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**2019**

**22nd Annual High School Mathematical Contest in Modeling (HiMCM)**
**Summary Sheet**

(Please make this the first page of your electronic Solution Paper.)

**Team Control Number: 9824**
**Problem Chosen: A**

# Summary

Ever since electric light bulb was invented, all sorts of electric equipment have begun to dominate our world. With advancement of the technology and people's increasing reliance on electric devices, the demands for charging in public places have emerged and grown rapidly. The increasing charging consumption has urged more public places to provide free charging service. In this problem, we construct our model to explore the trends and evaluate the costs of free charging in public places.

We collect data on the number of mobile phone users and the number of electric vehicles from 2010 to 2018. We adopt Least Squares regression analysis to determine the number and increasing rate in the following two years. We obtain that the increasing rate of mobile phone users is linear and will be 8.45% in 2020, and the increasing rate of electric vehicles is quadratic and will be 23.38% in 2020.

To calculate the requirements and possible impacts on public places based on the trend we predicted, we compare the current ratio between electric devices and charging equipment to the recommended ideal ratio. In the US, the average ratio of electric vehicles to electric charging outlets is approximately 17:1, which is much higher than the ideal ratio of 10:1, and the gap is identified as the unsatisfied demand.

We construct our model for the net cost of free charging in three parts:equipment fee, electricity fee and the potential profits. Distinguishing different types of free charging service, we classify the public places into three categories that provide:free charging for phones, for electric vehicles and for both. In commercial public places including shopping malls and coffee shops, the result of the net cost is negative under certain value of the sensitive coefficients. This reveals that the places can always benefit from free charging service under these sensitive coefficients because the potential profits compensate for the cost.

To ensure the validity and flexibility of our model, we employ sensitivity analysis. By plugging different values into the sensitive coefficients in our formulas (such as the ratio between electric devices and charging equipment), and observe how the costs will change accordingly. After identifying the influence of the sensitive coefficients, we seek initiatives to change these coefficients in order to lower the cost.

## Newspaper Article: Free Charging in Public Places

With the rapid development of electronic devices, it is an undeniable fact that these devices are becoming inseparable parts of our daily life. Based on the data of the national electricity consumption, the commercial use of electricity has kept on growing in recent years. More public places, such as airports, schools, and shopping malls, have set up their free charge stations for visitors to use. However, have you ever considered the impacts and the costs behind free charging in public places? Team 9824 now provides an answer.

First of all, here is the most basic question: What stimulates the emergence of those free charging stations? The answer could be as simple as one word: demand. The increasing numbers of electric devices and equipment reveal the fact that the demand for charging has been continuously rising, and according to the prediction model of team 9824, the demand will continue to grow in the near future. International Energy Association (IEA) has recommended that the ideal ratio between charging outlets and electric vehicles is 1:10. However, the average ratio in the U.S. now is almost 1:17, which implies that the demands of charging are largely unsatisfied.

The gap between the demand and supply is huge, but the cost of setting up a charging station (for electric vehicles) is not any less. For example, the average cost of a charging outlet (including installing and maintaining) can be up to 685 dollars. However, the cost can be largely reduced. For profit-making enterprises such as shopping malls and coffee shops, providing free charging services can attract more visitors, thus bring large potential profits. According to the calculating result of team 9824, public places can almost certainly benefit from the service as long as the service is attractive. For charging equipment of less cost such as charging connections for phones, the profits are more striking.

For non-profit public institutions and businesses, although no economical profits can be obtained, it is still worthy to start free charging services. Free charging service not only brings convenience to citizens, but also largely increases the efficiency of electricity transmitting. Moreover, free charging service in these public places contributes to the converting of energy consumption. More people will be willing to purchase electric cars, and thus the emission of carbon dioxide can be reduced. In addition, free charging helps the institutions gain positive reputations.

Public free charging is exactly like a kid in its childhood, remaining immature and unknown. The more we carefully explore the positive possibility of it, the more we will benefit from it.

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# 1 Introduction

## 1.1 Background Information and Problem Analysis

With the rapid development of electronic devices and electric vehicles, people are used to having all kinds of electronics in their lives and thus might seek to obtain convenient sources of charging. According to data of recent years, the demand for charging has been growing at an incredible speed[1], and the service of "free charge" has grown more popular in public places. Some public places, such as Hartsfield–Jackson Atlanta International Airport, have already installed free charging devices. In addition, the reach of free charging sites has increased from 17% to 30% in 2016, according to FMA (Financial Management Association)[2]. While public free charge is becoming a trend, the cost of setting up free charging sites and other impacts should be taken into consideration. In this problem, we aim to predict and analyze the trend of free charging consumption in public places, and then establish a model of high accuracy and flexibility to measure the resulting costs.


Figure 1: Public free charging site

We follow the steps below to complete our model for the resulting costs of increasing demands and requirements:

1. In order to predict the trend of charging consumption in the future, we refer to data presenting the energy consumption in recent years, and use Least Squares regression method to illustrate the future trend. The document containing data of gross electricity consumption within the US provides us with sufficient supporting data as the basis of regression analysis.

2. We calculate the costs of supporting public free charge by two indexes: equipment expenditure, and electricity fee. Each of these two factors for the total costs is calculated separately, and we give several equations for the calculation of these factors.

3. We divide the public places into three categories, and choose coffee shops, shopping malls and schools as the representatives for each category. We use the equations we determined to calculate the cost and potential profits of places in each category. We will make certain adjustments and analyze the sensitive coefficients in order to make an accurate and complete calculation of the total cost.

4. According to the results of our model and the influence of the sensitive coefficients, we propose initiatives to reduce the cost and increase the profits.

## 1.2 Problem Restatement

The problem we solve has several steps and we restate them as the following:

1. Discuss the energy consumption changes in recent years and make our prediction about the trend of free charging in the future by evaluating factors including the electricity price and the growing demands. Determine the impacts and requirements for public places in response to these changes.

2. Develop a model to evaluate resulting costs of the increasing energy and charging demand by considering the impacts and requirements that have been discussed above.

3. Consider the similarities and differences of different charging equipment in various public places. We divide public places into several categories in order to better analyze the variables of each public place. By distinguishing the differences of fundamental factors, we determine how our model should change to measure different circumstances.

4. Give recommendations based on the model results to reduce the resulting costs of the public free charge.

5. Summarize the model results and recommendations in a one-page article to our school newspaper.

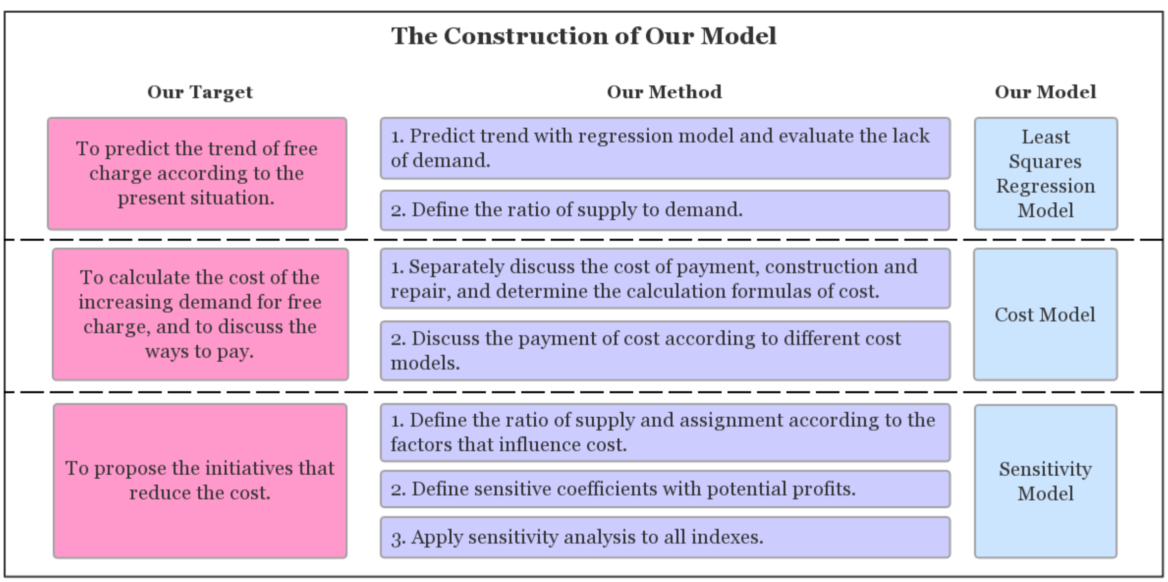


Figure 2: The Construction of Our Model

# 2 Assumptions

**Assumption1**:We only analyze energy consumption data after 2010.
**Justification**: By using the data after 2010, we can facilitate the calculation and maintain data consistency by reducing the influences from other factors including the different research methods and inflation. We use the data to analyze the trend of energy consumption and predict future data.
**Assumption2**:We assume the ideal ratio of electric vehicles to charging outlets is 10:1.
**Justification**: International Energy Association (IEA) has recommended on a level a ratio of 10 electric vehicles to 1 charging connection. The ratio is used for estimating the demand for electric charging outlets.
**Assumption3**:The electronic devices that use electric charging connections are mobile phones and laptops.
**Justification**: In public places including schools and coffee shops, the majority of electronic devices used are mobile phones and laptops. Thus, we only consider mobile phones and laptops as a representation of small electronic devices. We make this assumption to simplify the calculation of the demand for charging connections in public places.
**Assumption4**:We assume the electricity price is constant.
**Justification**: To simplify the calculation of the cost of electricity, we use the average commercial electricity price from 2010 to 2018. We use the electricity price to calculate the electricity fee for charging.
**Assumption5**:We assume the ideal ratio of phones to the charging connection is 6:1.
**Justification**: The majority of public places open for 12 hours per day, so we may assume that the working time for charging connections is 12 hours. Besides, the average charging time for a smartphone is 2 hours. We can determine that one charging connection is available for 6 phones to use per day. The assumption is used for estimating the demand for charging connections.
**Assumption6**:We assume that the average number of costumers that come in one car is approximately 3.
**Justification**: The majority of cars have 5 seats. The average customers per car are 3. The number is used to predict the potential benefits per car.

