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Application and advancement in Two-dimension multi-factors weight mesh dividing method on distributing charging station

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Abstract: In this paper, we provide a model that tells solutions of distributing charging stations. The model based on Two-dimension multi-factors weigh mesh dividing method. We divide target areas into grid, and assign weight on the basis of population density, vehicle ownership, number of main road. We apply our model to determining locations of charging station and successfully we come to a solution.

1. Introduction

With the birth of Tesla electric car, the brand-new technology of electric car turned out. However, there are many problems that follow.In order to solve the problem of the distribution of charging stations in cities and between cities, our team established Kurtosis model and Grid Covering model based on two-dimensional multi-weight grid segmentation method. Then, we determine the weight of influencing factors through AHP, and get the basic model of distribution. Finally, divide the "honeycomb" hexagonal dense mesh in different cities, each hexagonal center is the location of a charging station, and divide the hexagons into different sizes according to the distribution.The second most important issue is the development model of electric vehicles. We refer to the "Logistic" model of population growth in biology and establish a "S" -type growth curve for Tesla's electric vehicle development in a country.

2. Problem Analysis

We analyzed the problems above. Then we made necessary assumptions and defined relevant notations. In order to solve those problems, we made works as follows:

1) Develop the mesh segmentation method of population density, vehicle ownership and numbers of main road to analyze the distribution of charging stations more comprehensively. 2) Choose Uruguay as the nation where chargers are distributed and explain how to determine the solution and what's the key factor to promote. 3) Optimize existing model, in order to meet demand of most countries.

We made Assumptions as follows:

1) Per capita amount of car ownership in every economic zone is evenly distributed

2) Charging without waiting. When drivers come to a charging stations, they can always find a plug to use immediately.

3) The average speed of vehicle on motorway is 100km/h. The average urban speed of vehicle is 40km/h.

4) Each station provides charging service for 15 vehicles on average. No more than 10% of the total electric vehicles need to charge at the same time.

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3. Symbol Description

Table 1. Symbol Description

Symbol	Description
Q	Car ownership
C	Human flow in unit time
T	Arterial traffic node
CCW	Charging station number

4. Distribution of Charging Stations in the US and Uruguay

According to our subjective experience and common sense, we speculate that the distribution may relate to population density, vehicle ownership and numbers of main road. Our task is to visualize and analyze the data, and establish the model for the US, then extend the model to solve the problem of other countries.

4.1 Collect Data

We collect the data from the Internet [5-7], and visualize it. Generate the thermodynamic diagram of main road and car ownership as shown in figure 1, 3 and the three-dimensional diagram of population density as shown in figure2, figure 4.

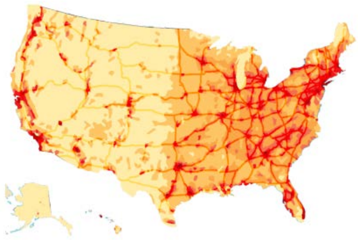

Figure 1 the thermodynamic diagram of US

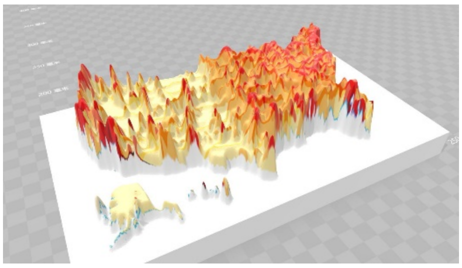

Figure 2 the three-dimensional diagram of US

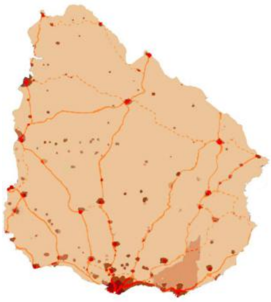

Figure 3 the thermodynamic diagram of Uruguay

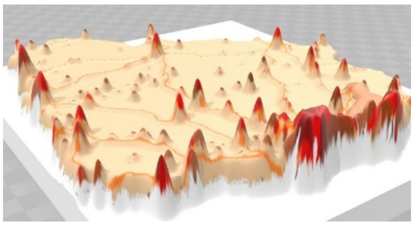

Figure 4 the three-dimensional diagram ofUruguay

4.2 Kurtosis Model

Analytic hierarchy process is an easy way to work out some complicated, multi-model problems, and it is especially suitable for those problems that are difficult to fully quantify.

