A new analytical framework for the location selection of shared car site

Yonggui He¹, Meng Wang¹* and Qi He¹
¹ North China Elect Power Univ, Dept Econ & Management, Baoding, Hebei, China
*Corresponding author’s e-mail: 377124119@qq.com

Abstract. Reasonable and effective sharing of vehicle location plans will be of great significance for improving the overall efficiency of shared vehicles and the allocation of urban transportation infrastructure resources. This paper predicts the demand for shared cars in Hangzhou by evaluating the ownership rate of shared cars, and estimates the maximum number of people that can be served at each level. Then, using K-means clustering method, the initial clustering center is selected according to the center of gravity method, and the clustering condition is formed by using the minimum distance from each vehicle demand point to the clustering center to form a clustering cluster. The number of service groups of the cluster is added, and the cluster center iteration is performed according to whether each cluster satisfies the number of service groups until the optimal number and location of the network points are obtained. Finally, according to the number of service persons, the construction scale of 12 selected outlets will be determined, and the plan for the location selection of shared car outlets in downtown Hangzhou will be obtained. The research results show that this method can provide an effective basis for the decision-making of shared car site selection.

1. Introduction
The problem of traffic congestion has become a common problem in big cities in China. As urbanization continues to accelerate, urban population density and industrial density continue to increase, and urban burdens are becoming heavier, leading to increasing traffic pressures in cities [1]. Traffic congestion will not only cause unnecessary economic losses, but also increase pollution and emissions due to increased fuel consumption. In the context of traffic congestion and environmental pollution, the concept of car sharing has gradually attracted people's attention [2]. In China, in order to more actively respond to and solve traffic problems, in August 2017, the Ministry of Transport, the Ministry of Housing and Urban-Rural Development jointly issued the “Guiding Opinions on Promoting the Healthy Development of Small and Minibus Leases” (referred to as “Guiding Opinions”). The promulgation of the "Guidance Opinions" is of positive significance for protecting the rights and interests of users, improving the effective supply of small and minibus rentals, optimizing the transportation system, and promoting the development of healthy and standardized industries. Up to now, many scholars have studied the site selection of outlets. Lu et al. [3] used the greedy algorithm to construct an optimal scheduling model for shared bicycles. Xiao et al [4], Wang et al [5] and Yu [6] also made relevant research on shared bicycle location. Lu et al. [7] used Wuhan as an example to construct a mathematical model for the location of shared car sites by setting the objective function. Wang [8] studied the location of shared car sites based on AHP and fuzzy comprehensive evaluation method. Overall, there are few studies on the location of emerging shared car outlets. This paper uses K-means clustering method to analyze and study the location planning and inter-station scheduling
problem of automobile shared network, which has strong practical significance.

2. Estimation of shared car demand in various regions based on the 10,000-owned rate method

The method predicts the number of shared vehicles in the downtown area of Hangzhou based on the number of shared vehicles per 10,000 people in major cities with similar economic development levels, combined with the population development scale of downtown Hangzhou.

\[ N = R \cdot \alpha \]  \hspace{1cm} (1)

Where: \( R \) is the size of the urban resident population (10,000 people); \( \alpha \) is the 10,000-person ownership rate (car/10,000). In order to obtain the expected 10,000-person ownership rate of shared cars in Hangzhou, statistics on the sharing of automobile planning data in some first-tier cities in China, taking the average 10,000-person ownership rate as the index \( \alpha \) of downtown Hangzhou, and then using the formula (2.1) to calculate the downtown area of Hangzhou. The total demand for shared cars in urban areas and the demand for shared cars in various street areas. The parameters and estimation results are shown in Table 1.