# 3 Definitions and Notations

| | |
|---|---|
| $C$ | the possession number of mobile phones |
| $E$ | the possession number of electric vehicles |
| $P_{cost}$ | the total cost of charging connections for mobile phones |
| $C_1$ | the total cost of the electricity fee caused by mobile phone charging within a certain public place in a day |
| $C_p$ | the number of users of free charging services |
| $p_1$ | the fee of charging a mobile phone from empty battery to full battery |
| $p_2$ | the cost of one charging connection |
| $s_1$ | the average service life of a charging connection |

| | |
|---|---|
| $C_3$ | the potential profits of free charging connections |
| $\Delta C_p$ | the increasing number of users of free charging service |
| $\Delta P_{cost}$ | the increasing number of the total cost of charging connections for mobile phones |
| $C_2$ | the fee of acquiring and building charging connections distributed to each day |
| $E_{cost}$ | the total cost of charging outlets for electric vehicles |
| $ev$ | the number of electric vehicle possession |
| $P_1$ | the average expenditure of electricity that one car uses in a day |
| $P_2$ | the cost of acquiring and building the charging outlets |
| $s_2$ | the service life of an electric car |
| $C_4$ | the total electricity fee per day |
| $C_5$ | the material and building fee distributed to each day |
| $C_6$ | the potential profits of installing outlets in a day |
| $\Delta E_{cost}$ | the amount of increasing cost for electric charging outlets |
| $\Delta ev$ | the amount of increasing possession of electric vehicles |
| $\gamma$ | the potential profit each customer can bring |
| $\alpha$ | the ratio of customers that come only because of the free charging services |
| $\beta_1$ | the current rate of charging connections to the number of mobile phones over that of the ideal rate |
| $\beta_2$ | the current rate of charging outlets to the number of electric vehicles over that of the ideal rate |

# 4 Model Design

## 4.1 Trends, Requirements and Impacts

### 4.1.1 Regression Model

In order to predict the future trends of charging energy consumption, we adopt an indicator: the number of possession of electric devices in each year. Based on the assumption that each person possesses one mobile phone, the number of mobile phone users can represent the possession of mobile phones as well. We obtain the data of the number of electric vehicle possession and mobile phone users within the US in each year from 2010 to 2018[3][4][5]. The data are presented in the chart below:

Table 1: Number of Mobile Phone Users and Electric Cars in the US

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| EV | 57462 | 67295 | 81545 | 128806 | 225508 | 348855 | 462877 | 619989 | 814468 |
| Phone User | 62.6 | 92.8 | 122 | 144.5 | 171 | 190.64 | 208.61 | 246.6 | 257.3 |

According to the data above, the possessions of both electric vehicles and mobile phones have been continuously increasing since 2000. In order to predict the future possession of electric devices, we employ **Regression Analysis** and use the data above as the basis of the analysis. Regression Analysis includes the process of illustrating the data by the points in a graph. The line chart representing the data above is shown below:

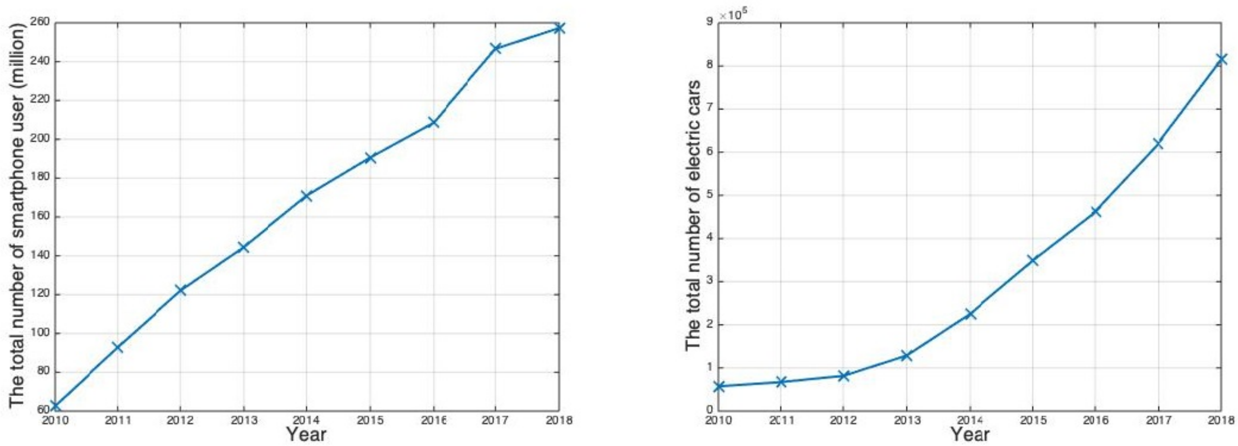


Figure 3: Electric Devices Possession

Next, we determine the line or curve that fits the points. The requirement for a best fit line is that all the points are distributed around the line with slight differences (except for the points that are identified as abnormal values).

• For mobile phones in the left chart, the increasing rate has approximately remained unchanged, except in 2017. We can identify the point of 2017 as an abnormal value. Thus, we observe that the best fit line can be well obtained by adopting a **linear function** which can be represented by the following formula:

$$C = ax + b \tag{1}$$

where $C$ represents the possession number of smart phones, $x$ represents the year, and $a$,$b$ are coefficients. We then use the model of **Least Squares** to determine $a$ and $b$. The model of Least Squares is represented by the formula below:

$$[a, b] = arg\ min \sum_{i=1}^{n} [C_i - ax_i - b]^2 \tag{2}$$

where $C_i$ represents the mobile phone possession number of the $i^{th}$ year, $x_i$ represents the $i^{th}$ year, and $x_1$ represents the first year, which is 2010 in this case. This formula is used to obtain the minimized sum of the squares of the residuals made in the results of the equation, and then calculate the best match point on a function graph for each of the origin data. By using *Matlab* to operate the formula, We are able to calculate $a$ and $b$. The reference of the code in *Matlab* is listed in the section of Appendices.

• For electric vehicles in the right chart above, the increasing rate has a tendency of rapid growth. Thus, it can be illustrated by either an exponential function or a quadratic function. Considering the fact that in a given market such as the electric vehicle market in the US, the demands of the products cannot maintain a slope of an exponential function once the market is approximating saturation. The demands will ultimately reach a maximum under unchanged conditions. The phenomenon that the demands of electric vehicles in recent years have been increasing dramatically is partly due to the environmental protection movements and technological improvements. Under such circumstances, we eliminate the exponential function and adopt **quadratic function** to fit the data. The quadratic function can be represented as follows:

$$E = dx^2 + ex + f \tag{3}$$

where $E$ represents the possession number of electric vehicles, $x$ represents the year, and $d$,$e$,$f$ are the coefficients of the quadratic function.

We then use the same process of Least Squares as shown in formula (2) to determine $d$, $e$ and $f$.
The results of the coefficients of the two formulas above are listed below:

$$C = 24.326x - 4.8826 \times 10^4 \tag{4}$$

$$E = 1.3246 \times 10^4 x^2 - 5.3260 \times 10^7 x + 5.3538 \times 10^{10} \tag{5}$$

After obtaining the formulas above, we present the fitting results of both electric devices:

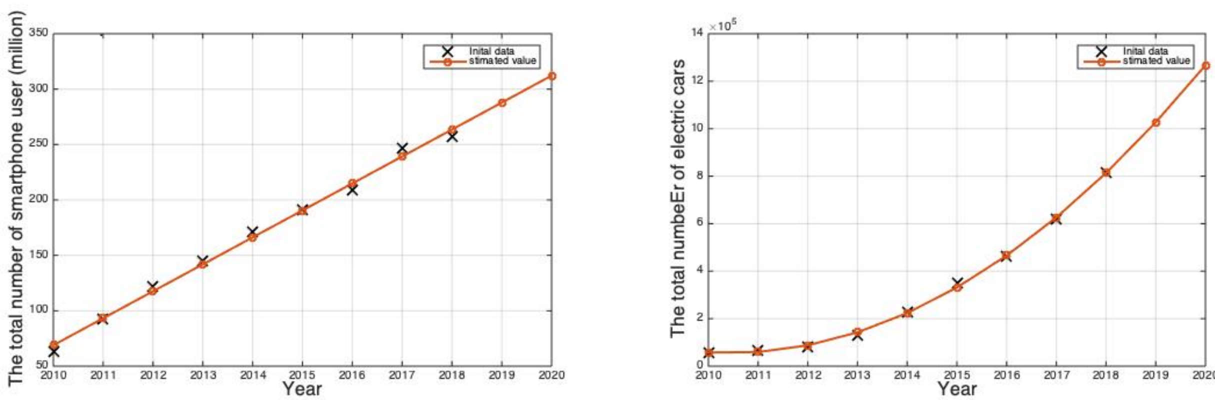


Figure 4: Fitting results of Electric Devices Possession

By employing the formulas of the best fit lines, we are able to obtain the value of electric devices possession in the next two years(including 2019). The predicted number of mobile phones will be 278.8578 million in 2019, and 312.1838 million in 2020. The predicted number of electric vehicles is $1.0271 \times 10^6$ in 2019, and $1.2673 \times 10^6$ in 2020.

