Research on Improvement of Parking Generation Rate Model Based on Behavior Selection

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Abstract. The traditional parking generation rate model can no longer forecast the demand of parking slots accurately under the pattern of shared parking. Shared parking, which can make full use of the free time of private or non-private parking slots, has become an effective way to ease the pressure of urban parking. Therefore, shared parking behavior selection generation (SPBSG) model is established, based on the analysis of residents’ shared parking selection behavior. The SPBSG model fully simulates residents’ parking choice preferences, shared slots management, parking time differences between different land types, and walking distance after parking. Experiment shows that the SPBSG model can reduce parking slots by 24.45\% compared with the traditional parking demand prediction method.

1. Introduction
The problem of parking has gradually become a key link affecting the urban transport system. With the increasing supply-demand contradiction of parking space, the concept of shared parking \cite{1} has emerged. Shared parking makes use of the differences in time distribution and space distribution among parking users with different purposes (commuting, shopping, commuting, etc.) to realize the sharing of parking slot, improve the utilization rate of parking slot, and alleviate the supply-demand contradiction of parking.

The studies on shared parking are mainly conducted in three aspects, including: parking space allocation, price and management policy formulation and shared parking demand forecasting. Zhang \cite{2} established a double-target parking space allocation model that maximizes the utilization rate of shared parking space and minimizes the walking distance after parking. It uses particle swarm multi-object search algorithm to solve the parking difficulty to a certain extent. Chen \cite{3} established a theoretical model for overflow parking demand, share parking space supply and spatio-temporal resource allocation, which can calculate shared parking allocation plans corresponding to the spatial and temporal characteristics of different parking demands. Xiao \cite{4} proposed a repeated double VCG (FRD-VCG) auction mechanism to reduce the withdrawal of potential participants (people with demand for parking space and parking space suppliers), and proposed rules for parking space allocation and rules for transaction payment. Su \cite{5} proposed the maximum trading cycle and trading (TTCD) mechanism and trading chain (PC-TTCC) mechanism to match the capital flow in the market shared parking. He \cite{6} analysed the differences between commuter parking and non-commuter parking in shared parking.
selection, and built a model of shared parking selection. Ran\cite{7} came up with a method of parking space demand based on the implementation of combined parking sharing measures.

At present, the main methodology for parking demand forecasting is parking generation rate model. Therefore, on the basis of parking generation rate, various correction coefficients are added to adapt the traditional model to forecast the demand of shared parking. However, when modifying the traditional model, researchers did not fully consider the parking preferences of individual residents, nor did they consider the changes in parking space demand caused by the differences between shared parking slot and ordinary parking slot. Therefore, this study focuses on the impact of residents’ selection preferences, parking space management and usage differences on shared parking slot demand, and builds shared parking behaviour selection generation (SPBSG) model, so as to improve the accuracy of shared parking slot demand forecasting.

2. Methodology

2.1. Residents’ Shared Parking Selection Behavior

Parking selection refers to the process of residents looking for and selecting parking spaces \cite{8}. Residents’ parking preference will be affected by parking fees, income, driving years, walking distance after parking, travel purpose and parking duration. When parking spaces can be shared, residents’ parking choices are also affected by the characteristics of shared parking slots, such as convenience, information accuracy, usage time constraint, and vehicle safety. The study of residents’ parking choice behaviour and analysis of the impact of various factors on parking choice will help to modify the parking demand forecasting model and improve the accuracy of regional parking demand forecasting.

2.1.1. Shared parking selection utility function

According to utility theories, the utility for parking option $i$ of decision maker $n$ can be expressed as $U_{in}$. $V_{in}$ is the fixed term of utility function for parking choosing plan $i$ of decision maker $n$, and $\varepsilon_{in}$ is the probability term of utility function for parking choosing plan $i$ of decision maker $n$.

$$U_{in} = V_{in} + \varepsilon_{in}$$ (1)

