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T3 __________	Problem Chosen	F3 __________
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2018
MCM/ICM
Summary Sheet

Summary

For these years people have come to realizing that the overuse of fuel and gas is posing a great threat to the environment. At the same time, electricity resource as an alternative has drawn more and more attention. Global interest in switching to electricity vehicles has given rise to an increasing number of charging stations. In this essay, we propose our model named Spatial-Temporal Linear Programming(STLP). We first integrate our solution into the framework of an Integer Linear Programming(ILP) taking only distance into consideration. In the following tasks, we gradually add more constraints to make our model more comprehensive and applicable. We abstract the problem of determining locations as minimizing an objective function under a set of constraints. Due to the NP-hard complexity of the ILP problem, we employ the technique of simulated annealing algorithm to improve efficiency.

Firstly, we analyze the current network of charging stations of Tesla in the US and draw the conclusion that the attempt made by Tesla is actually leading in the effort of totally switching to EV. We then apply our model to both the US and the South Korea. While the preliminary version only considers the locations in a microscopic view, we now pay attention to vehicle density around a charging station since it affects number of chargers in average waiting time. We employ the Queuing Theory to model the situation of power shortage. This factor is gracefully integrated into our framework by adding additional constraints and a term in the objective function indicating minimizing the average waiting time.

Secondly, we further extend our model to a temporal perspective. In other words, we assume that the scheduling is not done overnight. We still apply the optimization tool to the objective function by making the assumption that the locations at a former stage remain optimal later since the cost of tearing down a station is considered intolerable. By merging both the spatial and temporal factors together, we've finally reached our version of STLP.

Thirdly, not only the distance and vehicle density influence our conclusion but also some other specific factors. After taking a closer look at countries such as China, Singapore with totally different geographical conditions, we propose a new classification system for determining the timeline to cater to specific conditions in economics, road construction and so on.

Finally, we spend some time discussing the possible influences of some emerging techniques on our model. We also write a handout for leaders from different countries to make decisions to better facilitate the proposal of EVs after they return.

Keywords: **Linear Programming ; Queuing Theory; Simulated Annealing Algorithm**

Contents

1 Introduction

1.1 Background

The reliance on the fossil fuels of traditional vehicles causes great pollution, which calls urgently for the widespread diffusion of clean energy. Many countries have announced that gasoline cars and diesel cars will be banned in the near future. There are mainly six barriers to the promotion of alternative-fuel vehicles, limited numbers of refueling stations, limited range, high costs, safety and liability concerns, improvements in the competition (i.e., more efficient combustion engines), and high initial costs for consumers (Romm, 2006).

It is the same with electric vehicles. Though they are environmental-friendly generally, the limited range restrains long-distance trips without the help of charge stations. Considering the transfer from traditional vehicles to electric vehicles has to take some time, whether consumers are willing to respond to the appeal depends much on the development of charging infrastructure. There is a strong need to direct investments of charging facilities to minimize the cost and maximize the efficiency.

When a country plans to establish the refueling station network, several factors have to be taken into account. The number and location of the charging stations. The number of the chargers.

The different demands between the city and country In different stages of the construction, the network appears different, for example, when electric vehicles cover 10% of all cars, 30% of all cars, 50% of all cars, and 90% of all cars.

1.2 Our work

In this paper, our proposed model solves the problem of placing charging stations for convenience of EV owners. Using our model, we completed several specific tasks.
(1) By analyzing the network of charging stations of Tesla as well as some other data we collected, we figured out the trend for the growth of charging stations in the US.
(2) We applied our model to the South Korea and took the specific conditions into consideration. By adopting the queuing theory, we successfully predicted the distribution of charging stations and the number of chargers as well.
(3) In realistic situations, we have to break the process into several steps. So we extended our model to a spatial temporal linear programming. Base on the extended version, we tracked how the network grows at different stages.
(4) When it comes to a country with totally different conditions, we came up with a classification system that determines how a country can push ahead with a timeline for totally switching to EVs nationwide.
(5) We analyzed several emerging factors that would have impact on the result of our model.
(6) We wrote a handout for the leaders at the conference where we gave advice on how to come up with a timeline to facilitate the procedure of switching to EVs nationwide.
The rest of the paper is organized as follows:
(1) In section 2, we will give some assumptions in favor of our proposed model.
(2) In section 3, we will give a brief introduction to our preliminary version of model. To

be more specific, the objective function, constraints as well as the applied scenes.
(3) In section 4, we dive into the tasks and will see how our model can be applied to realistic problems.
(4) Section 5 consists of our handout for leaders to propose a reasonable timeline for switching to EVs in their countries.

2 Assumptions

(1) The locations can only be located at crossroads or the middle of roads, based on which we can generate our candidates for nodes in the graph.
(2) The demands of charging is in proportion to the vehicle density at the region where it's located.
(3) The number of vehicles can be estimated through logistic regression from statistics from previous years.

3 The Spatial Temporal Linear Programming Model

3.1 Basic Theoretical framework

3.1.1 framework

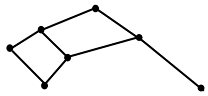

Figure1:Graph Abstraction

Following the successful practice of Integer Linear Programming(ILP) as well as the efficient algorithms proposed these years on network flow, our solution is formulated as a standard ILP, where we minimize a object function given a set of constraints.

To begin with, we simplify the problem under some strict assumptions, and many factors are not taken into consideration. Experiments show that our model works well on several simple occasions. However, in the following tasks, we will gradually eliminate the assumptions and make our model more applicable to different scenarios.

Taking advantage of the road conditions, we can regard the distribution of charging stations as a graph G. The possible location for a charging station, which we'll explain later, is seen as a node. We denote the set of nodes as V. On the other hand, the roads connecting two possible locations are seen as edges, which we denote as E.