Table 1. Estimated demand for shared vehicles based on the 10,000 ownership rate method.

| city     | Reference area | Estimated area |
|----------|----------------|----------------|
|          | Beijing        | Shanghai       | Guangzhou     | Hangzhou Central District |
| Total population / 10,000 people | 2200 | 2500 | 1400 | 208 |
| Shared car total / vehicle      | 25000 | 20000 | 20000 | 2331 |
| 10,000 people ownership rate / (car • million people -1) | 11.36 | 8.00 | 14.28 | 11.21 |

The 10,000-capital rate method estimates the demand for shared cars in the downtown area of Hangzhou on a macro level through horizontal comparisons with other cities. It is estimated that the demand for shared cars in the downtown area of Hangzhou are 2,331 vehicles, and the ownership rate of 10,000 people is 11.21 per 10,000 people. The demand for shared vehicles in various downtown areas of downtown Hangzhou based on the 10,000-owned rate method is shown in Table 2 below.

Table 2. Demand for shared vehicles in various streets in downtown Hangzhou based on the 10,000-person ownership rate.

| Area number | Street      | Cover population /10,000 people | Demand for shared vehicles /vehicle | Area number | Street      | Cover population /10,000 people | Demand for shared vehicles /vehicle |
|-------------|-------------|---------------------------------|------------------------------------|-------------|-------------|---------------------------------|------------------------------------|
| 3101        | Mishixiang Street | 4.72                            | 53                                 | 3123        | Dongxin Street | 6.35                            | 71                                 |
| 3102        | Hushu Street    | 3.18                            | 36                                 | 3124        | Shiqiao Street | 1.67                            | 19                                 |
| 3103        | Xiaoh Street    | 3.43                            | 38                                 | 3125        | Linying Street | 5.50                            | 62                                 |
| 3104        | Hemu Street     | 2.02                            | 23                                 | 3126        | Beishan Street | 4.31                            | 48                                 |
| 3105        | Daguan Street   | 3.29                            | 37                                 | 3127        | Xixi Street   | 8.64                            | 97                                 |
| 3106        | Gongchenqiao Street | 3.67                          | 41                                 | 3128        | Cuiyuan Street | 8.59                            | 96                                 |
| 3107        | Banshan Street  | 2.91                            | 33                                 | 3129        | Wenxin Street | 6.39                            | 72                                 |
| 3108        | Shangtang Street | 2.02                            | 23                                 | 3130        | Gudang Street | 5.31                            | 60                                 |
| 3109        | Kangqiao Street | 1.34                            | 15                                 | 3131        | Liuxia Street | 4.51                            | 51                                 |
| 3110        | Xiangfu Street  | 2.19                            | 25                                 | 3132        | Zhuantang Street | 5.50                        | 62                                 |
| 3111        | Hubin Street    | 3.92                            | 44                                 | 3133        | Jiangcun Street | 1.83                            | 21                                 |
| 3112        | Xiaoying Street | 10.05                           | 113                                | 3134        | Xixing Street | 2.81                            | 32                                 |
3. Shared car site location model based on K-means clustering

3.1. Analysis of the economic scale of shared car outlets
From a theoretical point of view, the concentration and scale of shared car outlets have the following advantages: 1. The scale of outlets brought about by the concentration of outlets is conducive to the reduction of construction costs. According to the principle of economics, this paper reasonably assumes that the unit construction cost of shared car outlets and its scale show a U-shaped distribution. The shared car parking point setting requires fixed charging piles, and inherent parking spaces, as well as the necessary management and maintenance personnel. As the size of the network points expands, the unit construction cost decreases. However, if the network size is too large, the site selection will be difficult and the construction difficulty will increase costs. Moderate concentration helps to reduce the cost of building a single parking space. 2. With the expansion of the scale of shared car outlets, the supply and demand of individual outlets tend to be stable and predictable, which is more conducive to scientific scheduling and fostering the loyalty of shared car customers. 3. The increase of the distance between the outlets brought by the network concentration is beneficial to increase the driving distance of the single-scheduled vehicle, and is beneficial to the income increase for the shared-vehicle mode of the mileage-based charging method. Therefore, in order to optimize the cost structure, the construction scale of a single shared car network is limited, and the number of vehicles that can be accommodated should be as close as possible to the economic scale of the parking lot. This article assumes that there is an upper limit for the number of regional service providers for a single shared car network. This paper draws on Li [10] to analyze the economic scale of the high-speed rail station parking lot and find that the outlets can accommodate the estimated number of vehicles and the number of people in service (Table 3), and the economic scale of the increase of 20% as the largest scale of shared car network construction.

