

Finally, we learned a lot about solar cells in the process of learning in school. We can use solar energy to generate electricity. Due to the high cost, we hope to introduce solar panels into our school to reduce the demand for electricity, thus saving a lot of operating costs. The electric energy of solar power generation is mainly used for small equipment ports such as mobile phones, and the rich energy will be used for electric vehicle charging. We think we would like solar energy to enter our campus. This is our understanding of energy in public areas.

Appendices

Sensitivity Analysis Results



Sensitivity Analysis Results of different class.

MATLAB Code

```
T =[2011,2012,2013,2014,2015,2016,2017,2018];
EV_all = [22000,75000,170000,290000,400000,550000,740000,1080000];
portion = [0.52,0.55,0.54,0.57,0.62,0.64,0.53,0.66];
```

```
EV_pure = EV_all .* portion
plot(T,EV_pure,'-or','LineWidth',3)
grid on
xlabel('Year')
ylabel('Ownship of Pure EV ')
alpha = 0.07;
q = 18;
d = 50;
phi_ev =0.16;
E_vehicle = 3.65* EV_pure *alpha*q *d/(1-phi_ev);
E_vehicle

n_phone=[92.8,122,144.5,171,190.64,208.61,246.6,257.3];
w = [5396,5434,5700,6403,6697.5,10241,10907.9,12049.8];
alpha_phone = 0.51;
n_day = 0.68;
phi_phone =  0.39;
E_phone = 365*n_phone.*alpha_phone.*w*n_day/(1-phi_phone);
E_phone



X= EV_pure(1:7);
Y = EV_pure(2:8);
p =polyfit(X,Y,2)
f = polyval(p,X);
plot(X,Y,'o',X,f,'-','LineWidth',3)
legend('Ownship of Pure EV ','fit')
p(1),p(2),p(3)

X= n_phone(1:7);
Y = n_phone(2:8);
p =polyfit(X,Y,2)
f = polyval(p,X);
plot(X,Y,'o',X,f,'-','LineWidth',3)
legend('Ownship of Cell Phones','fit')
p(1),p(2),p(3)

%%%predict
```

```
EV_pure = [1.49E+06,3.20E+06,5.39E+06,8.45E+06,1.15E+07]
alpha = 0.07;
q = 18;
d = 50;
phi_ev =0.16;
E_vehicle = 3.65* EV_pure *alpha*q *d/(1-phi_ev);

n_phone=[271.9008,283.8188,293.3435,300.824,306.617];
w = [3421,3671,3921,4171,4471]*3.8;
alpha_phone = 0.51;
n_day = 0.68;
phi_phone =  0.39;
E_phone = 365*n_phone.*alpha_phone.*w*n_day/(1-phi_phone);
E_all = E_vehicle + E_phone
t = [2019,2020,2021,2022,2023]



clear;clc;
x=[1 2 3 4 5 6 7 8];%
% training20_testing50
% y1=[69 33 90 95 96 94 100 73];
% y2=[94 67 88 93 98 85 100 77];

% training10_testing50
 y1=[60 51 83 69 96 61 100 61];
 y2=[92 46 63 95 98 54 98 60];
y_all=[y1;y2]';
bar(x,y_all)
title(' 10-Training and 50-Testing')
xlabel('Class')
ylabel('Accuracy')
set(gca,'xticklabel',{'Hyt','Maple','Su','Zm','Bob','Hly','Hhf','Yq'});




clc;
x=[2011:2018];
y=[5396,5434,5700,6403,6697.5,10241,10907.9,12049.8];
plot(x,y,'r*',x,y,'-r','LineWidth',2);
grid on
```

```
xlabel('Year')
ylabel('Ownership of Phone')
%title('name')
%legend('r*','-r')


clc;
x=[2011:2018];
y=[22000   75000   170000  290000  400000  550000  740000  1080000];
plot(x,y,'r*',x,y,'-r','LineWidth',2);
grid on
xlabel('Year')
ylabel('Ownership of Pure EV')
%title('name')
%legend('r*','-r')


clear;clc;
x=[1 2 3];%
y1=[0,16530,16530,];
y2=[67541660,1492729.4,69034389.4,]
y3=[28556352,148808000,177364352];
y4=[300735600,932812.9,301668412.9];
y_all=[y1;y2;y3;y4]';
bar(x,y_all)
title('Cost Difference')
xlabel('Class')
ylabel('Cost Amount($)')
legend('coffee shop','airport','mall','school');
set(gca,'xticklabel',{'Phone Charging Cost','Vehicle Charging Cost','Total Cost'});


clear;clc;
x=0.8:0.05:1
y=1;
z=1;
y2=x*36000000+y*650000+z*308971660;
%y2=x*
y3=x*6412800+y*52000+z*22091552;
y4=x*83407500+y*357500+z*216870600;
plot(x,y2,'k:',x,y3,'b--',x,y4,'rp')
title('Cost Difference with A1')
xlabel('Class')
ylabel('Cost Amount($)')
legend('airport','mall','school');


clear;clc;
x=0.6:0.05:1
y=1;
z=1;
y2=x*36000000+y*650000+z*308971660;
%y2=x*
y3=x*6412800+y*52000+z*22091552;
y4=x*83407500+y*357500+z*216870600;
plot(x,y2,'k:',x,y3,'b--',x,y4,'rp')
title('Cost Difference with A2')
xlabel('Class')
ylabel('Cost Amount($)')
```

```
legend('airport','mall','school');

clear;clc;
x=1;
y=0.7:0.05:1
z=1;
y2=x*36000000+y*650000+z*308971660;
y3=x*6412800+y*52000+z*22091552;
y4=x*83407500+y*357500+z*216870600;
plot(y,y2,'k:',y,y3,'b--',y,y4,'rp')
title('Cost Difference with A3')
xlabel('Class')
ylabel('Cost Amount($)')
legend('airport','mall','school');

clear;clc;
x=1;
y=1;
z=0.7:0.05:1;
y2=x*36000000+y*650000+z*308971660;
y3=x*6412800+y*52000+z*22091552;
y4=x*83407500+y*357500+z*216870600;
plot(z,y2,'k:',z,y3,'b--',z,y4,'rp')
title('Cost Difference with A4')
xlabel('Class')
ylabel('Cost Amount($)')
legend('airport','mall','school');

clear;clc;
x=1;
y=1;
z=0.6:0.05:1;
y2=x*36000000+y*650000+z*308971660;
y3=x*6412800+y*52000+z*22091552;
y4=x*83407500+y*357500+z*216870600;
plot(z,y2,'k:',z,y3,'b--',z,y4,'rp')
title('Cost Difference with A5')
xlabel('Class')
ylabel('Cost Amount($)')
legend('airport','mall','school');

clear;clc;
x=[1 2];%
y1=[0,0,];
y2=[67541660,67541660]
y3=[28556352,28556352];
y4=[300735600,217328100];
y_all=[y1;y2;y3;y4]';
bar(x,y_all)
title('Cost Difference with A6')
xlabel('Class')
ylabel('Cost Amount($)')
legend('coffee shop','airport','mall','school');
set(gca,'xticklabel',{'Phone Charging Cost without A7','Phone Charging Cost with A7'});
```

```
clear;clc;
m=1;
n=0.7:0.05:1;
p1=m*240+n*16290;
p2=m*150400+n*1342329.4;
p3=m*14080+n*148793920;
p4=m*384000+n*548812.9;
plot(n,p1,n,p2,'k:',n,p3,'b--',n,p4,'rp')
title('Cost Difference with A8')
xlabel('Class')
ylabel('Cost Amount($)')
legend('coffee shop','airport','mall','school');
```