In the analysis of shared parking choice behaviour, the parking options for decision making can be divided into two categories, namely, shared parking and non-shared parking. $V_{1n}$ is used to represent the utility of shared parking, $V_{2n}$ is used to represent the utility of non-shared parking, $X$ is feature variable, and $\theta$ is unknown parameter corresponding to the feature variable. The utility functions can be expressed as:

$$V_{1n} = f(\theta_1, X_{1n})$$ (2)

$$V_{2n} = f(\theta_2, X_{2n})$$ (3)

2.1.2. Feature selection

In order to find out the feature variables and their parameters, we conducted an RP/SP survey on shared parking among residents in Jiangbei New District, Nanjing. It obtains 5952 data of 249 parking users, such as gender, income, driving years, parking purpose, parking duration, parking fee, distance of walking after parking, etc. Data with low relevance are removed through data cleaning and feature selection, the feature variables and parameters are shown in Tab.1.

| Name   | Value   | Std.err | t-test | p-val | Rob.std.err | Rob. t-test | Rob.p-val |
|--------|---------|---------|--------|-------|-------------|-------------|-----------|
| $\varepsilon_1$ | 0       | -       | -      | -     | -           | -           | -         |
| $\varepsilon_2$ | 3.98    | 2.83E+03 | 0      | 1     | 3.07        | 1.3         | 0.19      |
| X_dist | 15.4    | 979     | 0.02   | 0.99  | 1.08        | 14.19       | 0         |
| X_limit | -1.44   | 615     | 0      | 1     | 0.577       | -2.5        | 0.01      |
Notes: $X_{\text{dist}}$ - walking distance after parking, $X_{\text{limit}}$ - time limit of shared parking, $X_{\text{delay}}$ - parking information delay, and $X_{\text{safety}}$ – vehicle safety

2.2. Shared Parking Slot Demand Forecast

Under the condition of shared parking, the demand for parking slot is usually affected by such factors as walking distance after parking, time limit of shared parking, parking information delay and vehicle safety. Therefore, on the basis of the original parking generation rate model, adjustment coefficients should be added to modify the shared parking demand forecasting model.

2.2.1. Shared parking selection adjustment coefficient

According to the above analysis of parking selection behaviour, the utility ratio of non-shared parking and shared parking is defined as shared parking selection adjustment coefficient, which is represented with $\mu$:

$$\mu = \frac{V_n}{V_s} = \frac{f(x_{\text{limt}}, X_{\text{delay}})}{f(x_{\text{limt}}, X_{\text{delay}})}$$

(4)

2.2.2. Parking time distribution adjustment coefficient

There are obvious differences in the time distribution of parking demand of different land types in a day. In order to clarify the relationship between parking demand of single land type and parking demand of mixed land types, the quotient of single land parking demand in the peak hour of mixed land and parking demand of the land in the peak hour can be defined as parking time distribution adjustment coefficient $\tau$. $\tau_j$ is used to represent the hourly parking demand adjustment factor in the peak period of land type $j$, and it’s expressed as follows:

$$\tau_j = \frac{d_j^T}{d_j^T}$$

(5)

In this equation, $T$ is the peak hour of parking demand in a day for the land of mixed use, $d_j^T$ is parking demand of land type $j$ at time $T$, $T_j$ is the peak hour of parking demand in a day for land type $j$, $d_j^{T_j}$ is peak hour parking demand of land type $j$.

2.2.3. Public transportation adjustment coefficient

The impact of public transportation on parking demand is mainly reflected in its ability to replace private cars. Public transport has the characteristics of strong carrying capacity and high transport efficiency, and can effectively meet residents’ travel needs and alleviate traffic congestion in cities. Good bus stop allocation and reasonable bus network layout can make residents more inclined to choose public transport over private cars. Studies have shown that the parking demand within a 500m radius with a subway station as the centre is lower than that in the non-radiation area. The public transportation adjustment coefficient takes the number of bus stops (including conventional bus stops and subway stations) as the impact factor to construct the correction coefficient $\rho$ of public transport to parking demand.

$$\rho = 1 - PR^k$$

(6)

In this equation, $\rho$ is the public transportation adjustment coefficient, $PR$ is the growth rate of public transport travel ratio, and $k$ is the number of bus stops in the region.