Table 3. Estimated Table of Number of Vehicles and Maximum Number of Serviceable Persons.

| Index | number |
|-------|--------|
| 10,000 people ownership rate / (car • million people -1) | 11.21 |
| The maximum scale of a single Shared car network/vehicle | 432 |
| The maximum number of people served by a single car-sharing network/10,000 people | 38.54 |

3.2. Hypothesis and Symbol Description of K-means Clustering Model

3.2.1. Hypothetical description
1) Assume that the upper limit of the number of service providers in the shared car level is 385,400, that is, the total number of people in the coverage of the network is less than 385,400;
2) Suppose all the vehicle demand in a single area is concentrated in the regional center point, that
is, the demand point. The position of the demand point is expressed as \( X_i (x_i, y_i) \) by the geographic coordinates of the center point of the area.

3) Assume that all resident populations in a single area share demand for automotive vehicles. That is, the number of people required is equal to the population of the region.

4) Suppose a demand point is only covered by a shared car service network, and there is no cross coverage;

5) It is assumed that the distance between the respective regions is based on the distance between the center points of the respective regions.

6) Assume that there is no limit to the physical coverage of each shared car site service.

7) Assume that each demand area must have shared car network coverage.

3.2.2. Symbol Description

| symbol | symbol description |
|--------|--------------------|
| \( K = \{ k_1, k_2, \ldots, k_n \} \) | Initial cluster center set |
| \( h_i \) | Cluster center |
| \( l_i \) | Regional center point |
| \( x^1 \) | First level shared car outlets |
| \( x^2 \) | Secondary level shared car outlets |
| \( H(x) \) | Demand for shared vehicles of \( x \) /10,000 people (people number) \( x \) represents a demand point or area |
| \( d_{ij} \) | Direct line distance of node \( i \) and \( j \) |
| \( X_i(x_i, y_i) \) | Regional center \( X_i \) and its geographic coordinates \( (x_i, y_i) \) |

3.3. Establishment of K-means clustering model

3.3.1. Gravity method selects the initial cluster center

In this paper, K-means and K-center point clustering method are used to cluster the central points of each region. This method is a relatively simple clustering algorithm. First, select \( K \) points as the initial clustering center, and then all the elements to be clustered are divided into clusters with the smallest degree of dissimilarity, and the clusters with the lowest degree of dissimilarity are obtained. Then recalculate the center of the cluster, re-cluster all the elements in the cluster according to the new center, and judge whether the cluster center point satisfies the condition until the clustering result satisfies the condition and does not change.

A key step in the K-means and K-center point clustering method is the selection of the initial cluster center. The selection of the initial cluster center has a greater impact on the clustering results. Once the initial value is not well selected, it may not be available. Effective clustering results. Assume that each demand area must have shared car network coverage. When selecting the initial cluster points, spread the whole area as much as possible to avoid partial equilibrium. In this paper, the downtown area of Hangzhou is roughly divided into \( 3 \times 3 \) rectangular areas, as shown in Figure 1. In Figure 1, the horizontal axis is the GPS east longitude coordinate, and the vertical axis is the GPS north latitude coordinate. Each point represents the geographic location of the demand point.
For each rectangular area, the initial cluster center $K$ is selected according to the center of gravity method, which can greatly ensure the average geographical distribution from the demand point to the initial cluster centers to achieve a comprehensive coverage of the demand range. According to Figure 1, there is no demand point in Area 1, so there is no need to select the initial cluster center. In this paper, eight locations are selected as the initial clustering centers, which are located in the 2 to 9 regions, with the weight of the regional shared car demand as the weight, and the initial clustering center point selected according to the center of gravity method. The center of gravity method selects the initial cluster center of gravity. The specific calculation process is as follows:

**Objective function:**

$$
\text{min } z = \sum_{i=1}^{n} H_{(i)} \left[ (x - x_i)^2 + (y - y_i)^2 \right]^{1/2}
$$

Where $n$ indicates that there are $n$ regional center points in the square; $d_i = \left[ (x - x_i)^2 + (y - y_i)^2 \right]^{1/2}$ represents the distance from point $(x_i, y_i)$ to the center point of the cluster. Then find the partial derivatives for $x$, $y$ and make them equal to 0. Obtain the differential equations as follows:

$$
\frac{\partial z}{\partial x} = \sum_{i=1}^{n} \frac{H_{(i)}(x - x_i)}{d_i} = 0; \quad \frac{\partial z}{\partial y} = \sum_{i=1}^{n} \frac{H_{(i)}(y - y_i)}{d_i} = 0
$$

According to this, we can directly get the coordinates of the center point as:

$$
x^0 = \frac{\sum_{i=1}^{n} H_{i} x_i}{\sum_{i=1}^{n} H_{i}}, \quad y^0 = \frac{\sum_{i=1}^{n} H_{i} y_i}{\sum_{i=1}^{n} H_{i}}
$$

The obtained center of gravity point coordinate table is shown in Table 5:

| Initial cluster center number | East longitude coordinates (X) | Coordinates of latitude (Y) |
|------------------------------|-------------------------------|-----------------------------|
| 1                            | 120.05                        | 30.1917                     |
| 2                            | 120.065                       | 30.2673                     |
| 3                            | 120.157                       | 30.1849                     |
| 4                            | 120.159                       | 30.2824                     |
| 5                            | 120.16                        | 30.3413                     |
| 6                            | 120.229                       | 30.1973                     |
| 7                            | 120.221                       | 30.2695                     |
| 8                            | 120.227                       | 30.3391                     |

3.3.2. K-means clustering and iteration

After 8 centers of gravity points are reasonably selected as the initial clustering center, the minimum
distance from the center point of each area to the initial cluster center point is used as the clustering condition, and 44 center points are divided into 8 clusters. Then recalculate the center point \( h_i \) of each cluster instead of the initial cluster center point, and add the number of shared car demand for each regional center point in each cluster. The result of the summation is the number of shared car demand at each cluster center point. Since the model assumes that the shared car first-level outlets meet the upper limit of the number of service people of 385,400, judge whether it is \( \exists H(h_i) > 38.54 \), and if so, add an initial cluster center, that is, \( K_{m+1} \), and update the previously obtained \( h_i \) to the new initial cluster center set \( K' \). Update \( K' \) categories of each point update basis: After the cluster of \( H(h_i) \geq 38.54 \) increases the initial cluster center, the total demand of the cluster cluster is less than the upper limit of the number of shared car outlets. Repeat the above operation until \( \forall H(h_i) \leq 38.54 \).

### 4. Solution results and adjustment and optimization of shared car outlets

After several iterations through the above method, 12 clusters are obtained. The cluster center points of the 12 clusters are shared car sites. The selected shared car service outlets are classified, and according to the number of outlets, that is, the required construction scale, it is determined that each site belongs to a first or second-level shared car service outlet. For the calculation results in the table, the point of \( 25 < H(h_i) \leq 38.54 \) can be used as the first-level shared car service outlet, and the point of \( H(h_i) \leq 25 \) as the secondary shared car service outlet. The Second-level dot layout position results are shown in Table 6:

| Node number | East longitude coordinates | Coordinates of latitude | Network level | Number of covered demand points |
|-------------|---------------------------|-------------------------|---------------|-------------------------------|
| 1           | 120.1255                  | 30.27785                | first-level   | 4                             |
| 2           | 120.0654                  | 30.26727                | Second-level  | 2                             |
| 3           | 120.136                   | 30.31895                | Second-level  | 5                             |
| 4           | 120.1612                  | 30.29650                | first-level   | 7                             |
| 5           | 120.1779                  | 30.23801                | Second-level  | 3                             |
| 6           | 120.2576                  | 30.30559                | Second-level  | 2                             |
| 7           | 120.2071                  | 30.25510                | first-level   | 5                             |
| 8           | 120.0863                  | 30.16488                | Second-level  | 1                             |
| 9           | 120.1961                  | 30.18244                | Second-level  | 3                             |
| 10          | 120.1819                  | 30.27407                | first-level   | 7                             |
| 11          | 120.1775                  | 30.35693                | Second-level  | 3                             |
| 12          | 120.2271                  | 30.33909                | Second-level  | 2                             |

In order to more intuitively reflect the distribution of the first-level and second-level outlets, the position information of the two-level outlets is reflected in the position coordinate map, as shown in Figure 2: the red solid dots represent the first-level outlets, and the white hollow dots represent the second-level network.
As can be seen from Figure 2, the central area shared car outlets are more dense and the average size is larger. The first-level outlets are located in the center of Hangzhou. This is in line with the dense population density in the city center and the more demanding demand for shared cars. The side reflects the rationality of the shared car network planning plan.

5. Conclusion

Based on the case study of Hangzhou downtown area, this paper predicts the demand of regional shared cars by evaluating the ownership rate of shared cars, estimates the maximum number of people serving at all levels by the number of cars covered, and uses K-means clustering model to get the best number and location of network points. On account of the above research structure and research path, the number of service personnel sharing the clusters in the central city of Hangzhou is added, it is judged whether each cluster satisfies the number of service people for cluster center iteration, and finally the outlets are preferably selected according to the number of service persons. The scale of construction is studied, and the plan for the location selection of shared car outlets in the downtown area of Hangzhou is obtained. This paper provides a more effective research tool for the scientific decision-making of shared car site selection, also has important reference value for the research of related topics.

References

[1] Xu, H.L. (2018) Competitive Analysis of Shared Vehicles Based on Porter's Five Force Model. Modern trade industry. (2):65-67.
[2] Cao, G.Y, Liu, Q, Jin, Y. (2016) A Survey of Research on Vehicle Sharing System Scheduling Methods. Transportation. (2):89-93.
[3] Lu, S.H, Li, Q.W. (2018) Optimal Scheduling Model of Shared Bicycle Based on Greedy Algorithm——Taking Chengdu as an Example. Consumer guide. (3):26
[4] Xiao, L. Cui, Y.Q, Zhong, L. (2018) Research on the most preferred address problem of shared bicycle. Chinese business theory. (2):162-163.
[5] Wang, J.W, Zhu, J.M, Qi, H.Y. (2018) Research on Optimal Allocation of Urban Shared Bicycles Based on VRP Model. Journal of Shenyang Ligong University. (1):81-86.
[6] Yu, S. (2018) Research on Optimized Scheduling of Shared Bicycles under Multi-objective Programming. Modern trade industry. (7):86-87.
[7] Lu, T, Huang, J, Jiang, W. (2017) Construction of Shared Car Site Selection Model——Taking Hongshan District of Wuhan as an Example. Transportation research. (4):8-15.
[8] Wang, L.M. (2013) Research on Location Selection of Shared Vehicle Sites Based on AHP and Fuzzy Comprehensive Evaluation Method. Jiangsu Science and Technology Information. (7):60-62.

[9] Cao, G.Y, Liu, Q, Jin, Y. (2016) A Survey of Research on Vehicle Sharing System Scheduling Methods. Transportation. (z2):89-93.

[10] Li, S.S. (2018) Economic Model Analysis of Scale Design of High-speed Railway Station Parking Lot. Economic and trade practice. (06):141-142.