Step 1：Construct Judgment Matrix. Establish a pair comparison matrix by comparing factors in mutual. That is, take two factors Q_i and Q_j at a time, a_{ij} means the ratio of Q_i and Q_j to the size of W, the total result is expressed by matrix $A = (a_{ij})_{n\times m}$. Obviously, if the ratio of Q_i and Q_j to CCW is a_{ij}, the ratio of Q_j and Q_i to CCW is $a_{ji} = \frac{1}{a_{ij}}$.

Step 2: Hierarchical single order and consistency test. Judge the sort weights of matrix A corresponds to the eigenmatrix W of maximum eigenvalue λ_{max}.

$$w = (\omega_1, \dots, \omega_1)^r,\ a_{ij} = \frac{\omega_i}{\omega_j}\quad \forall i, j = 1,2, \dots, n$$

$$A = \begin{bmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} \cdots & \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_i} & \frac{\omega_2}{\omega_2} \cdots & \frac{\omega_2}{\omega_n} \\ \cdots & \cdots\ \cdots & \cdots \\ \frac{\omega_n}{\omega_1} & \frac{\omega_n}{\omega_2} \cdots & \frac{\omega_n}{\omega_n} \end{bmatrix}$$

Step 3: Calculate consistency Metrics CI.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Step 4: Find the corresponding average random consistency index RI. The values of RI as shown in table 1.

Step 5: To find the mean value of the maximum characteristic root λ'_{max}, and define RI.

$$RI = \frac{\lambda'_{max} - n}{n - 1}$$

Step 6: Calculate consistency proportions CR.

$$CR = \frac{CI}{RI} = \frac{\sum_{j=1}^{m} CI(j)a_j}{\sum_{j=1}^{m} RI(j)a_j}$$

4.3 Grid Covering Model

Tabu search algorithm is a kind of dependent memory structure (taboo table) records the better solution, and compares and sorts the neighbor of the current solution, which directs the iterative optimization algorithm of the next step search direction. Self-learning Tabu search algorithm is an improved algorithm combining search strategy, which includes rule-based objective function, adaptive search and dynamic neighborhood selection. The target function based on rules can increase the rate of generating candidate solution, and adaptive search and dynamic neighborhood selection can improve the performance of multiple search and intensive search.

Step 1: By A number of grids consisting of areas that meet the charger requirements, recorded as S,$S = \{S_1, S_2, \dots, S_n\}$, wherein: n is the grid number of the research area, S_i is the state of the first grid, that is, whether it is selected as charging station.

Step 2: To set the current scheme as the best solution $x_{best} = s, f(x_{best}) = f(s)$.

Step 3: According to the number of cells and dynamic neighborhood strategy to determine the size of the super-unit size $scale(n)$, juxtaposition neighborhood evaluation period $t = 0$.

$$scale(n) = \begin{cases} \frac{n}{10} & n \le 100000 \\ \frac{n}{20} & 100000 < n \le 300000 \\ \frac{n}{30} + 9860 & 300000 < n \le 900000 \\ \frac{n}{40} + 18520 & 900000 < n \end{cases}$$

Step 4: Generate the current scheme x neighborhood, denoted as N (x), calculate the neighbor objective function value [f (N (x)]. And the average value of the neighborhood objective function [E(f)], $E(f) = \sum_{k=1}^{l} f_k\ [N(x)]$. Among them, k is the kth neighbor scheme; l is the number of neighbors

Step 5: According to the rules-based objective function to determine the program ranking, you can use the taboo state, the objective function and other rules in turn as a judgment rule.

