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Research on Site Selection of Shared Car based on Two-dimensional Analysis Method

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Abstract

Aiming at the difficult problem of site selection for shared cars, this paper proposes a site selection method for shared cars based on site two-dimensional analysis. Firstly, the study area is divided into m×n small regions by the method of regional discretization. Then, the geographic information of the study area is collected and divided into regions. Secondly, according to the necessary conditions of the facilities and land marked out, it is scored, and the demand level of each district is calculated by region, and the demand matrix is obtained. Then, according to the obtained demand matrix, combined with the development strategy of car rental enterprises, reasonably determine the service capacity and service scope of standard car-sharing sites, establish the service mode matrix, and calculate the location matrix. Finally, a two-level objective function is established to optimize and adjust the car-sharing sites through the coordination factor of planning layout, and then the genetic algorithm is used to solve the optimal number of stations and the location of the sites, so as to establish an efficient and scalable car-sharing location model.

Keywords

Car Sharing; Two-dimensional Analysis; Location Selection; Genetic Algorithm.

1. Introduction

In 1909, the German economist Alfred. Weber first proposed the facility location theory [1]. In 1974, church et al. proposed the maximum coverage problem, that is, to study how to maximize the accepted service demand by establishing p service stations under the condition of known service quantity and radius of facilities [2]. In 2012,Correia & Antunes took vehicle depreciation cost, dispatching cost and maintenance cost of outlets into consideration. Taking operating profit as the objective function, they proposed the location and scale of car rental sites, where the scale was represented by the number of parking Spaces. Among them, the maximum number of cars assigned to the station in a working day determines the number of parking Spaces in the station [3]. In 2014, Correia, Jorge & Antunes extended the model of Correia & Antunes by introducing the flexibility of users to choose the starting and ending points, real-time information of users to obtain parking Spaces, and consumer satisfaction, and established a mixed integer programming optimization model. And the model is applied to the time-sharing leasing project in Portugal [4].

2. Principles of Site Selection

This paper mainly studies the site selection theory and method of shared car rental site. The site selection of shared car rental site should meet the following principles:

2.1 Approach the User Principle

Car rental site due to mainly provide face-to-face service for customer, meet the demand of a certain area of car rental, so network location should be close to the user, to guarantee the business once

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carried out to provide customers with more convenient and quick service, such ability can maximize attract those to the car rental to transact business [5-6].

2.2 Layout Coordination

Operating companies usually hope to maintain a high rental rate for a long time. However, in order to control the development intensity and optimize the land use structure, cities will plan urban land into other types of land, which is an important influencing factor for the site selection of operating and leasing sites. In order to quantitatively describe the adjustment between the lease site and the surrounding planned land. The commercial and residential land use in some areas will adjust the coordination of land plot planning, and the adjustment of planned land use in the study area is analyzed.

2.3 Coverage of Service Capability [7-8]

The coverage degree of service capability of shared car rental points refers to the degree of demand points that are covered within a circle of appropriate radius with the site as the center. The higher the area covered by a site, the higher the service quality of the site. If the demand point is within the coverage radius, the demand point is satisfied by the site, which is considered as complete coverage; if it is outside the coverage radius, the coverage degree decreases with the increase of the distance between the site and the demand point. As shown in Figure 1, D1 is the coverage radius of a site. When the demand point is within the service radius D1, it is 100% covered by the site. When the distance between the demand point and the site exceeds D1 but not beyond D2, the coverage degree of the site decreases with the increase of the distance length. When the distance between the demand point and the site exceeds D2, the extent to which the demand point is covered is zero. In this paper, a part of the cosine function is used to represent the relationship between the coverage degree and the distance after the distance exceeds D1. This change trend is more consistent with the change relationship between the coverage degree and the distance in practice.