Based on the notations given above, it is clear that our goal is to find a subset of nodes, i.e. $V' \subset V$ to meet the requirements of both cost and convenience, and vice versa.

We consider a total of n possible locations for charging stations. For $i \in \{1, 2, \ldots, n\}$, we use a binary variable X_i to denote whether we will build a station at v_i, and c_i refers to the cost of building it. Our aim is obviously to minimize the construction cost, i.e. $\Sigma_{i=1}^{n} c_i X_i$.

Several constraints have to be taken into consideration before we jump to the next step of optimization. We will introduce more notations to make the formulation more clear. Suppose that we are ignoring the factors of car density as well as population. That is, we only have to guarantee that every single car can take a trip as it will based on the current charging network. Let's look into a single car's traveling. We use r_i to denote the remaining electricity at station v_i, and f_i for the electricity refueled at station v_i. Obviously, it satisfies:

$$r_i \geq 0, \forall i \in \{1, 2, \ldots, n\}$$

$$f_i \geq 0, \forall i \in \{1, 2, \ldots, n\}$$

One assumption is that the electricity cost is linear to the distance the vehicle travels. Suppose it costs a vehicle δ units of electricity for one unit of distance.

Every time we travel from one node(v_i) to another(v_j), we can build an equation between the two states. So the next constraint is as follows:

$$r_j = r_i + f_i - d_{ij} \times \delta, \forall e_{ij} \in E, \forall i \in \{1, 2, \ldots, n\}$$

It's not hard to think up another constraint that the electricity capacity a vehicle can hold is limited. Suppose for a specific mode of vehicles we consider, the capacity is η, so we have to satisfy:

$$f_i + r_i \leq \eta, \forall i \in \{1, 2, \ldots, n\}$$

For a single vehicle, y_i denotes whether it charges at station v_i, and we find out that it can only charge at v_i if there is a station built there. Note that y_i is also a binary variable for $i \in \{1, 2, 3, \ldots, n\}$.

$$y_i \leq X_i, \forall i \in \{1, 2, \ldots, n\}$$

Putting it all together, we've attained our primary version of formulation, which we'll extend later.

$$\text{Minimize } \Sigma_{i=1}^{n} c_i X_i$$

$$\text{s.t. } r_i \geq 0, \forall i \in \{1, 2, \ldots, n\}$$

$$f_i \geq 0, \forall i \in \{1, 2, \ldots, n\}$$

$$r_j = r_i + f_i - d_{ij} \times \delta, \forall e_{ij} \in E, \forall i \in \{1, 2, \ldots, n\}$$

$$f_i + r_i \leq \eta, \forall i \in \{1, 2, \ldots, n\}$$

$$y_i \leq X_i, \forall i \in \{1, 2, \ldots, n\}$$

$$y_i, X_i \in \{0, 1\}, \forall i \in \{1, 2, \ldots, n\}$$

3.2 Efficient Solutions

Since it has been proven that the problem of ILP is NP-hard, we have to come up with an efficient solution to make it applicable. We've experimented with two approaches, i.e. greedy algorithm and simulated annealing algorithm. Quantitative comparison and analysis are as follows.

3.2.1 Greedy Algorithm

Due to the high complexity of the scheduling problem, we have come up with an efficient greedy algorithm. At each iteration, our aim is to decrease the objective function as much as possible, while not necessarily global optimal minimum. Obviously, this will lead to a sub-optimal solution. However, we've found that our solution is not much worse than the optimal one.

The procedure of the problem is described as follows:

In each iteration, choose a node j with the largest c_j, set $X_j = 0$. If the solution still satisfies the constraints, then the optimal solution at this iteration is set to current solution. Else, we set X_j back to 1 and continue with the next iteration.

3.2.2 Simulated Annealing Algorithm

Simulated Annealing Algorithm is an algorithm based on probability. To be more specific, it is carried out on the basis of Monte Carlo iteration. The essential of simulated annealing algorithm lies in three aspects:

(1).The setting of initial temperature; (2).The policy for iteration; (3).The criterion for stopping.

Here we adopt an iteration policy based on probability. Since the feasible solutions are strings composed of 0 and 1, we generate a new feasible solution from the neighborhood of the current solution X, which consists of those solutions which comes from reversing n bits of the current solution.

Our choice of parameters and some other settings are exemplified in the following procedures.

(1).Randomly generate L different feasible solution $X_1, X_2, \ldots, X_L$, compute their object function, and choose the optimal solution X^* as the current solution. Set the initial temperature $t_0 = (F_{min} - F_{max})/\ln P_0$, where P_0 is the initial acceptance probability. Set $k = 0$.

(2).Generate a new solution X' based on the iteration policy proposed, and compute its corresponding object function $f(X')$. Set $k = k + 1$.

(3).If $k = W$, goto (5), else goto (4).

(4).Compute $\Delta f(X) = f(X') - f(X^*)$, if $\Delta f(X) \geq 0$, then $X = X'$; if $\exp(\Delta f(X)/t) >$ random$(0, 1)$, then $X = X'$, goto (2).

(5).If the current solution hasn't changed for up to T latest steps, return the current optimal solution; else, goto (6).

(6).If $t_r \leq t_{min}$, return the current optimal solution, else, let $t_{r+1} \leq \alpha t$, goto (2).

We experimented the two algorithms on a graph generated from road statistics in a province of China.As the optimization procedure goes, the convergence rate as well as the decrease of objective function of the two algorithms are shown in the following diagram.