Step 6: According to the ranking to determine the candidate program x'.

Step 7: Update the optimal solution $x_{best} = x'$.

Step 8: Update the current scheme $x = x'$ and record the change of the objective function of the scheme $\Delta' = f(x) - f(\dot{x})$, where $f(\dot{x})$ is the previous scheme. If $\Delta' > 0$, and the previous period $\Delta' > 0$, then $u = u + 1$, $\Delta' \leq 0$, and the previous period $\Delta' \leq 0$, then $d = d + 1$, otherwise set $u = 0$, $d = 0$.

Step 9: TS uses the objective function to evaluate the merits of the scheme, which is not only one of the comparison operators to determine the rules, but also can be used as the basis for program output, the smaller the value of the better. The form of the objective function:

$$obj = \sum_{j=1}^{m} weigh_j \cdot criteria_j$$

Where: obj is the objective function value, m is the target number, $weight_j$ is the weight of the jth target; $criteria_j$ is the standardized score of the jth target, the standardization formula is:

$$criteria_j = \begin{cases} 0 & c_j = c_{min,j} \\ \dfrac{c_{max,j} - c_j}{c_{max,j} - c_{min,j}} & c_{min,j} < c_j < c_{max,j} \\ 1 & c_j = c_{max,j} \end{cases}$$

Cost formula is:

$$criteria_j = \begin{cases} 0 & c_j = c_{max,j} \\ \dfrac{c_j - c_{min,j}}{c_{max,j} - c_{min,j}} & c_{min,j} < c_j < c_{max,j} \\ 1 & c_j = c_{min,j} \end{cases}$$

Where: c_{ij} is the score of the ith plan on the jth goal, $c_{max,j}$ is the maximum score of jth goal. $c_{min,j}$ is the minimum score of j goal. For purposes of distributing stations, we take car ownership, population, economic development index, main road and other factors into consideration

4.4 Result & Analysis of the US

Based on the data we got above, we set the weights and consider the locations comprehensively. The distribution of charging stations in the US is shown as table 2.

Table 2. The Distribution of Charging Stations in the US

Area	**urban**	**suburban**	**rural**	**total**
Number	1.024 million	368,000	208,000	1.6 million

It's obvious that urban area takes the largest proportion, however, the difference between suburban area and rural area is small. It seems that urbanization is a trend.

4.5 Logistic Growth Model

In the history of economy, when new products are introduced there is an intense amount of research and development which leads to dramatic improvements in quality and reductions in cost. This leads to a period of rapid industry growth. Some of the more famous examples are: railroads, incandescent lightbulbs, electrification, cars and air travel. Eventually, dramatic improvement and cost reduction opportunities are exhausted, the product or process are in widespread use with few remaining potential new customers, and markets become saturated.

Logistic Growth Model is a common model of object growth. A logistic function or logistic curve is a common "S" shape, with equation:

$$f(x) = \frac{L}{1+e^{-k(x-x_0)}}$$ {\displaystyle f(x)={\frac {L}{1+e^{-k(x-x_{0})}}}}

Where e = the natural logarithmbase (also known as Euler's number), x_0 = the x -value of the sigmoid's midpoint, L = the curve's maximum value, k = the steepness of the curve.

4.6 Result & Analysis of Uruguay

We use the two basic models to distribute the charging stations in Uruguay as shown in table 3, and use logistic growth model to predict the conversion rate of electric vehicle. In addition, we analyze the key factors that shaped charging station plan and growth plan timeline.

Table 3. The Distribution of Charging Stations in Uruguay

Area	urban	suburban	rural	total
Number	7600	2670	428	10700

4.6.1 The Key Factors That Shaped Charging Station Plan

Grid specification, People travel mode

According to the information we know, Uruguay Grid crashes in the event of a drought. Basic electricity cannot be guaranteed, it is less likely to power the car and Car rental is popular in the country and urbanization is very high at 95%. This will reduce the travel of private cars. To some extent these will affect the implementation of the plan.