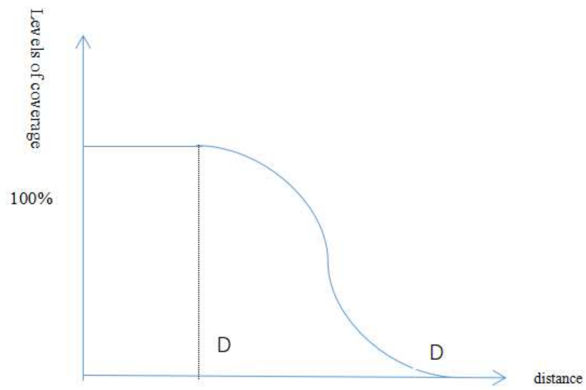

Fig. 1 The relationship between coverage and distance

$$\begin{cases} 1, \mathrm{d}_i < D_1 \\ w_i = \left\{ \dfrac{1}{2} + \dfrac{1}{2} \cos\left(\dfrac{\pi}{D_2 - D_1} \left(d_i - \dfrac{D_2 + D_1}{2} \right) + \dfrac{\pi}{2} \right), d_i \in [D_1, D_2] \right. \\ 0, \mathrm{d}_i > D_2 \end{cases}$$

Where, w_i represents the coverage level of the i site, and d_i represents the distance of the i site from the center.

2.4 Principle of Balance between Supply and Demand [9-10]

The best situation for the site selection of shared car rental sites is that the service capacity of all shared car rental sites in the planning area can exactly meet the demand of car rental in the region.

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3. Two Dimensional Analysis Location Model of Shared Car Rental Site based on Supply and Demand Balance

3.1 Discretization of Regions

In order to facilitate the two-dimensional space analysis, the analysis area needs to be discretized first, that is, the analysis area needs to be replaced by discrete points. In the specific operation, the study area can be divided into several study plots and the center point of each study plot can be used to replace the study plot.

3.2 Model Parameters

Assuming that the research area is divided into m×n small areas, the parameters in the model are set as follows:

i -- indicates the number of rows in which the region is located.

j -- Number of columns in the region.

d_{ij} -- regional demand value, $d_{ij}(i=1,2,3,\cdots,m,n=1,2,3,\cdots,m)$ is the shared car rental demand in the region of row i and column j.

D -- Demand matrix, which is an m×n order matrix composed of d_{ij}, describing the demand situation of the whole region.

A -- network service mode matrix, which represents the service supply of a standard car-sharing rental site, and is the demand size that car-sharing rental site can provide.

s_{ij} -- the shared car rental service level in the region of row i and column j.

$s_n(i,j)$ -- Services provided from the n site to the (i,j) region.

s_n -- Service matrix of the n node.

S -- the shared car rental service matrix in the whole region, which is the sum of the services of N shared car rental outlets.

e_{ij} -- the difference between supply and demand in region (i,j).

N -- The total number of shared car rental sites set in the area.

L_n -- the location of the n shared car rental site.

L -- the location matrix of shared car rental sites, where L_{ij} represents the number of rental sites in the area of row i and column j. When there are no rental sites in the area, $L_{ij}=0$; when there are t rental sites in the area, $L_{ij}=t$. For example, if there is a shared car rental site in the area of row 3 and column 2, then $L_{32}=1$ in the matrix.

The location matrix of the rental site is the sum of each site location matrix, that is, $L=\sum_{n=1}^{N} L_n$.

3.3 Objective Function

The shared car rental location problem is to solve the distribution matrix of shared car rental sites under the condition that the least number of shared car rental sites are configured and the demand of shared car rental in the region can be satisfied. Therefore, this problem can be described as finding the minimum shared car rental site when the service level at any point in the region is not less than the demand level,that is,

$$Min \| \sum_{n=1}^{N} L_n \|$$

The following conditions are met: $\forall e_{ij} \geq 0$, （i=1, 2, 3. . . m, n=1, 2, 3. . . m）.

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3.4 Establishment of Demand Matrix

The demand matrix refers to the demand for shared cars by users at each site. Through the research, it is found that the demand for shared car rental is mainly distributed in six types of areas: aviation, railway and highway transportation hubs, business districts, hotels and restaurants, satellite cities, tourist attractions, residential areas and busy areas of traffic trunk roads.

Therefore, when establishing the demand matrix, the basic geographic information of the research area should be collected first, and the above six types of land and facilities should be marked out in the research area.

Once the labeling is complete, a detailed analysis of the level of demand for various sites and facilities can be conducted.The demand level of car rental is divided into five levels: very good, very good, good, good and general. The scores of each level are shown in Table 1. Through research and expert scoring, the potential of car rental demand for specific sites and facilities can be quantified.

Then, the scores of each land use and facilities were marked on the corresponding positions on the map, and the sum of scores of different facilities and land use in each divided area was calculated to obtain the demand matrix of the study area.