### 4.1.2 Definition of Requirements

According to the International Energy Association (IEA), the **recommended ratio** of electric vehicles to charging connection is **10:1**. The ideal ratio represents the sufficient charging outlets for electric vehicles. In the analysis of the trends of charging energy consumption, we identify that the demands of electric vehicles has been increasing and will continue to increase in the near future. Given this background information, we define the amount of electric vehicles above the ratio of 10:1 under the current charging connection supply as the requirement for the charging connections. In order to reach the recommended ratio of 10 : 1, the charging connections in public places should be increased. The unsatisfied demand of charging outlets is shown as the figure below:

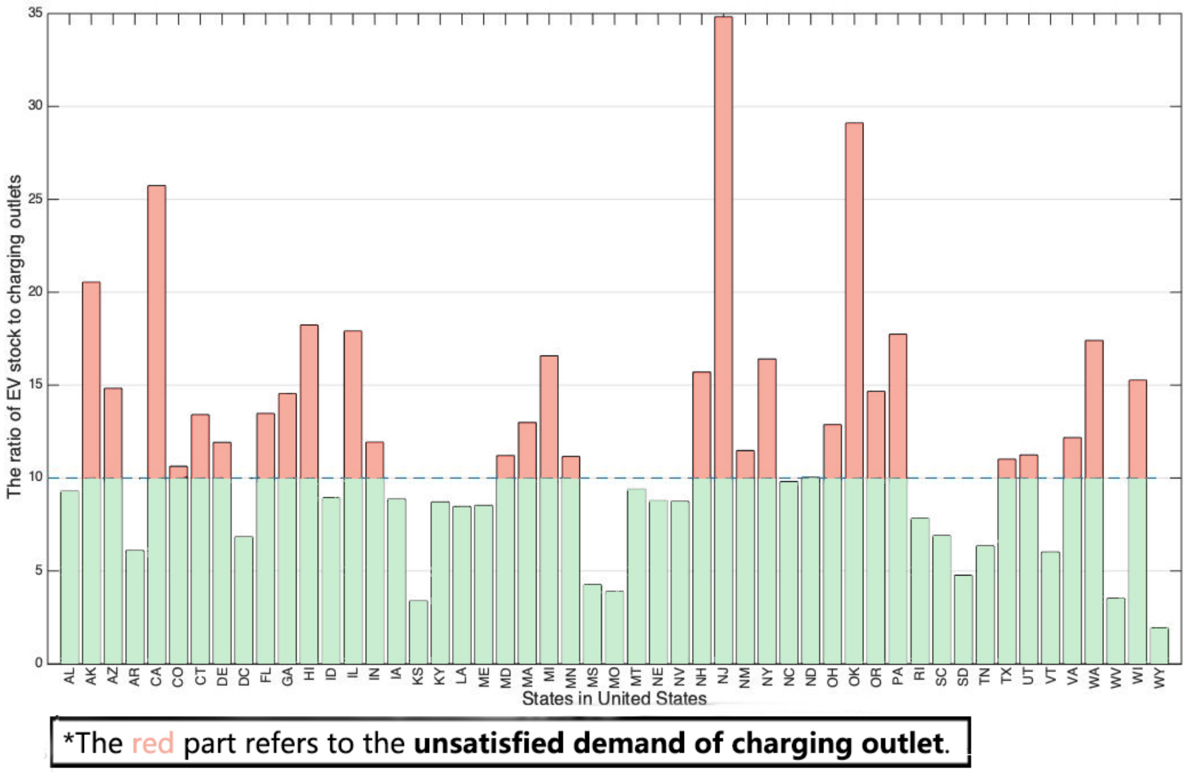


Figure 5: Unsatisfied Outlets Demand in Each State[6]

In the figure above, we can see that the state of the highest ratio is New Jersey, and the lowest is Wyoming. Higher ratio shows that the demands for electric vehicles are increasing, but the number of charging outlets is not yet sufficient for the increasing demands. In most states, the ratio is above 10:1, which means that **most of demands are unsatisfied**. Thus, increasing the installations of the charging outlets in public places is a crucial part of balancing the demands and supply across the nation.

### 4.1.3 Possible Impacts

After predicting the trend of charging consumption, we can identify the possible impacts of the booming of charging consumption:

• The technological improvements on electric vehicles encourage potential consumers to purchase more electric vehicles and the number of electric vehicles will increase.

• The increased demands for charging would add pedestrian flow to public places that provide free charging services.

• The increasing consumption of electric vehicles will add the stock of vehicles and the traffic system might be affected. When the demands for charging increase, the chance of having traffic jams around the charging outlets stations will increase, thus making the area around the public places more crowded.

• Companies producing electronic devices will continue to gain more profits due to the increasing consumption, especially for companies producing electric vehicles.

• The use of the electric vehicles will lead to less carbon dioxide emission. As the demands for electric cars increase, electric cars are going to replace some of the automobiles that use oil, thus contributing to the protection of the environment.

The figure representing the impacts is shown below:

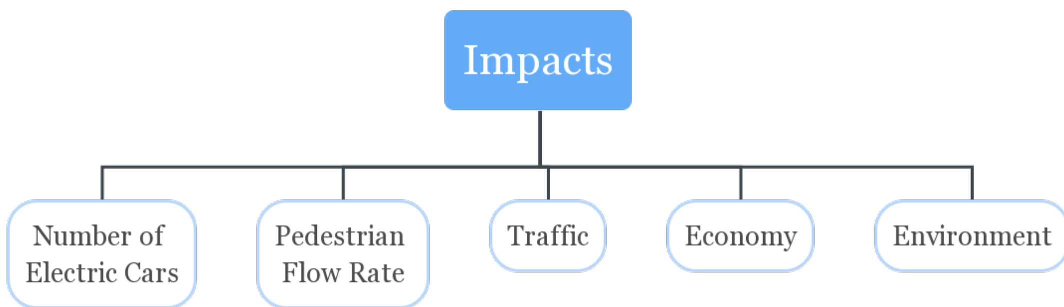


Figure 6: Possible Impacts

## 4.2 The Resulting Costs

### 4.2.1 Model Establishment

We determined the impacts and the requirements of free charging in the last section, and we establish a model to calculate the total cost of providing free charge services in public places in this section.

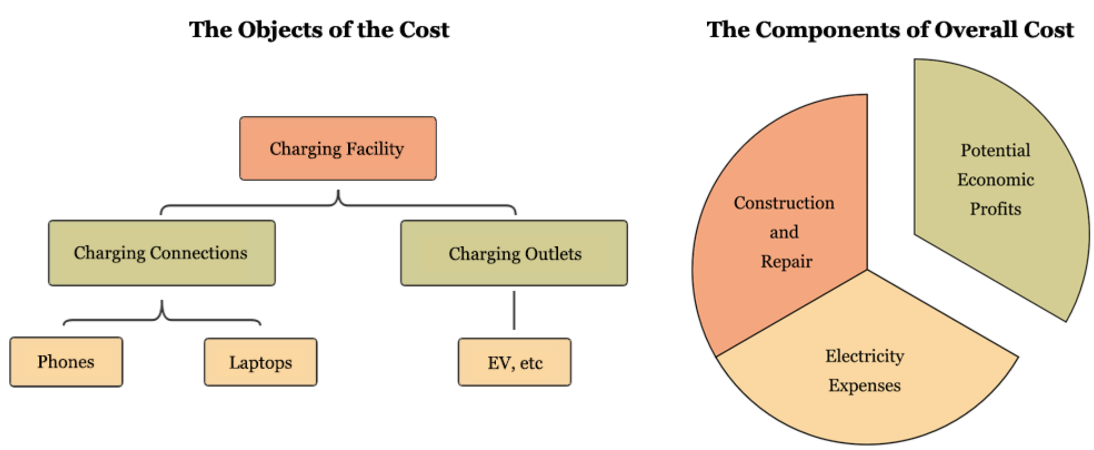


Figure 7: The Structure of Calculating the Total Cost

The objects and the components of the cost are shown in the figure above. In order to better estimate the total costs, we consider two aspects: **expenditure and profits**. While purchasing, installing, and maintaining the charging equipment result in expenditure for the public places, the increasing number of the visitors can bring potential profits. We calculate the total costs of **charging outlets** for electric vehicles and **charging connections** for mobile phones as the equipment of free charging.