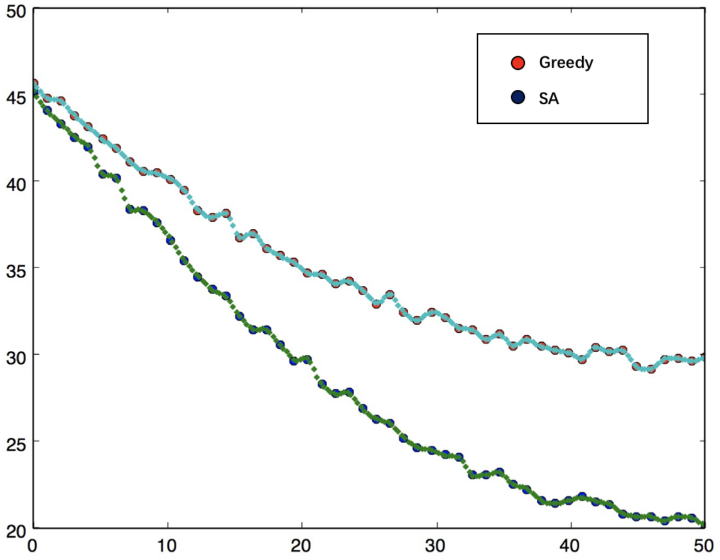

Figure2: Optimization procedure

From the figure above, we find out that simulated annealing is actually working better than greedy algorithm both in efficiency and accuracy.

4 Analysis of charging station placement

4.1 Tesla charging network in the US

After careful consideration, we come to the conclusion that if current trends continue, there is no doubt that Tesla has the ability to promote a complete switch to all-electric in the United States.

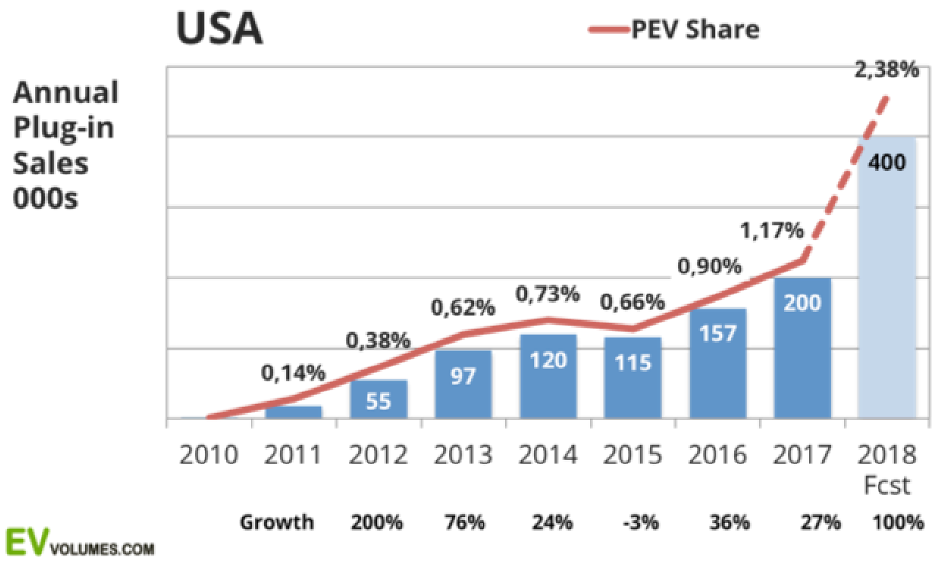

Figure3: PEV Share in the USA

From Figure 1, we can see the plug-in electric vehicles have make up more than 1 percent of the auto market in the US. In 2018, the number is anticipated to add up to 2.38%. Meanwhile, the inventory is growing rapidly (figure 2).