Table 1. Demand level classification

Level	Level1	Level 2	Level 3	Level 4	Level 5
Grade	10-8.1	8-6.1	6-4.1	4-2.1	2-0

3.5 Establishment of Site Service Mode Matrix

In practice, the service level provided by a shared car rental site is related to the distance from the user, and decreases with the increase of the distance. According to the law of distance decay, the service matrix of the site should show the maximum value of the center point, and the service value of the other points decreases with the increase of the distance from the center. Generally speaking, this law of decline is the same as the theory of the business circle.

Business circle theory [63] divides the service scope of business service facilities into three components, namely, core business circle, secondary business circle and marginal business circle.

1) Core business area: It is the area closest to commercial service facilities and has a high density of customers. Usually, 55%-70% of customers of commercial service facilities come from the main business area.

2) Secondary business district: This is an area outside the main business district with relatively low customer density, which includes about 15%-25% of customers of commercial service facilities.

3) Marginal business area: it refers to the area outside the secondary business area, where customers are thinly distributed and commercial service facilities are less attractive. Small commercial service facilities have almost no customers in this area.

According to this principle, the service mode matrix of the shared car rental site can be set as the service capacity of the center point of the matrix is 100, then the service capacity of the center point to the core business area is 75%-55%, and the service capacity of the secondary business area is 15%-25%, beyond the service scope of the secondary business area, the service capacity is 0.

According to the characteristics of car-sharing rental service sites, the area where the time from the demand point to the service point is less than 10 minutes is defined as the core business area, the area of 10-20 minutes is defined as the secondary business area, and the area of more than 20 minutes is defined as the marginal business area. If 20km/h of the city bus is defined as the average travel speed, then the area with outlets 0-3.3km is the core business circle, the area between 3.3-6.7km is the secondary business circle, and the area outside 6.7km is the marginal business circle.

Therefore, if it is assumed that the research area is divided into small regions with side length of 4km and the service capacity of the core area is 100, the service moment can be obtained as follows:

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$$A=\begin{bmatrix} 0 & 15 & 20 & 15 & 0 \\ 15 & 20 & 75 & 20 & 15 \\ 20 & 75 & 100 & 75 & 20 \\ 15 & 20 & 75 & 20 & 15 \\ 0 & 15 & 20 & 15 & 0 \end{bmatrix}$$

3.6 Calculation of Shared Car Rental Service Matrix

The shared car rental service matrix of the n shared car rental site can be obtained by the following formula:

$$S=\sum_{n=1}^{N} Sn=\sum_{n=1}^{N} A\otimes L_n$$

Where, $\otimes$ stands for two-dimensional discrete volume integration operation, namely:

$$S_n\left(i,j\right)=\sum_{r=-L_{\frac{A}{2}}}^{I_{\frac{A}{2}}}\sum_{s=-J_{\frac{A}{2}}}^{J_{\frac{A}{2}}} A(r,s)L_n\left(i+r,j+s\right)$$

Where I_A and J_A represent the number of rows and columns of the site service pattern matrix. For example, suppose the site service pattern matrix is:

$$A=\begin{pmatrix} 30 & 50 & 30 \\ 50 & 100 & 50 \\ 30 & 50 & 30 \end{pmatrix}$$

There are two stations in the region, and the location matrix is:

$$L=\begin{bmatrix} 0&0&0&0&0&0\\ 0&0&0&0&0&0\\ 0&1&0&0&0&0\\ 0&0&0&0&0&0\\ 0&0&0&0&0&0\\ 0&0&0&0&0&0 \end{bmatrix} \qquad L2=\begin{bmatrix} 0&0&0&0&0&0\\ 0&0&0&1&0&0\\ 0&0&0&0&0&0\\ 0&0&0&0&0&0\\ 0&0&0&0&0&0\\ 0&0&0&0&0&0 \end{bmatrix}$$

According to the above formula, the service matrix of shared car rental can be obtained:

$$S=S_1+S_2=\begin{bmatrix} 0&0&30&50&30&0\\ 0&0&50&100&50&0\\ 30&50&60&50&30&0\\ 50&100&50&0&0&0\\ 30&50&30&0&0&0\\ 0&0&0&0&0&0 \end{bmatrix}$$

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4. Solution of the Model

The above multi-objective and multi-constraint problem is a NP-hard problem, which is solved by particle swarm algorithm, genetic algorithm and simulated annealing algorithm. In this paper, the site selection model has a large number of candidate points and a complex objective function. In order to improve the running speed, the improved NSGAII genetic algorithm is considered to solve the problem. Up to now, NSGAII genetic algorithm has been widely used in practical optimization and scheduling engineering, but there are few researches on solving the location problem. This paper firstly applies this algorithm to solving the network address problem of shared car.