• For the total cost of charging connections for mobile phones ($P_{cost}$), several secondary indicators are considered:

1. The total cost of the electricity fee caused by mobile phone charging within a certain public place in a day is represented as $C_1$. $C_1$ is determined by three variables: the number of mobile phone users ($C_p$), the fee of charging a mobile phone from empty battery to full battery ($p_1$), and the average time usage for a phone to exhaust from its full battery ($D$). The formula of $C_1$ is as follows:

$$C_1 = \frac{C_p \times p_1}{D}\ (dollar\ per\ day) \tag{6}$$

In order to determine $p_1$ and $D$, we need to obtain the average energy consumption of charging a phone and the price of electricity. By referring to data, we obtain the average battery capacity as $3400(mAh)$, the average voltage as $4(volt)$, the average commercial electricity price as $10.5(cent/kWh)$, and $D$ as $1.8(day)$.[7][8][9] Then we can give the calculation equation of $C_1$:

$$C_1 = \frac{3400 \times 10^{-3} \times 4 \times 10.5 \times 10^{-3} C_P}{1.8}\ (dollar\ per\ day) \tag{7}$$

2. We use $p_2$ to represent the cost of one charging connection(including material, installing and maintaining), and $s_1$ to represent the average service life of a charging connection. Thus, the fee of one charging connection distributed equally to each day can be represented as the ratio between $p_2$ and $s_1$. According **assumption 5**, the ideal ratio between mobile phones and charging connections is 6:1. Then we obtain the formula for $C_2$, the fee of charging connections distributed to each day:

$$C_2 = \frac{C_p \times p_2}{6s_1}\ (dollar\ per\ day) \tag{8}$$

According to data, $p_2$ is 193 dollars and $s_1$ is 13 years.[9][10] Then $C_2$ can be represented by a formula with constant coefficients:

$$C_2 = 0.00678C_p \tag{9}$$

3. We define $C_3$ as the potential profits of providing free charging connections. We will discuss the extend and the calculation of $C_3$ in the next section. After considering the three aspects above, we eventually summarize our formula for the determination of $P_{cost}$:

$$P_{cost} = C_1 + C_2 - C_3 = \frac{1.428 \times 10^{-3} C_P}{1.8} + 0.00678C_p – C_3\ (dollar\ per\ day) \tag{10}$$

We define $\Delta C_p$ as the increasing number of mobile phone possession, then $\Delta P_{cost}$ can be represented as follows:

$$\Delta P_{cost} = \frac{1.428 \times 10^{-3} \Delta C_P}{1.8} + 0.00678\Delta C_p – C_3\ (dollar\ per\ day) \tag{11}$$

- For the total cost of charging outlets for electric vehicles ($E_{cost}$), we can follow the similar steps we used when determining $P_{cost}$. When calculating the total cost of charging outlets a public place, we consider total electricity fee per day ($C_4$), material, construction and maintenance fee distributed to each day ($C_5$), and the potential profits of installing outlets in a day ($C_6$). We define $ev$ as the number of electric vehicle possession, and $P_1$ as the electricity expenditure of charging one car in a day. Then $C_4$ can be represented as follows:

$$C_4 = ev \times P_1 \tag{12}$$

In order to determine $P_1$ constant, we collect average mileage for one car in a day as 29.2 (mile per day), the number of miles that a electric vehicle can run using one degree of electricity as 2.71 (mile/kWh), and the electricity price as 10.5 (cent/kWh).[11][12][13] Thus, $P_1$ can be represented by the following equation:

$$P_1 = \frac{29.2 \times \times 10.5 \times 10^{-2}}{2.71} = 1.13\ (dollar\ per\ day) \tag{13}$$

We define $P_2$ as the total cost of one charging outlet (including construction and maintenance), $s_2$ as the service life of a electric car, and $\gamma$ as the potential profit of providing one charging outlet. According to previous assumptions, the number of the charging outlets can be represented as $\frac{ev}{10}$ due to the ideal ratio of 10 electric vehicles to 1 charging outlet. Then, the equation used to determine $C_5$ is as follows:

$$C_5 = \frac{ev \times P_2}{10s_2} \tag{14}$$

According to data, $P_2$ is approximately 700 dollars, and $s_2$ is 15 years.[14][15] Converting the units and summarizing the above equations, we are able to obtain the calculation formula for the total cost of charging outlets (including the potential profits $C_6$):

$$E_{cost} = C_4 + C_5 - C_6 = 1.13ev + 0.01278ev - C_6\ (dollar\ per\ day) \tag{15}$$

When the number of electric car possession increases, the increasing cost can be measured as well. We define the amount of increasing cost as $\Delta E_{cost}$, and the amount of increasing possession as $\Delta ev$. $\Delta E_{cost}$ can be represented as follows:

$$\Delta E_{cost} = 1.13\Delta ev + 0.01278ev - C_6\ (dollar\ per\ day) \tag{16}$$

#### 4.2.2 Payment of the Costs

In the previous sections, we obtain the formulas for calculating the costs, and we discuss the possible ways to pay the costs in this section. The various ways of paying the cost are shown in the following figure:

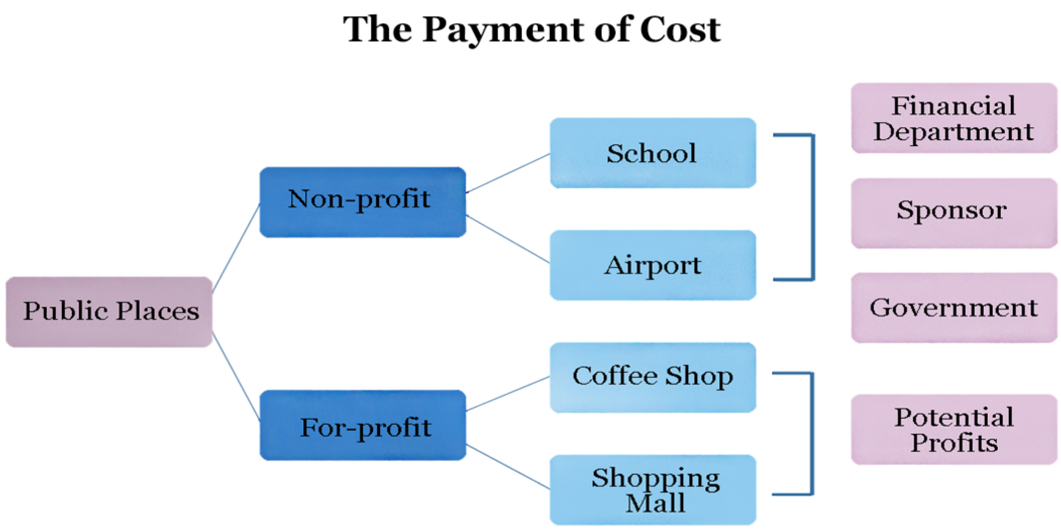


Figure 8: Payment of the Cost

• For commercial or for-profit public places such as coffee shops and shopping malls, the costs of free charging service have to be paid by the companies that own the place. However, according to the formulas of calculating the costs, the actual costs are largely compensated or even exceeded by the potential profits of free charging service. The effect of **attracting more consumers** to the place using free charging service can be dramatic. Thus, the main way for commercial public places to pay the cost is attracting more visitors to purchase.

• For non-profit organizations such as universities and airports, there are several ways to pay the cost. For example, the cost can be paid using the **school budget** from the financial department. Non-profits public places can also seek for private **sponsors** to support the free charge service, and these sponsors can also gain potential profits by inserting advertisements around the charging stations in schools. For instance, electric cars companies can provide schools or airports with free charging equipment in exchange for putting advertisement to attract potential consumers to buy their products. Some of the non-profit public places can also apply for **government support**.

# 5 Model Applications

In each public places, the conditions and circumstances do not always stay the same. In order to better calculate the costs, we assign the public places into **three categories**, of which the representatives are: coffee shops, shopping malls and schools. We then discuss each category separately.

## 5.1 Coffee Shops

Coffee shops represent the type of public places that only provide charging connections for **smaller electronic devices** such as mobile phones and laptops, so that we only adopt the equation of $P_{cost}$ (formula 10) to calculate the costs in coffee shops. In formula 10, we choose mobile phones as a representative of smaller electronic devices for the sake of simplicity. However, when calculating $P_{cost}$ in real life situations, we also consider laptops' charging demands because some visitors use their laptops as well as their mobile phones in coffee shops. According to data, the energy consumption of a laptop is approximately 3 times that of a mobile phone.[16] We adopt the average energy consumption of the two devices and decide to adjust the average energy consumption to **2 times** that of a mobile phone. The adjusted formula of $C_1^*$ is as the following:

$$C_1^* = \frac{1.428 \times 10^{-3} C_P}{0.9} \tag{17}$$

In order to determine $C_3$ as a coffee shop's potential profits from installing more charging connections, we define variable $\gamma$ as **the average profit one customer brings to the place**. Then the profits per day of a coffee shop can be represented as $\gamma$ times the number of customers in a day.
It is a fact that some visitors don't use the charging connections in the coffee shop and some consumers might as well purchase coffee even if the coffee shop does not provide free charging service. Thus, the profits of installing more charging connections only make up a relatively small proportion of the total profits of a coffee shop. We define the proportion of profits gained from free charging service to the total profits as $\alpha$. After defining the variables, we can represent $C_3$ as the following:

$$C_3 = \alpha \times \gamma \times C_p \tag{18}$$

By collecting data of typical types of coffee shops in the US, we know that a large shop which has 434 visitors a day obtains the profits of 362.8 dollars per day.[17][18] Divide the average profits by the number of visitors, we obtain the value of $\gamma$ as 0.84 dollar per person.
For the reason that $\alpha$ is considered as **a sensitive coefficient** (when conditions change), we can assume $\alpha$ as 0.05 in this section. This proportion is only roughly estimated, but we are going to analyse the sensitivity of $\alpha$ in the section of initiatives for reducing the costs to develop our model.
After obtaining $\gamma$ and $\alpha$, we can calculate $C_3$ as the following:

$$C_3 = 0.05 \times 0.84 \times C_p = 0.042 C_p \tag{19}$$

Combining the equations of $C_1$ (formula 17),$C_2$ (formula 9), and $C_3$ (formula 19), we obtain the equation for $P_{cost}$ in coffee shop:

$$Pcost = \frac{1.428 \times 10^{-}3C_P}{0.9} + 0.00678C_p – 0.042C_p = -3.36 \times 10^{-2} C_p \tag{20}$$

Since the coefficient of the equation above is $-3.36 \times 10^{-2}$, the potential profits always exceed the expenditure, which means that under the current $\alpha$ and $\gamma$, a coffee shop can always benefit from free charging service regardless of pedestrian flow rate. We then plug 100, 250 and 434 (as representatives of small, medium and large size) into $C_p$, relatively, and obtain $P_{cost}$ for each scenario as shown in the table below.[19] In the section of future trends, we obtain that the increasing rate of mobile phone users will be approximately 8.45% in 2020, so in addition to calculating $P_{cost}$, we can also calculate the increasing costs in 2020 ($\Delta P_{cost}$) by using formula (11) and employing the increase rate of 8.45%. The result is also shown as the table below:

Table2: Costs for Coffee Shops

| $\alpha = 0.05$, $\gamma = 0.84$ | small-scale | medium-scale | large-scale |
|---|---|---|---|
| The Increasing Costs(dollar per day) | 0.078 | 0.195 | 0.335 |
| Potential Profits(dollar per day) | 0.3549 | 0.88725 | 1.52607 |

The results of both $P_{cost}$ and $\Delta P_{cost}$ are illustrated in the figure below:

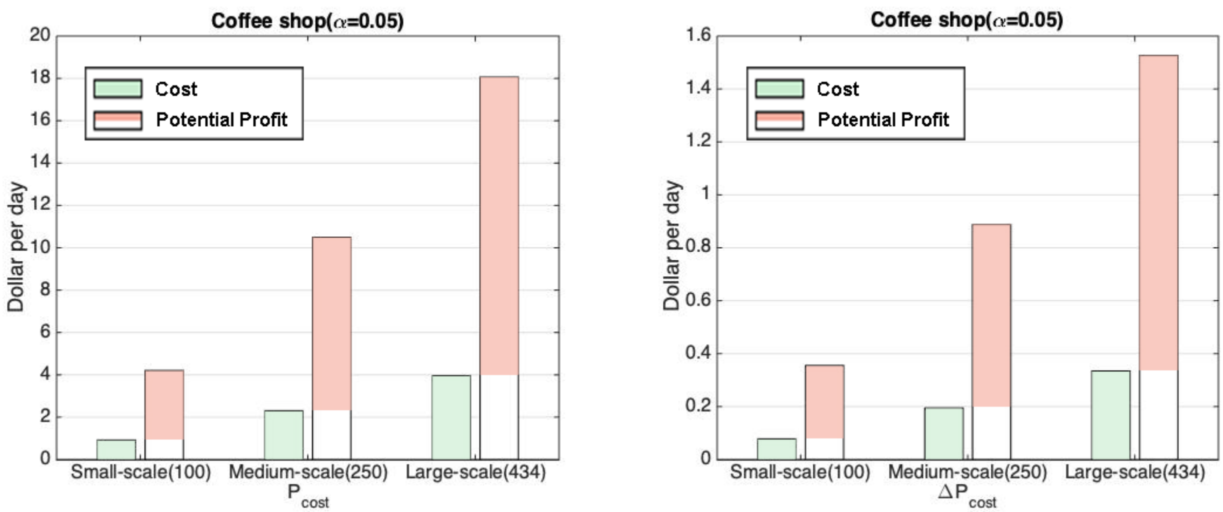


Figure 9: Coffee Shop Costs

## 5.2 Shopping Malls

Shopping Malls represent the types of public places that do not provide charging connections for smaller electronic devices, but only charging outlets for electric vehicles. Thus, we solely use the equation of $E_{cost}$ (formula 15) to calculate the costs in shopping malls.

In addition to the material cost, we also consider the maintenance cost of these charging outlets. We obtain that the maintaining cost of one charging outlet a month is 6.36 dollars, so that the cost of a day is $\frac{6.36}{30}$.[20] Then we add $\frac{6.36C_p}{30\times10}$ to the total cost as the increasing maintaining cost.

We measure $C_6$ by multiplying the potential profits brought by each electric vehicle ($\gamma$) and the number of vehicles (ev):

$$C_6 = ev \times \alpha \times \gamma \tag{21}$$

To determine $\gamma$, we take $Morrison$ as an example for shopping malls and collect data of it. We obtain that the number of stores is 491, the value of the aggregate profits of these stores in a year is 0.815 billion dollars, and the aggregate number of customers in a year is 1.2565 million.[21][22][23] Under these conditions, we can obtain $\gamma$:

$$\gamma = \frac{0.815 \times 10^9}{491 \times 1.2565 \times 10^6} = 1.32\ (dollar) \tag{22}$$

We assume that the average number of consumers come in one car is approximately 3, so that $C_p$ can be calculated as $3ev$. Due to the fact that a large proportion of consumers will still purchase equal products in a shopping mall, even if the shopping mall does not offer free charging service, we $\alpha$ again as the proportion of all customers that come to the shopping mall solely for the sake of the free charging service. Here, we first assume $\alpha$ is 30 percent. This number is roughly estimated and we are going to analyse the sensitivity of it when discussing the initiatives to reduce the cost. Thus, $C_6$ can be represented as the following:

$$C_6 = 1.32 \times 0.3 \times 3ev \tag{23}$$

The changed $E_{cost}$ for a shopping mall is as follows:

$$E_{cost} = 1.13ev + \frac{700ev}{10 \times 15 \times 365} - 1.32 \times 0.3 \times 3ev = -0.024ev \tag{24}$$

The value of $E_{cost}$ appears to be negative, which means that by installing sufficient charging outlets, the shopping mall can have **net profits instead of net costs**. This result relies on the proportion of 30% we assumed, and in the next section, we are going to discuss the impacts of $\alpha$ on the total cost (or profits).
In the section of predicting the future trends, we obtain that **the increasing rate of electric vehicles** is approximately 23.38%, and now we use it to calculate the increasing cost of providing free charge service for electric vehicles ($\Delta E_{cost}$). We express the calculating results by the table below:

Table 3: Cost For Shopping Malls

| $\alpha$=0.3 | 701 | 760 | 818 | 877 | 935 | 994 |
|---|---|---|---|---|---|---|
| Cost(dollar per day) | 264.464 | 286.503 | 308.542 | 330.580 | 352.619 | 374.658 |
| Potential Profit(dollar per day) | 277.754 | 300.901 | 324.047 | 347.193 | 370.339 | 393.485 |

We can present to the results using the figure below:

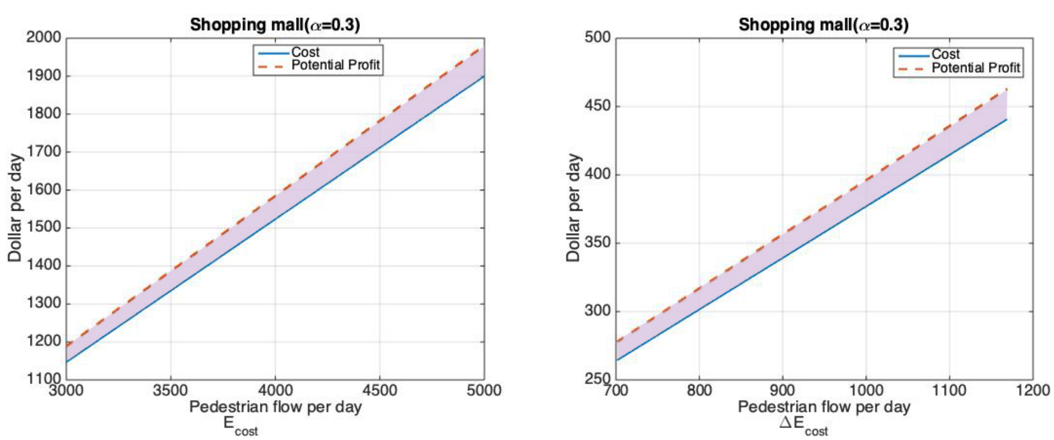


Figure 10: Costs For Shopping Malls

From the figure above, we can see that the difference between potential profits and the cost slightly increases when the pedestrian flow increases. It implies that in larger shops, the net profits of installing charging outlets are more striking.

## 5.3 Schools

For schools, we consider both charging connections for electronic devices and charging outlets for electric vehicles. The steps we follow are similar to the previous two examples:
• For charging connections, we employ the same equation for calculating $P_{cost}$. The difference is that **schools do not have potential economic profits**. The changed equation for $P^*_{cost}$ is as the following:

$$P^*_{cost} = \frac{1.428 \times 10^-3 \times C_P}{0.9} + 0.00678C_p \tag{25}$$

• For charging outlets, we employ the same equation as well, but without the potential profits:

$$E^*_{cost} = 1.13ev + \frac{700ev}{10 \times 15 \times 365} + \frac{6.36ev}{30 \times 10} \tag{26}$$

The total costs ($T_{cost}$) of charging connections and outlets in schools are combined as the following:

$$\begin{aligned} T_{cost} &= E^*_{cost} + P^*_{cost} \\ &= \frac{1.428 \times 10^-3 \times C_P}{0.9} + 0.00678C_p + 1.13ev + \frac{700ev}{10 \times 15 \times 365} + \frac{6.36ev}{30 \times 10} \\ &= 0.008367C_p + 1.16399ev \end{aligned} \tag{27}$$

We choose University of California, Los Angeles (UCLA) as the representative of schools. For UCLA, the number of students is 44947, the number of faculty members is 7388.[24] Assuming that one person possesses one phone or laptop, we obtain that the total number of electronic devices in UCLA is 52335 ($C_P$). In order to estimate the number of electric cars possession, we collect the data from the state of California. The total population in California is 39.915 million, and the electric cars possession is 506608.[6][25] According to the proportion between population and electric car possession, we obtain that there are approximately 664 electric vehicles in UCLA ($ev$). After plugging the values into $C_p$ and $ev$, we present the result in the figure below:

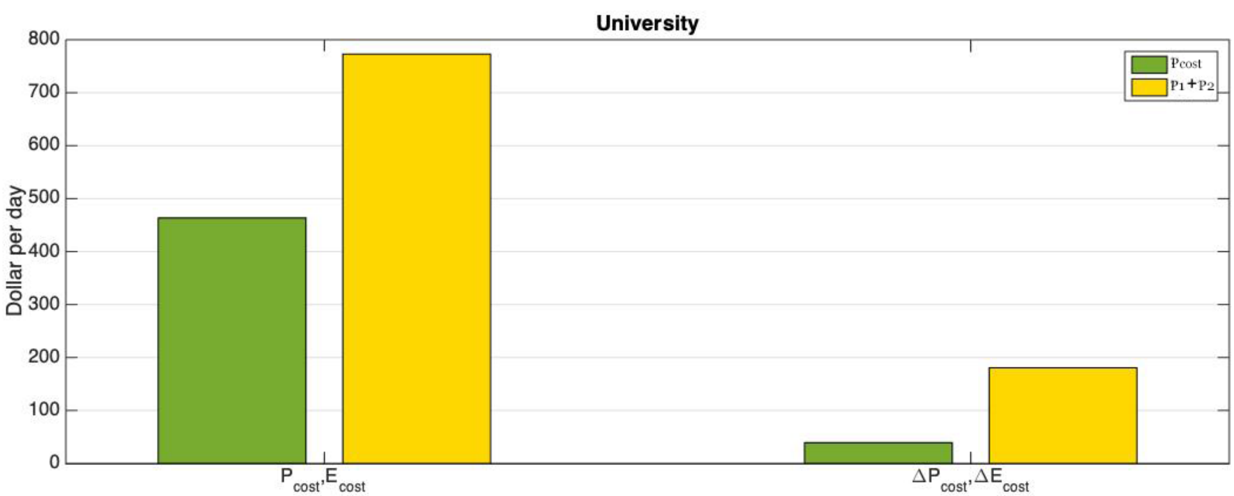


Figure 11: Different Types of Cost For Universities

# 6 Initiatives

1. For the purpose of compensating for the cost of charging stations, commercial public places can **promote the purchasing power of customers**. The advancement in purchasing power will increase the income of these public places.

2. **Raising the prices of the products** sold in public places can make up the cost of setting up the charging equipment. The charging station is considered part of the customer service and it is reasonable for the customer to pay more for the extra services they receive. By raising the prices of the products, the costs of charging services can be largely compensated.

3. **Reducing the equipment ratio** in a particular situation can also reduce the cost of building up charging equipment in public places. In certain places, the ideal ratio of charging outlets to electric vehicles is not limited to 1:10. The authority of public places can adjust the ratio to 1:15, for example, in order to reduce the cost. We are going to discuss these options in different categories of public places in the following sections.

The figure below shows the three ways of reducing the cost: promoting purchase power, increasing the price, and lowering the equipment ratio.

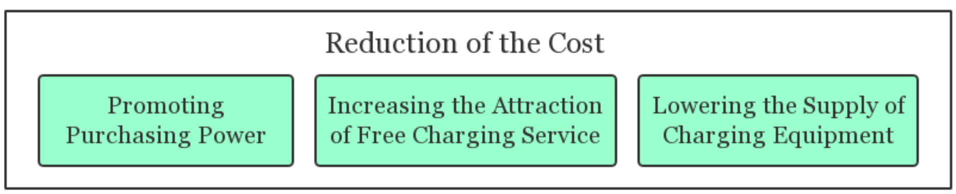


Figure 12: Reduction of the Cost

## 6.1 Initiatives For Coffee Shops

Coffee shop is a representative of public places that only provide charging connections for mobile phones. According to formula (20), the correlation between $P_{cost}$ and $C_p$ is negative, which means that a coffee shop can benefit from installing sufficient charging connections regardless of its size. However, it is partly due to the reason that the value of $\alpha$, the ratio between customers that come to the shop because of the charging service and the total number of customers. In previous sections, we assume that $\alpha$ is equal to 0.05 by rough estimations. However, $\alpha$ **is a sensitive coefficient because of its uncertainty and mutability**, and the different values of it can largely affect the final result of the total cost. In order to develop our model accurately, we should discuss the influence of $\alpha$ on the resulting cost. By adjusting the value of $\alpha$, we can obtain a figure as shown below.

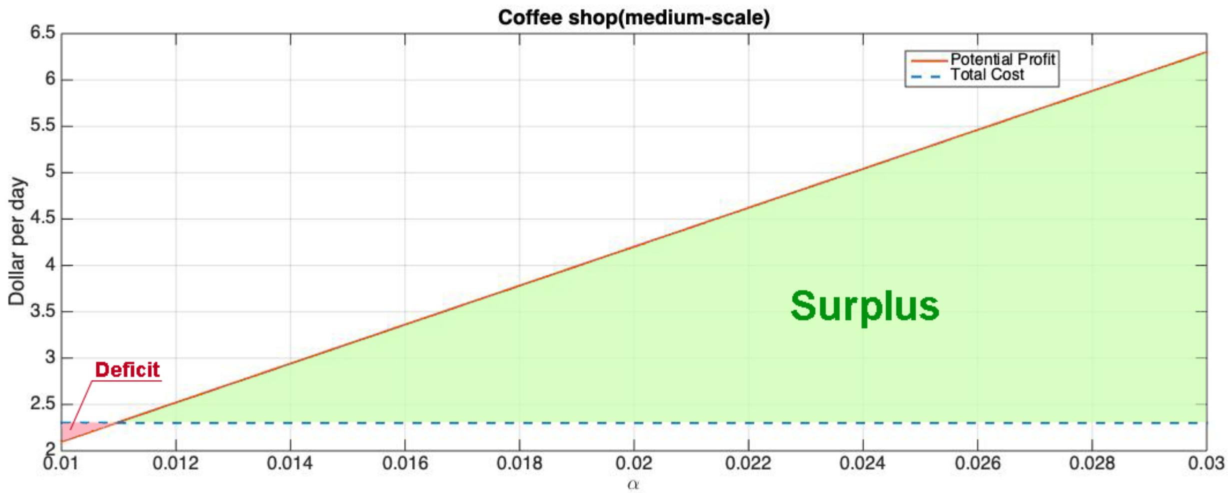


Figure 13: Costs For Coffee Shops

From the figure above, we can see that if $\alpha$ is any value above 0.011, the profits will exceed the cost. Thus, to reduce cost or to increase profits, increasing the value of $\alpha$ is a useful method. Strategies to raise $\alpha$ include putting **more advertisements** about the free charging service to attract more consumers.

## 6.2 Initiatives For Shopping Malls

Shopping malls are the representatives of the types of public places that only provide charging outlets for electric vehicles. The formula of $E_{cost}$ is negative under the value of 0.3 for $\alpha$, which means that the shopping mall can have profits instead of deficit.

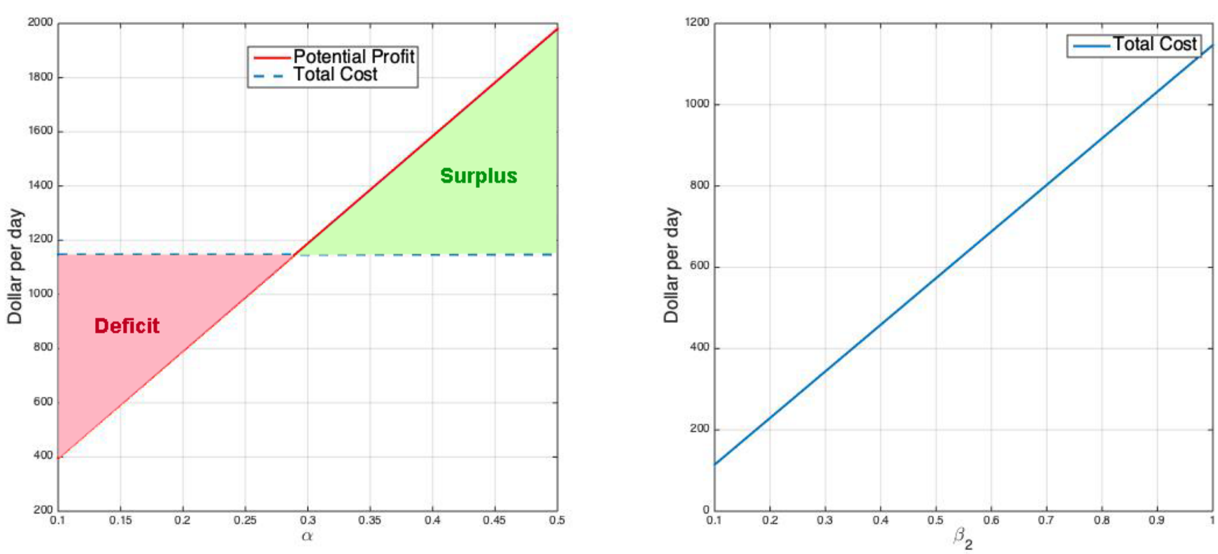


Figure 14: Costs for Shopping Malls

In the left chart above, the total cost is determined ($\beta 2$ is fixed), and the potential profit

increases as $\alpha$ increases. This represents the phenomenon that if more customers come to the shopping mall due to the reason that it provides them with free charging services, the potential profit caused by the service will increase. From the figure, we can see that once the value of $\alpha$ reaches 0.28, the shopping mall benefits from free charging.
In the right chart above, when the value of $\beta_2$ changes, the total cost changes as well. **When $\beta 2$ increases**, the total cost increases as well. This represents that when shopping malls add more outlets to satisfy the demands, the cost will naturally increase.
Considering both $\alpha$ and $\beta_2$, it can be recommended that the shopping malls **increase $\alpha$ while reducing $\beta_2$**. However, the decrease of $\beta_2$ can result in the decreasing of the satisfaction index of the consumers, thus making them unwilling to come. Thus, balancing the two sensitive coefficients is important for shopping malls.