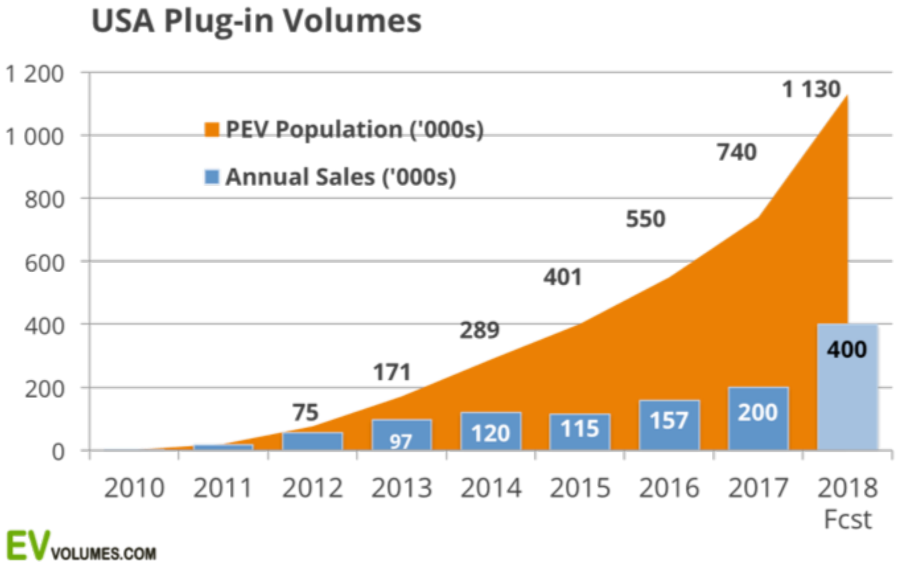

Figure4: USA Plug-in Volumes

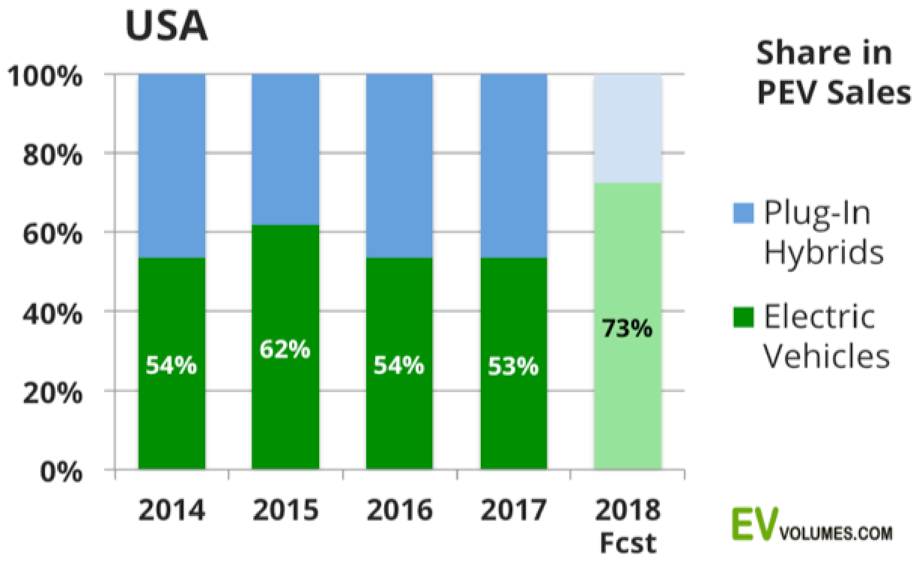

Figure5: Share in PEV Sales

Over the past two years, electric vehicles have made up more than a half of the electic car market and Tesla always takes the lead. In 2018, the pioneering advantages will be more obvious , which benefits speedind up the transition from PEV to EV.

Since Tesla is going to launch mass production of the more affordable all-electric Tesla Model 3, we consider the coming year a significant turning point. In fact, more than one million people has been in the waitlist. By the end of the year, the number of electric vehicles on road is conservatively estimated to exceed 1.1 million, which is double of that of 2016.

Based on the above analysis, electric vehicles stand a good chance to be the mainstream or even the monopolist of the auto market. Though electric cars is well-received, the convenience of charging possibly stops more people to purchase electric vehicles, for which we should do our best to solve the problem.

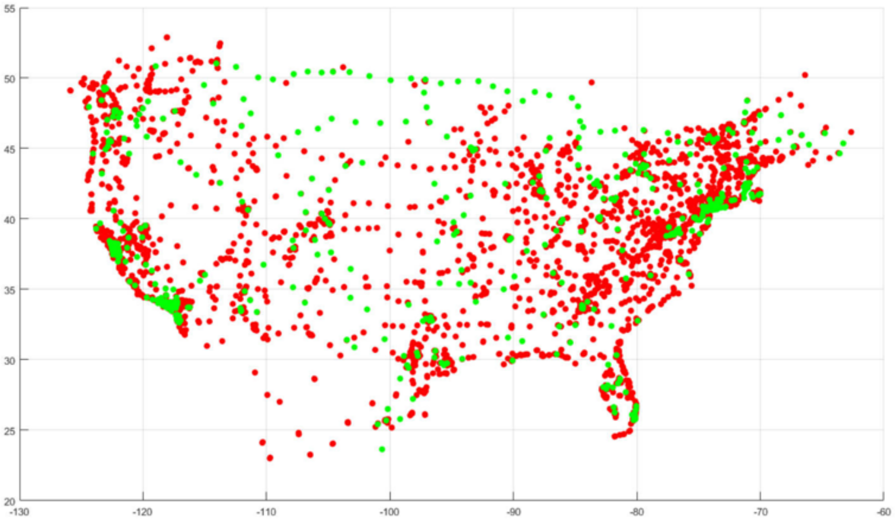

Figure6: Tesla Charging Stations in USA

From the data provided by Tesla on the official website, we can obtain the list of destination chargers and superchargers in the US. Up to now, there are 3,014 destination chargers and 903 superchargers (including the ones will come soon) distributed among the United States. We can see the distribution visually in Figure 4. As asked in the task, rural, suburban, and urban are three different ways of explaining a geographic area based on the population that live there, of which the distribution of charging stations are absolutely different.

- Rural areas are open and spread out. This is countryside where farming and natural resources are predominantly used for family income. These people travel to cities for medical care and any other basic living needs.
- Suburban areas are outlying single-family housing areas that are surrounding larger cities and metropolitan areas. Typically, they don't have a system of politics; however, some do have medical services and smaller shopping areas.
- Urban areas contain a high population where there are more than 1,000 people per block. Urban areas are very congested and have political autonomy along with any living resources needed.

During the transition from tradition personal vehicles to the electric ones, we assume that the total number will remain stable to simiplify the answer. Based on the existing data(Figure 6), we can use basic linear regression to predict final results:

$$y = bx + a + \varepsilon, \varepsilon\ N(0, \sigma^2)$$

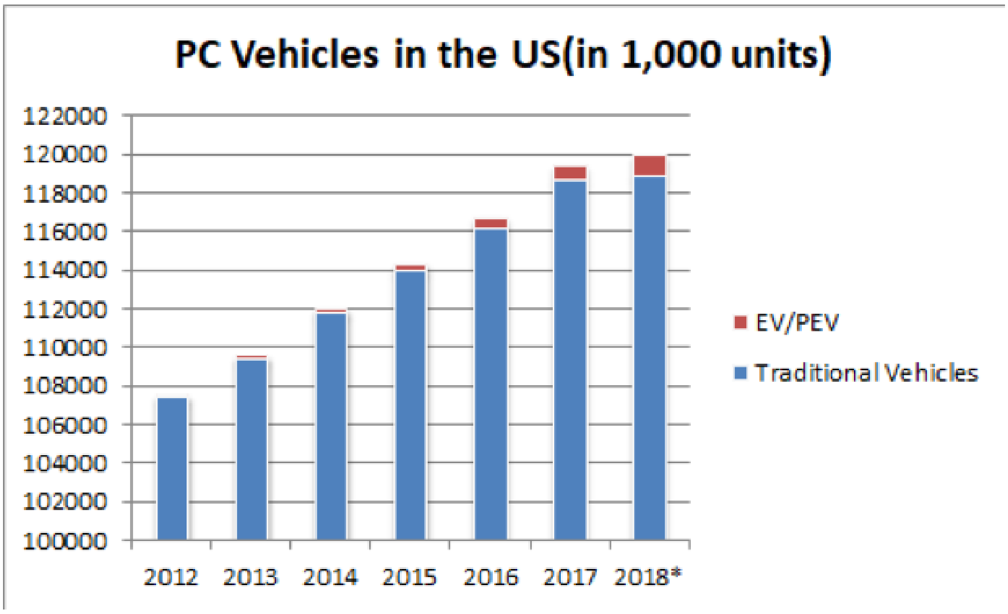

Figure7: PC Vehicles in the US

After our calculation, about 415,000 charging stations are needed when the complete switch happens in the US, including 320,000 destination-charging stations and 95,000 superchargers. When it comes to the differences between urban, suburban, and rural areas, we consider the most ideal conditions:

- The population proportion of urban, suburban and rural areas is 48%, 32%, 20%.

- There is no demand for supercharger in rural areas.
- We don't add more chargers in original charging stations or extend the capacity of each station.

Table 1:Predicted volumes in the US

	Destination Charger	**Supercharger**	**Total**
Rural	64,000	0	64,000
Urban	153,600	57,000	210,600
Suburb	102,400	38,000	140,400
Total	320,000	95,000	415,000

4.2 Proposal for the South Korea

4.2.1 Formulation with Queuing Theory

The above discussions are based on the assumption that there's no difference in vehicle density and shortage in chargers will never happen. So one charger each station is enough. However, in real cases we are faced with the problem of power shortage. Thus, we have to carefully examine the layout of chargers which not only involves the spatial location but also the number of chargers at each location. For those stations faced with a more tense situation of power shortage, we have to place more chargers there.

Adding the number of charges to the formulation automatically integrates with the factor of vehicle density and population. Placing an excessive number of charges at each station surely relieves the problem, but brings about a huge waste of resources. On the other hand, two few charges leads to the intolerable long time of waiting.

Thus, in this section, we employ a powerful tool to analyze the problem, i.e. queuing theory.

First, we suppose that the charging demands are in proportion to population or vehicle density. We estimate the approximate range of demands based on the statistics of car owners. We assume the

The process of vehicles queuing in the station for charging can be regarded as a model of q queuing system with limited servers, also known as M/M/c, where c represents the number of chargers in the station.

For every single station, assume that its number of chargers is c_i. We can suppose that the coming of charging demands obeys the Poisson distribution. In other words, random variable X indicating the incoming demands satisfies:

$$P(X = k) = \frac{\lambda^k}{k!}e^{-\lambda}, k = 0, 1, \dots$$

Here λ is related to the average arrival rate. For $i \in \{1, 2, \dots\}$, we first compute an average generating rate h_i. Then λ_i is easy to estimate if we only consider those demands that are not too far from the current station(which means the distance $d(i, j) \leq d$).

So we have:

$$\lambda_i = \Sigma_{i \in S_i} h_i$$

where

$$S_i = \{j|d(j,i) \leq d\}$$

According to the queuing theory, the average queuing time for station i can be represented as:

$$w_i(c_i, \lambda_i, \mu_i) = \frac{(c_i\rho_i)^{c_i}\rho_i}{c_i!(1-\rho_i)^2\lambda_i}P_i(0)$$

where μ_i refers to the number of electrical vehicles charged at station i, and $P_i(0)$ is the probability where no vehicle comes to charging station i.

The way to compute $P_i(0)$ and ρ_i is as follows:

$$P_i(0) = [\Sigma_{k=0}^{c_i}\frac{1}{k!}(\frac{\lambda_i}{\mu_i})^k + \frac{1}{c_i}\frac{1}{1-\rho_i}(\frac{\lambda_i}{\mu_i})^{c_i}]^{-1}$$

$$\rho_i = \frac{\lambda_i}{c_i\mu_i}$$

One fantastic thing about employing the queuing theory and taking number of chargers into consideration is that we can gracefully merge this approach with our former formulation.All we have to do is modify the objective function and constraints to cater to the new considerations.

Based on the discussion above, our ILP framework is shown below.

$$\text{Minimize } \Sigma_{i=1}^{n}c_iX_i + \gamma_ic_iX_i + \alpha_iw_iX_i$$

$$\text{s.t. } r_i, f_i \geq 0, \forall i \in \{1,2,\dots,n\}$$

$$r_j = r_i + f_i - d_{ij} \times \delta, \forall e_{ij} \in E, \forall i \in \{1,2,\dots,n\}$$

$$f_i + r_i \leq \eta, \forall i \in \{1,2,\dots,n\}$$

$$y_i \leq X_i, \forall i \in \{1,2,\dots,n\}$$

$$w_i(c_i, \lambda_i, \mu_i) = \frac{(c_i\rho_i)^{c_i}\rho_i}{c_i!(1-\rho_i)^2\lambda_i}P_i(0)$$

$$y_i, X_i \in \{0,1\}, \forall i \in \{1,2,\dots,n\}$$

$$\alpha_i, w_i \geq 0, \forall i \in \{1,2,\dots,n\}$$

$$c_i \in N^*, \forall i \in \{1,2,\dots,n\}$$

In the objective function, the first term is the same as that before, which minimizes the cost of building a new charging station. The second term is used to minimize the number of chargers at each station. The third term is used to minimize the total waiting time of drivers according to our discussion above. α_i is a parameter that can be adjusted accordingly. γ_i is the cost of adding a new charger at station i.