4.6.2 The Key Factors That Shaped growth plan timeline

Electric vehicle ownership, People's approval level

We plot the car growth curve as shown in figure 5. From the figure we can see that the curve shows a s-shaped curve, the curve tends to the maximum in the 6th-7th year, but it cannot reach 100% degree of transformation. Because the people can be recognized quickly, but the existence of fossil fuels will certainly hinder the implementation of the plan as long as there is one to provide, some people will not change to electric vehicle.

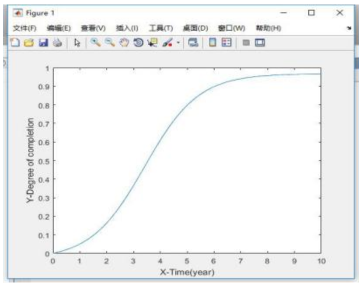

Figure 5 vehicle growth curve

5. The Feasibility of Classification System for General Growth of EV

This model is established by reference to the "Logistic model" and is valid for most countries, except that the parameters of the influencing factors involved may vary. Of course, depending on the national conditions and system, there is bound to be a far cry from the national development model.

For countries with a noticeable pattern in the distribution of wealth and a disparity between the rich and the poor, the model must be differentiated. In regions with higher average wealth, the model should be basically in line with the development model that our team has constructed. In regions with the same average domestic wealth, due to different economic levels and population concepts, the development starts time lags behind the development speed Faster, some similar to J growth, but the starting point will be lagging behind. As shown in figure 6

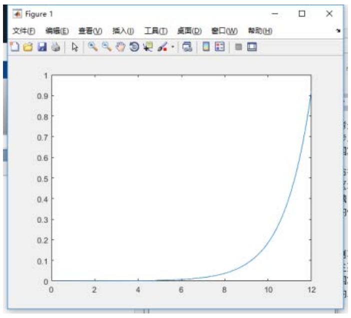

Figure 6 J growth

However, in some countries with different systems, taking China as an example, China's economic development model has great differences from other countries mainly because it has some "planned economy" components in its economic system. Therefore, countries like China may adapt to different development models due to policy implications. When the policy factors are small, they basically conform to the development model we have established. However, the results correspond with the policy support and the relative lack of encouragement are as follows:

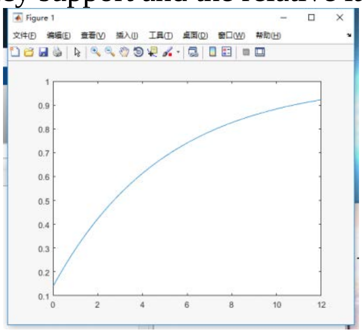

Figure 7 Policy support

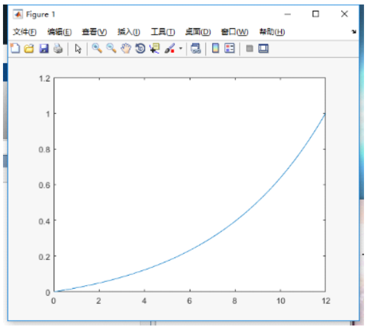

Figure 8 Policy not advocate

6. The Strengths and Weaknesses

We summarize the strengths from the application of our model, as well, we point out our weaknesses in the following.

Strengths: The index given in the model basically measure the distribution of charging stations in a nation. The assumptions and results are realistic and convincing, Based on credible data and integrated model, we can predict the general growth of electric vehicle in a nation.

Weaknesses: In some cases, the data in some areas can not fit the result we predicted, Assumptions can not completely replace the reality, and it always deviate from the reality, When the model is established, we only consider five important factors, and we will simplify some of the small variables, the actual site selection and forecasting will be of some deviation.

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