The other way to reduce the costs of free charge for commercial public places is to increase the purchase power of the consumers. In other words, increase the unit profit gained from each consumer ($\eta$). The chart below represents the relation between the average profits gained from each consumer and the cost (or profits) of free charge for both coffee shops and shopping malls.

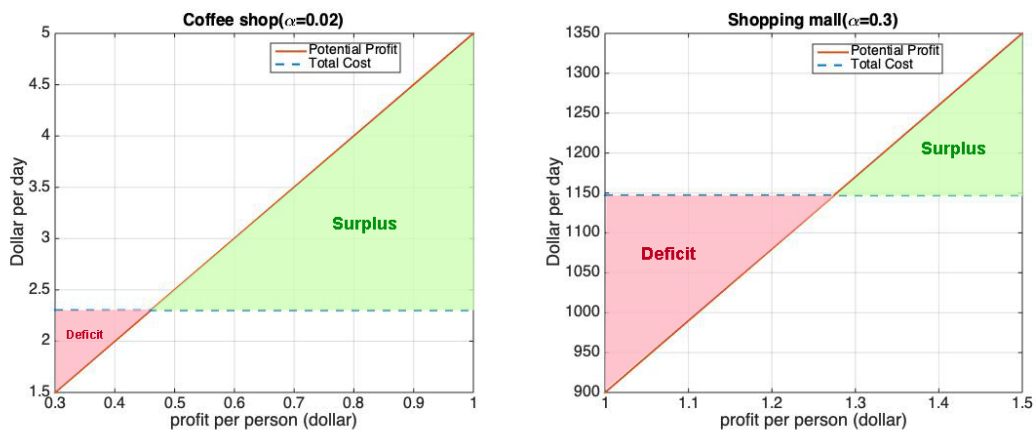


Figure 15: The Influence of Purchase Power on the Cost of Free Charge

For coffee shops, once the profits per person rise above 0.46 dollar, the cost can be completely compensated by the potential profits (when $\alpha$ is 0.02), and it is 1.27 dollars for shopping malls (when $\alpha$ is 0.3). The possible ways to increase the profit per person include increasing the prices of products within shopping malls or coffee shops and several other marketing strategies.

## 6.3 Initiatives For Schools

Schools represent the type of public places that provide both mobile phone charging connections and electric cars charging outlets. In addition, schools are non-profit public places, so that free charging services bring no potential profits for schools. In the formula of $T_{cost}$ (formula 27), $T_{cost}$ is determined by both $E^*_{cost}$ and $P^*_{cost}$. When considering $\beta_1$ and $\beta_2$ together, we can use a three dimensional image to represent the relations between these variables. The figure is shown below:

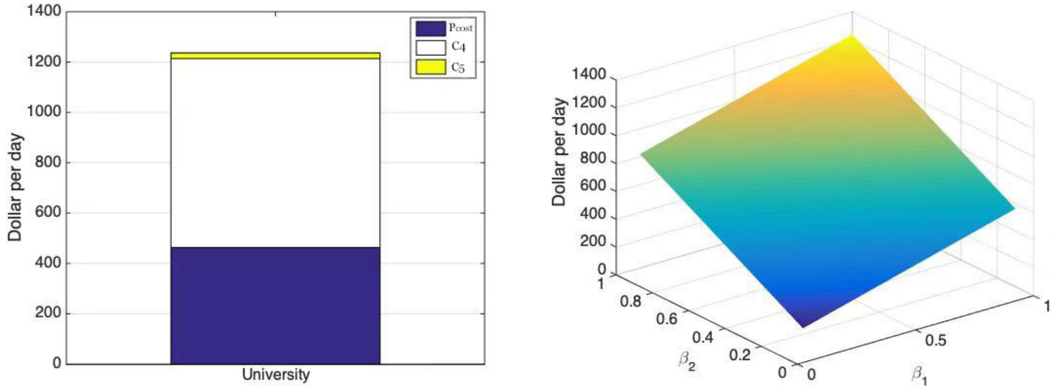


Figure 16: Costs For Universities

• In the left figure, $P_{cost}$ represents the total cost of free charging connections for mobile phones, $C_4$ represents the electricity expenditure for free charging outlets, and $C_5$ represents the constructing and maintaining cost for outlets. The three indicators add up to the total cost for universities to provide free charging for both mobile phones and electric vehicles.

• In the right figure, the three dimensional image represents $\beta_1$ and $\beta_2$. As shown in the figure, the best way to minimize the cost is to **reduce both** $\beta_1$ **and** $\beta_2$ to their minimums. However, the purpose of free charge in schools is to provide convenience and efficiency for the faculties and students. Thus, schools will inevitably receive deficit by providing free charge even if $\beta_1$ and $\beta_2$ have been reduced. Therefore, the core of reducing the cost for non-profit organizations as such is how the cost be paid. There are several ways to pay the cost, including government support, sponsors and the school budget.

# 7 Model Strengths and Weaknesses

## 7.1 Strengths

1. Since the public places are classified into different genres, we build up several different patterns of model, which keeps the model accurate no matter which places it is applied to.
2. Due to a mass of factual data use, the conclusions we reach to are of high veracity and trustworthiness.
3. When dealing with data that can not be acquired directly, we collect related data to help obtain a reliable estimated number; when facing the data that can not be found, we identify sensitive parameters to improve the flexibility and practicability of our model.
4. Matching the factual data with the model after it is constructed, we confirm the validity and reliability of the mode through emulation and analysis.

### 7.2 Weaknesses

1. Since some specific data and numbers about public places are difficult to obtain, some of the coefficients that our model used inevitably bring some errors .
2. While there are various kinds of devices that might be in need of charging, we only consider phones, laptops, and electric vehicles, which compromises the completeness of our model.

## 8 Conclusion

Our goal was to predict the future trend of charging energy consumption and evaluate the possible costs of providing free charging services in public places. To achieve the goal, we collected data on the stock of electric devices including mobile phones and electric vehicles. We adopted the Least Squares Regression model to predict the future trend and obtained the results that the increased rate of mobile phone users is linear and will be 8.45% in 2020, and the increasing rate of electric vehicles is quadratic and will be 23.38% in 2020. By comparing the ratio of electric devices to the charging equipment, we determined the demand of charging services. We discussed the costs based on the equipment fee, electricity fee, and the potential profits. We classified the public places into three categories and distinguished the differences in terms of the use of different electric devices and the ways to gain potential profits. We used factual data and employed sensitivity analysis to determine the costs and potential profits. By further discussions on the calculating process of the costs and profits, we proposed several initiatives to reduce the net cost, including promoting the purchasing power, lowering the equipment rate, and raising the prices of the products.

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# 10 Appendices

## 10.1 Appendices A: Original Data of Figure 5

| State | Charging Locations (1) | Charging Outlets (2) | Outlets Per Location | EV Stock (3) | EVs to Charging Outlets |
|---|---|---|---|---|---|
| AL | 115 | 268 | 2.33 | 2487 | 9.28 |
| AK | 16 | 26 | 1.62 | 534 | 20.54 |
| AZ | 454 | 1223 | 2.69 | 18129 | 14.82 |
| AR | 72 | 196 | 2.72 | 1194 | 6.09 |
| CA | 5095 | 19687 | 3.86 | 506608 | 25.73 |
| CO | 692 | 1857 | 2.68 | 19738 | 10.63 |
| CT | 335 | 814 | 2.43 | 10916 | 13.41 |
| DE | 49 | 159 | 3.24 | 1895 | 11.92 |
| DC | 122 | 340 | 2.79 | 2321 | 6.83 |
| FL | 1165 | 3010 | 2.58 | 40548 | 13.47 |
| GA | 773 | 2335 | 3.02 | 33947 | 14.54 |
| HI | 265 | 523 | 1.97 | 9539 | 18.24 |
| ID | 70 | 163 | 2.33 | 1459 | 8.95 |
| IL | 487 | 1255 | 2.58 | 22475 | 17.91 |
| IN | 207 | 507 | 2.45 | 6047 | 11.93 |
| IA | 127 | 316 | 2.49 | 2799 | 8.86 |
| KS | 185 | 777 | 4.2 | 2621 | 3.37 |
| KY | 115 | 251 | 2.18 | 2186 | 8.71 |
| LA | 91 | 213 | 2.34 | 1803 | 8.46 |
| ME | 155 | 288 | 1.86 | 2456 | 8.53 |
| MD | 593 | 1598 | 2.69 | 17900 | 11.2 |
| MA | 597 | 1758 | 2.94 | 22824 | 12.98 |
| MI | 401 | 1112 | 2.77 | 18434 | 16.58 |
| MN | 326 | 793 | 2.43 | 8845 | 11.15 |
| MS | 56 | 152 | 2.71 | 649 | 4.27 |
| MO | 408 | 1720 | 4.22 | 6676 | 3.88 |
| MT | 44 | 110 | 2.5 | 1033 | 9.39 |
| NE | 79 | 207 | 2.62 | 1816 | 8.77 |
| NV | 247 | 721 | 2.92 | 6296 | 8.73 |
| NH | 110 | 215 | 1.95 | 3375 | 15.7 |
| NJ | 290 | 745 | 2.57 | 25945 | 34.83 |
| NM | 68 | 183 | 2.69 | 2100 | 11.48 |

| | | | | | |
|---|---|---|---|---|---|
| NY | 1190 | 2828 | 2.38 | 46397 | 16.41 |
| NC | 582 | 1331 | 2.29 | 13054 | 9.81 |
| ND | 19 | 29 | 1.53 | 291 | 10.03 |
| OH | 432 | 996 | 2.31 | 12820 | 12.87 |
| OK | 67 | 169 | 2.52 | 4918 | 29.1 |
| OR | 605 | 1462 | 2.42 | 21433 | 14.66 |
| PA | 433 | 1029 | 2.38 | 18248 | 17.73 |
| RI | 85 | 251 | 2.95 | 1966 | 7.83 |
| SC | 234 | 500 | 2.14 | 3447 | 6.89 |
| SD | 33 | 89 | 2.7 | 424 | 4.76 |
| TN | 404 | 1054 | 2.61 | 6684 | 6.34 |
| TX | 1134 | 3109 | 2.74 | 34239 | 11.01 |
| UT | 210 | 602 | 2.87 | 6767 | 11.24 |
| VT | 212 | 550 | 2.59 | 3307 | 6.01 |
| VA | 578 | 1356 | 2.35 | 16505 | 12.17 |
| WA | 874 | 2383 | 2.73 | 41459 | 17.4 |
| WV | 87 | 212 | 2.44 | 746 | 3.52 |
| WI | 285 | 542 | 1.9 | 8271 | 15.26 |
| WY | 51 | 139 | 2.73 | 269 | 1.94 |
| Median | 234 | 550 | 2.58 | 6296 | 11.15 |
| Total | 21324 | 62153 | 2.91 | 1046840 | 16.84 |