We still employ the simulated annealing algorithm to solve the NP-hard problem, and the results are shown below.

4.2.2 Spatial Temporal Linear Programming

One big challenge about all switching to electricity vehicles is that we cannot wake up one morning finding that all gas refueling stations are replaced with electricity charging stations. As a matter of fact, we have to undergo the whole process where the ratio of electricity vehicles goes from zero to a hundred percent. Thus, how to figure out a plan for proposing electricity vehicles without harming the convenience becomes a significant issue.

We still regard the problem of optimization over time as a case of linear programming. However, the objective function and the constraints have to be largely modified to accommodate to the new requirements.

First, we have to make the assumption that the previous state is part of the next ones because the cost of tearing down a charging station and constructing a new one is high. Additionally, it is natural to suppose that the locations of previous charging stations reflect the supreme conditions for a proper site, such as the traffic conditions as well as the vehicle density at a certain district, which also applies to later decisions.

We still use a variable X_i to denote whether there is s charging station at place v_i. Different from the former formulation, the X_i here is no longer binary. Instead, it now refers to the probability of a specific choice at place v_i. We still use simulated annealing algorithm to optimize a carefully designed objective function.

Using the simulated annealing algorithm described above, we can optimize the objective function as before. However, since the objective function is somewhat complicated, it becomes even more important to choose the appropriate hyper-parameters to balance the influences from different aspects.

We denote the objective function with respect to X as $f(X)$. In our simulated annealing algorithm, it is easy to see that for two points X and X', the ratio

$$\delta(X, X') = e^{[f(X)-f(X')]/kT}$$

falls down as the temperature decreases. Thus we are able to use the Metropolis-Hastings method to decide whether a distribution is accepted. In the sampling method, the acceptance probability

$$\alpha_{ij}(T) = min(1, e^{-[f(X)-f(X')]/T})$$

The iteration method is also modified here. At each iteration, we choose two locations both from the old distribution and the possible locations. Exchanging the two locations gives a new distribution. Then we compute $\Delta f = f(X) - f(X')$ and decide whether we accept the distribution.

If $\Delta f \geq 0$, we accept the move and set distribution to the new one. Else, we accept it at a probability of $e^{\Delta f/T}$. The other parts of the algorithm is the same as before.

After a predefined number of iterations, we achieve a distribution of possible locations for charging stations, and we simply choose the n_B locations with the largest probability. n_B is the estimated number of stations from other factors.

4.2.3 Solution

We first only consider how to determine the locations of charging-stations, ignoring the factors of car density as well as population. From GIS data, we can obtain the structure of the road network in South Korea as Graph G, which provide the possible locations and road edges. Furthermore, we assume that the average cost of building a charging station is $400,00–ignoring daily operating cost and so on. When charged, the battery can support a cover of 80 kilometers per hour and the full state can sustain five hours. Then we can apply our model considering minimizing average waiting time and optimize it with simulated annealing algorithm.

There is no wonder that the key element of our plan is the cruising ability and charging efficiency of the battery.

After the calculation, we find the optimal number of charging stations is approximately 20,000. Considering the placement of the determined charging stations, the results show that it tends to locate in roads which has less intersections,which means the charging stations are more suitable to lay in the uninhabited areas or along the expressways or by the seaside. When it comes to charging station distribution, there is no doubt that the ones of urban areas make up more propotion than the rural ones.

When we have the chance to start with a clean slate, a plan of the overall launch of the chargers is needed. The analysis above is based on the assumption that there's no difference in vehicle density and shortage in chargers will never happen. So one charger each station is enough. However, in real cases we have to examine the layout of chargers which not only involves the spatial location, but also the number of chargers at each location.

To simplify the presented answers, we assume consistent $\lambda = 5$(per hour).

The result of stimulation shows that the optimal size of chargers are close to 35,000. Combined with the findings above, it is suggested that the country build a mix of city-based chargers and rural chargers, which proportion is affected by the different population density and types of demand there. Meanwhile, in order to encourage people to purchase electric vehicles to replace the traditional ones, we propose to build the chargers first and then people will buy more electric cars. In fact, the local authority has taken action in this way.

This time, the point of concern in my proposed charging station plan are the population distribution of South Korea(Figure) and the queuing efficiency we assumed.

A realistic plan is supposed to be a consistent one as time wears on, which means it is the best for the moment at any time. To satisfy it, we add hyper-parameters in the above model-STLP.

Table 1:Predicted volumes in the US

	Duration	**Year**
10%	10	2028
30%	18	2036
50%	20	2038
100%	25	2043

Considering it is a problem mixed several realistic factors like time, the crucial element in this plan is the control of the trend.

4.3 Proposal for other countries

In our basic model, we take distance as the main factor for charging station distribution. Considering the practicality in specific circumstances, we herein introduce population density distribution and wealth distribution that account for the characteristics of different countries to enhance our model. Different countries have varying national conditions. Different factors have varying levels of importance to the selection of the implementation plan to build the charging station network.

- Population density distribution (relevant to vehicle density distribution and electric car occupancy)
- Wealth distribution (relevant to education levels and ability to get a new vehicle)

Areas with high population density tend to have high vehicle density. People's travel ranges differ with population density levels and in turn influences people's willingness to change their vehicle into electric cars. People tend to have shorter travel ranges in crowded countries and the chargers should be established in advance in order to persuade customers into purchasing electric cars. The implementation plan should first focus on the preliminary establishment of charging station and then focus on the electric car market and further amendment.

However, in sparsely populated areas, the demand is more difficult to predict accurately in advance. The construction work is heavier and sometimes can be low in efficiency. So the preliminary purchase is a decisive factor when considering charging station distribution.