4.1 Construction of Service Pattern Matrix

The service capability of a single car-sharing rental site is generally given by car-sharing rental enterprises according to their own investment level and market demand. In this paper, according to the demand matrix of the research area, the service capability of the standard network is set as 30 in the center, and starts to decay from the center according to the service level. The area of 0-3.3km network is the core business circle, the area of 3.3-6.7km is the secondary business circle, and the marginal business circle is beyond 6.7km. The service mode matrix is constructed as follows:

$$A=\begin{bmatrix} 0 & 5 & 10 & 5 & 0 \\ 5 & 10 & 20 & 10 & 5 \\ 10 & 20 & 30 & 20 & 10 \\ 5 & 10 & 20 & 10 & 5 \\ 0 & 5 & 10 & 5 & 0 \end{bmatrix}$$

4.2 Calculate the Position Matrix

The location matrix of shared car rental site layout is obtained by calculation:

$$D=\begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The regional Communist Party should arrange 52 shared car rental stations.

The site service matrix is:

$$D=\begin{bmatrix} 0 & 5 & 20 & 25 & 30 & 25 & 25 & 30 & 30 & 20 & 25 & 30 \\ 10 & 20 & 20 & 20 & 30 & 25 & 25 & 35 & 30 & 40 & 30 & 35 \\ 10 & 20 & 40 & 45 & 55 & 60 & 55 & 60 & 40 & 50 & 25 & 20 \\ 30 & 50 & 45 & 50 & 60 & 60 & 50 & 60 & 45 & 35 & 20 & 10 \\ 30 & 40 & 40 & 60 & 75 & 70 & 60 & 65 & 55 & 50 & 30 & 20 \\ 25 & 40 & 45 & 65 & 70 & 75 & 65 & 70 & 70 & 60 & 35 & 15 \\ 40 & 40 & 50 & 60 & 65 & 55 & 50 & 70 & 80 & 75 & 40 & 20 \\ 50 & 45 & 45 & 55 & 45 & 45 & 40 & 50 & 55 & 50 & 35 & 15 \\ 25 & 35 & 50 & 50 & 40 & 45 & 40 & 35 & 40 & 45 & 25 & 5 \\ 15 & 30 & 40 & 50 & 50 & 50 & 50 & 40 & 30 & 20 & 15 & 15 \\ 5 & 15 & 30 & 40 & 35 & 35 & 40 & 30 & 25 & 10 & 10 & 10 \\ 5 & 20 & 25 & 30 & 25 & 25 & 20 & 25 & 20 & 15 & 15 & 5 \end{bmatrix}$$

The two objective functions of the site selection model ---- total government satisfaction and total coverage are taken as evaluation indexes. To simplify the calculation, the coefficients of each index are assigned, and a=0.7 and b=0.3 are set. The score results are shown in Table 2. The comprehensive score of each site selection scheme was calculated.

Table 2. Comprehensive scores of all site selection schemes

Site Selection Scheme No.	Total government satisfaction	The total coverage(%)	Composite scores
3	66	22	52.8
36	57	21	46.2
2	71	20	55.7
8	99	22	75.9
91	72	21	56.7
1	79	21	61.6
4	83	21	64.4
100	77	22	60.5
99	74	22	58.4
98	91	23	70.6

As can be seen from Table 2, Plan 8 has the highest comprehensive score of 75.9, so it is the final site selection plan. The site selection scheme contains 47 sites, with a government satisfaction score of 99 and a total coverage rate of 22%. The validity and superiority of the model are proved.

5. Conclusion

Car sharing is the development trend of the current transportation industry, because of the convenient and economic rental service has a great development prospect. However, there is a problem of low utilization rate in the development of car-sharing, which leads to low profit of car-sharing operators. In order to improve the utilization rate of vehicles, the optimal location and scheduling model of shared cars is designed. As for the location of shared cars, the previous scholars only considered the perspectives of individuals and enterprises, and the perspective of the problem was not comprehensive enough. Therefore, this paper comprehensively considered the perspectives of individual enterprises and the government to re-model the location of shared cars, so as to obtain an effective and highly generalizable location model of shared cars.

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