## 10.2 Appendices B: *Matlab* Realizations

Problem 1

```
data=[2010 57462 62.6;2011 67295 92.8;2012 81545 122;2013 128806 144.5;2014 225508
171;2015 348855 190.64;2016 462877 208.61;2017 619989 246.6;2018 814468 257.3];
figure(1)
subplot(121)
plot(data(:,1),data(:,3),'x')
x=data(:,1);
y=data(:,3);
P=polyfit(x,y,1);
xx=2010:2020;
yy=polyval(P,xx);
plot(data(:,1),data(:,3),'x',xx,yy,'-o')
grid on
legend('Inital data','stimated value')
xlabel('Year')
```

```
ylabel(’The total number of smartphone user (million)’)
subplot(122)
P=polyfit(x,data(:,2),2);
xx=2010:2020;
yyy=polyval(P,xx);
plot(data(:,1),data(:,2),’x’,xx,yyy,’-o’)
grid on
legend(’Inital data’,’stimated value’)
xlabel(’Year’)
ylabel(’The total number of electric cars’)
clc
clear
close all
d=[268 2.33 2487;26 1.62 534;1223 2.69 18129;196 2.72 1194;19687 3.86 506608;1857 2.68
19738;814 2.43 10916;159 3.24 1895;340 2.79 2321;3010 2.58 40548;2335 3.02 33947;523 1.97
9539;163 2.33 1459;1255 2.58 22475;507 2.45 6047;316 2.49 2799;777 4.20 2621;251 2.18
2186;213 2.34 1803;288 1.86 2456;1598 2.69 17900;1758 2.94 22824;1112 2.77 18434;793 2.43
8845;152 2.71 649;1720 4.22 6676;110 2.50 1033;207 2.62 1816;721 2.92 6296;215 1.95 3375;745
2.57 25945;183 2.69 2100;2828 2.38 46397;1331 2.29 13054;29 1.53 291;996 2.31 12820;169
2.52 4918;1462 2.42 21433;1029 2.38 18248;251 2.95 1966;500 2.14 3447;89 2.70 424;1054 2.61
6684;3109 2.74 34239;602 2.87 6767;550 2.59 3307;1356 2.35 16505;2383 2.73 41459;212 2.44
746;542 1.90 8271;139 2.73 269];
d1=d(:,3)./d(:,1);
bar(d1)
x1=0:51;
y1=10*ones(1,length(x1));
hold on
plot(x1,y1,’–’)
an=’AL’ ’AK’ ’AZ’ ’AR’ ’CA’ ’CO’ ’CT’ ’DE’ ’DC’ ’FL’ ’GA’ ’HI’ ’ID’ ’IL’ ’IN’ ’IA’ ’KS’
’KY’ ’LA’ ’ME’ ’MD’ ’MA’ ’MI’ ’MN’ ’MS’ ’MO’ ’MT’ ’NE’ ’NV’ ’NH’ ’NJ’ ’NM’ ’NY’ ’NC’
’ND’ ’OH’ ’OK’ ’OR’ ’PA’ ’RI’ ’SC’ ’SD’ ’TN’ ’TX’ ’UT’ ’VT’ ’VA’ ’WA’ ’WV’ ’WI’ ’WY’;
set(gca, ’XTick’, 1:51, ’XTickLabel’, an,’FontSize’,12)
set(gca,’XTickLabelRotation’,90)
```

Problem 3

```
clc
clear
close all
cp=[100 250 430];
for i=1:length(cp)
h(1,i)=cp(i)*0.1428*10^(-2)*2/1.8+217*cp(i)/6/13/365;
h(2,i)=cp(i)*0.84*0.05;
end
figure(2)
subplot(121)
```

```
bar(h')
legend('Cost','Potential Profit')
title('Coffee shop(\alpha=0.05)')
cp=[100 250 430]*0.0845;
for i=1:length(cp)
h(1,i)=cp(i)*0.1428*10^(-2)*2/1.8+217*cp(i)/6/13/365;
h(2,i)=cp(i)*0.84*0.05;
end
subplot(122)
bar(h')
legend('Cost','Potential Profit')
title('Coffee shop(\alpha=0.05)')
cp=3000:5000;
for i=1:length(cp)
h1(i)=cp(i)/3*1.13+700*cp(i)/3/10*0.034/15/365+6.36/30*cp(i)/3/10*0.034;
h2(i)=cp(i)*1.32*0.3;
end
figure(3)
subplot(121)
plot(cp,h1,cp,h2)
legend('Cost','Potential Profit')
title('Shopping mall(\alpha=0.3)')
subplot(122)
cp=cp*0.2338;
clear h1
clear h2
for i=1:length(cp)
h1(i)=cp(i)/3*1.13+700*cp(i)/3/10*0.034/15/365+6.36/30*cp(i)/3/10*0.034;
h2(i)=cp(i)*1.32*0.3;
end
plot(cp,h1,cp,h2)
legend('Cost','Potential Profit')
title('Shopping mall(\alpha=0.3)')
pause
xs=[44947+7388,948+376,1208+32];
qc=[664,16.8,0.4];
for i=1:3
G(1,i)=xs(i)*0.1428*0.01*2/1.8+(207*xs(i)/6)/13/365;
G(2,i)=qc(i)*1.13+700*qc(i)/10/15/365+6.36/30*qc(i)/10;
end
figure(4)
subplot(121)
temp2=[G(:,1),[0,0]'];
temp3=G(:,1);
bar(temp2')
```

```
legend('\eta_1','\eta_2+\eta_3')
subplot(122)
bar(G(:,2:3)')
legend('\eta_1','\eta_2+\eta_3')
xs=[44947+7388,948+376,1208+32]*0.0845;
qc=[664,16.8,0.4]*0.2338;
for i=1:3
G(1,i)=xs(i)*0.1428*0.01*2/1.8+(207*xs(i)/6)/13/365;
G(2,i)=qc(i)*1.13+700*qc(i)/10/15/365+6.36/30*qc(i)/10;
end
figure(5)
subplot(121)
temp2=[G(:,1),[0,0]'];
bar(temp2')
legend('\eta_1','\eta_2+\eta_3')
subplot(122)
bar(G(:,2:3)')
legend('\eta_1','\eta_2+\eta_3')
figure(6)
temp2=[temp3,G(:,1)];
bar(temp2')
legend('\eta_1','\eta_2+\eta_3')
count2=1;
for i=0.1:0.1:1;
count1=1;
for j=0.1:0.1:1;
for k=1:3
G(1,k)=(xs(k)*0.1428*0.01*2/1.8+(207*xs(k)/6)/13/365)*i;
G(2,k)=(qc(k)*1.13)*j;
G(3,k)=700*qc(k)/10/15/365+6.36/30*qc(k)/10;
s1(count1,count2)=G(1,1)+G(3,1)+G(2,1);
end
count1=count1+1;
end
count2=count2+1;
end
figure(7)
subplot(121)
temp1=[G(:,1),[0,0,0]'];
bar(temp1','stacked')
legend('\eta_1','\eta_2+\eta_3')
subplot(122)
surf(s1)
shading interp
xlabel('\beta_1')
```

```
ylabel('\beta_2')
zlabel('Costs(dollar)')
```

Problem 4

```
cp=3000;
clear h2
clear h3
h1=cp/3*1.13+700*cp/3/10*0.034/15/365+6.36/30*cp/3/10*0.034;
test=0.1:0.01:0.5;
for i=1:length(test)
h2(i)=cp*1.32*test(i);
end
h3=h1*ones(1,length(test));
figure(5)
subplot(121) plot(test,h2,test,h3,'--')
legend('Potential Profit','Total Cost')
xlabel('\alpha')
ylabel('Dollar per day')
grid on
subplot(122)
test=0.1:0.1:1
for i=1:length(test)
h4(i)=h1*test(i)
end
plot(test,h4)
xlabel('\beta_2')
grid on
legend('Total Cost')
ylabel('Dollar per day')
figure(6)
cp=250;
clear h1
clear h2
h1=cp*0.1428*10^(-2)*2/1.8+217*cp/6/13/365;
test=0.01:0.01:0.05
for i=1:length(test)
h2(i)=cp*0.84*test(i);
end
h5=ones(1,length(test))*h1;
plot(test,h2,test,h5,'--')
legend('Potential Profit','Total Cost')
xlabel('\alpha')
ylabel('Dollar per day')
```