Wealth distribution is another important factor. First, it is relevant to people's ability to get an electric car. The market tends to be more prosperous and the promotion of electric power is supposed to be easier. Second, wealth distribution usually has positive correlation with education level distribution. The significance of switching into electric power can be better understood among educated people. Therefore, the establishment of charging station network should begin in wealthier areas. Third, wealth distribution is relevant to vehicle distribution. Preferential policies for electric cars play a relevantly more important role in underdeveloped areas because people rely more on the development of charging station and the cost and convenience of making the change matter a lot before purchasing an electric car.

These consideration combined give an enhanced model to decide the implementation plan to build the charging station network.

Now we are using several countries' national condition as an example.

4.3.1 Australia

In general, Australia has a concentrated population distribution. The Australian population is mainly distributed in the southeastern coastal areas, the population distribution in the western and vast inland areas is very small. So the construction of charging station network should mainly focus on several densely populated areas first. The specific plan could refer to our model. The further development should refer to the electric car purchase distribution.

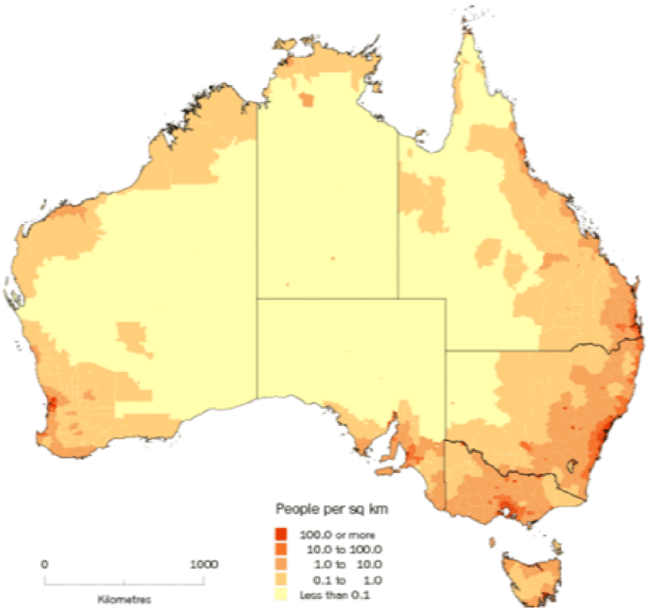

Figure8: Australia

4.3.2 China

China is the country with the most population in the world. There are several densely populated centers and the average population density is high. The promotion of electric cars should first begin in those densely populated centers as pilot implementation and gradually expand to the surrounding areas.

Considering that china is still a developing country, the cost and convenience are still the mainly factors that influence people's purchase willingness. So it is important to build some charging stations in advance and promote preferential policies for electric car purchase in order to persuade people into making the change. Through the pilot implementation, the government can have a grasp at the growth of electric car demand. After that, a comprehensive plan ought to be made to achieve the migration from gasoline and diesel cars to electric vehicles.

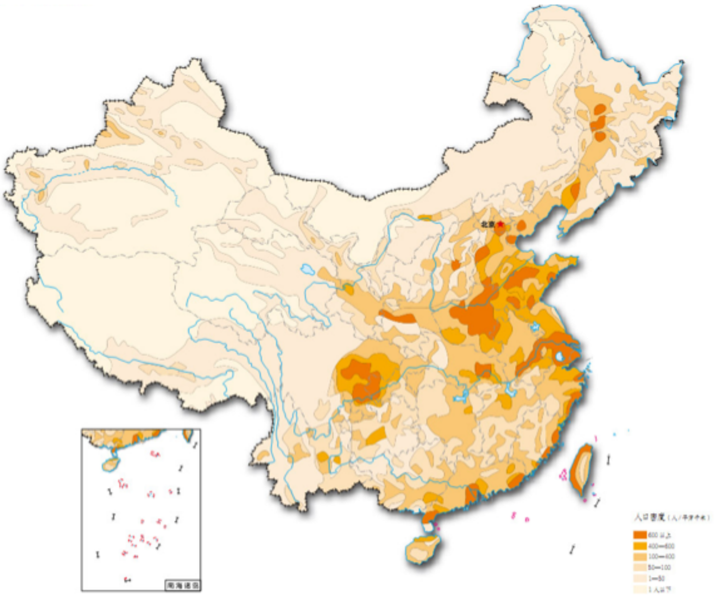

Figure9: China

4.3.3 Singapore

Singapore is one of the most crowded countries in the world and is highly developed and educated. So the promotion of electric cars takes less effort than other countries. In order to smooth the switch, developed charging station should be built in advance, too. Convenience is the main factor for customers to make a change. So the government should make a mass investment into the electric infrastructure construction in advance.

4.3.4 Saudi Arabia

Saudi Arabia is one of the countries with the lowest population density in the world but also is one of the richest countries in the world due to its abundant oil reserves. Considering half of the country is covered by desert, it is important to take topographic factors into account. The vast majority of the Saudi population is concentrated in the western coast of the Red Sea and the northern coast close to the Persian Gulf. Saudi Arabia is free of the threat of oil shortage so it is not so easy to promote electric cars. The charging stations should first be built in those two long and narrow zones that are most crowded in the country. Wealth factor does not play an important part in changing Arabian's willingness to use electric cars because the oil cost is quite low in Saudi Arabia. So to make the charging network as convenient as possible is vital to accelerate the switch to electric vehicles. The preliminary construction is of great importance.

4.4 Discussion on emerging techniques

In looking to the future, along with the progress of the technological world, the pressure of network is relieved and the process of the switch into electric power use is accelerated.

"Share economy" is the hottest word in past year. Car-share and ride-share services are gradually emerging in the market and will possibly have positive influence on the construction of the charging network. Car-share service is a great promotion for electric cars because it lowers the environmental cost and brings electric cars into more widespread practice. What is more, with reduction of private cars, car-share service can greatly improve the charging efficiency and maximize the capacity. It is also economical friendly choice for users and the infrastructure construction. The car-share service is a great tool for the government to promote electric cars. Electric car occupancy can increase at a faster speed. Therefore, the growth of the usage of electric cars can be faster and the switch from diesel to clean energy will be accelerated. The total amount of chargers will be reduced if people have a tendency to use car-share and ride-share service.

The rapid battery-swap stations can greatly cut down the waiting time of the drivers, which significantly improves the flexibility and efficiency of battery charging. Equivalently, the travel range of electric cars can be extended and therefore number of chargers can be cut down.

The invention of flying cars and hyper loop also improve the traffic efficiency. Hyper loop is a new high-speed transportation system that greatly relieves traffic stress. In consequence, it also relieves the pressure on charging stations on the highway. The waiting time of charging on the highway will be reduced. More importantly the development of technological transportation reduces people's reliance on traditional fuels and accelerates the transform into clean energy.

Throughout the development of our model, the distribution of possible locations rely much on the electric cars' travel range, population density and electric cars occupancy. The technological progress in transportation makes it easier and faster to switch into electric transportation world.

4.5 A handout for leaders

Dear leader Our world is faced with the scarcity of natural resources, green house effects and global warming caused by fossil fuels. The widespread diffusion of clean and renewable energy is urgently used.

Nevertheless, the absence of developed charging infrastructure is one of the major obstacles to the adoption of electric cars. Aimed to smooth the switch from gasoline cars to electric cars. There is a strong need to direct investments of charging facilities to minimize the cost and maximize the efficiency.

When it comes to the development of charging network, technical feasibility and economic efficiency both need to be taken into account.

Location is the prior element to be considered. Charging station location has to achieve users demand and convenience. The first thing to confirm is that the distance between stations and the range of cars should reach a balance. While insufficient stations cannot technically cover the range of cars while excessiveness can be a waste of resource.

Second is the capacity and type of stations, population density distributions matter a lot to the construction of charging network. In busy urban areas like big shopping malls, supercharging designed for longer road trips and shorter charging time is able to serve users' need better and maximize capacity utilization. However in remote rural areas, destination charging designed for charging for several hours can provide longer travel range.

Third is being quick and cost effective. The distributions should taken costs of building a charging station into consideration in order to improve investment efficiency. Demands of the customers can be reflected by the current set of the filling stations. Filling stations can be transformed into charging stations gradually for the concern of minimizing transition costs and avoiding the waste of infrastructure.

Fourth is time. Considering that the switch cannot be made overnight, the process of the transfer has to take time into account.

In sum, the migration from personal transportation towards electric cars takes great work to set a comprehensive national plan that can support maximum traffic flow.

5 Strengths and weaknesses

5.1 Strengths

- We solve the problem from both a macroscopic and microscopic view. In other words, we are not only considering the problem based on convenience of distance, but also from the average waiting time when there exists lack of chargers. This allows us to estimate both the locations and the number of chargers at a time.
- We extend our model to a spatial-temporal perspective. By using the optimization tool of simulated Annealing Algorithm and transforming the formulation into a probabilistic one, we can track the progress of switching to EVS and propose a timeline accordingly.
- By comparing between different optimization methods, we employ a rather efficient algorithm for solution.

5.2 Weakness

- We fail to integrate the population as well as the vehicle density directly into our framework. Instead, we estimate the impact of the former factors on our choice of parameters, thus they are indirectly used in our formulation. Future work might want to focus on a unified framework that can optimize the whole system taking those factors into consideration.

6 References

References

[1] Michael Kuby, Seow Lim.The flow-refueling location problem for alternative-fuel vehicles. Socio-Economic Planning Sciences 39 (2005) 125âĂŞ145

[2] Meysam Hosseini, S.A. MirHassani.Refueling-station location problem under uncertainty.Transportation Research Part E.

[3] Martin Frick, K.W. Axhausen, Gian Carle, Alexander Wokaun.Optimization of the distribution of compressed natural gas (CNG) refueling stations: Swiss case studies.Transportation Research Part D 12 (2007) 10âĂŞ22.

[4] Ying-Wei Wang.An optimal location choice model for recreation-oriented scooter recharge stations.Transportation Research Part D 12 (2007) 231âĂŞ237.

[5] Yingwei Wang, ChuahChih Lin. Locating road-vehicle refueling stations.Transportation Research Part E.

[6] Michael Kuby, Seow Lim.Location of Alternative-Fuel Stations Using the Flow-Refueling Location Model and Dispersion of Candidate Sites on Arcs. Netw Spat Econ (2007) 7:129âĂŞ152.

[7] Hendsong Wang,Qi Huang, Changhua Zhang, Aihua Xia. A novel approach for the layout of electric vehicle charging station. 978-1-4244-8026-510$26.00 2010 IEEE.

[8] Albert Y.S. Lam, Member, IEEE, Yiu-Wing Leung, Senior Member, IEEE, and Xiaowen Chu, Senior Member, IEEE. Electric Vehicle Charging Station Placement: Formulation, Complexity, and Solutions. IEEE Transanctions on smart grid, VOL. 5, NO. 6, November 2014.

[9] Shuangshuang Chen,Yue Shi, Xingyu Chen, Feng Qi. Optimal Location of Electric Vehicle Charging Stations Using Genetic Algorithm. APNOMS 2015.

[10] `http://www.tesla.com`

[11] `http://www.diva-gis.org/gdata`

[12] `http://www.ev-volumes.com`

[13] `https://data.worldbank.org`

[14] `http://www.oica.net/category/vehicles-in-use`