2.2.4. Shared parking behavior selection generation (SPBSG) model

Parking generation rate model predicts parking demand by studying parking generation rate of different land uses. Assuming that parking demand of a unit land area remains unchanged, the studied area is divided into $i$ areas. $i=1,2, ..., M$; $f$ stands for types of land use, $f=1,2, ..., N$; $\alpha_{ij}$ stands for parking demand
in area $i$ of type $j$; $R_{ij}$ stands for the area of type $j$ in area $i$, the total parking demand $P$ in the studied area is as follows:

$$P = \sum_{i}^{N} \sum_{j}^{M} \alpha_{ij} \times R_{ij}$$

(7)

Among them, $\alpha_{ij}$, the parking demand per unit area of the land can be obtained according to the study of regional parking characteristics, nature of land use, land planning and other data. Since the parking generation rate model is easy to use and has low data requirements, it is widely used for parking demand forecasting. However, the model assumes that parking demand for a unit land is stable, and does not take the development of urban public transport, parking turnover, traveller characteristics and other influencing factors into consideration.

In order to optimize the parking generation rate model, and improve the accuracy of shared parking slot demand forecasting, the three above adjustment coefficients can be added to the original parking generation model. The adjustment coefficients are shared parking selection adjustment coefficient $\mu$, parking time distribution adjustment coefficient $\tau_{ij}$, and public transportation adjustment coefficient $\rho$. Thus, take $P_{S}$ as shared parking slot demand, SPBSG model is as follows:

$$P_{S} = \mu \sum_{j}^{M} (P \times \tau_{ij} \times \rho)$$

(8)

3. Case study
The study area, Rongsheng land lot, is located in Jiangbei New District, Nanjing. It includes a residential area of 171677.2 m², a commercial area of 62667.52 m² and Changcheng middle school with an area of 44579.02 m².

![Study Area](image)

3.1. Shared parking selection adjustment coefficient
According to (1) – (3) and Tab. 1, the utility function of shared parking $V_{1n}$ and the utility function of non-shared parking $V_{2n}$ can be described as follows:

$$V_{1n} = 15.4X_{dist} - 1.44X_{delay} - 1.06X_{safety} - 1.72X_{other}$$

(9)

$$V_{2n} = 3.98 + 15.4X_{dist} - 1.44X_{travel}$$

(10)

Choose 100 individuals randomly from the RP/SP database to calculate $\mu$, and the shared parking selection adjustment coefficient is:

$$\mu = \frac{V_{2n}}{V_{1n}} = 0.82$$

(11)

3.2. Parking time distribution adjustment coefficient
With the parking time of residential type as the benchmark, we calculate $\tau$ for both commercial area and school area according to (5).
### Table 2. Time adjustment coefficient table

| Type          | Residential | Commercial | School |
|---------------|-------------|------------|--------|
| Time distribution adjustment coefficient | 1           | 0.90       | 0.79   |

### 3.3. Public transportation adjustment coefficient

There are a total of 4 bus stops in the study area. According to the passenger volume of public transport in Nanjing from 2006 to 2018, the annual average growth rate of public transport is 1.36%. And according to (8), the public transportation adjustment coefficient \( \rho \) is 0.95.

### 3.4. Index of parking generation rate allocated to buildings

According to the classification in Standards and Guidelines for Setting Parking Facilities for Construction of Buildings in Nanjing City (Edition 2019), the calculation of parking space for different types is as follows:

### Table 3. Vehicle parking allocation index calculation table

| Type          | Residential | Commercial | School | Total |
|---------------|-------------|------------|--------|-------|
| Parking spaces \( P \) (pcs) | 1197 | 302 | 83 | 1582 |

### 3.5. Demand of shared parking slot

Residents’ demand for parking slots under shared parking pattern can be forecasted by the SPBSG model.

### Table 4. Demand of shared parking slot (Unit: pcs)

| Type          | \( \mu \) | \( \tau \) | \( \rho \) | \( P \) | \( P_s \) |
|---------------|----------|----------|----------|--------|--------|
| Residential   | 0.82     | 1        | 0.95     | 932    | 1197   |
| Commercial    | 0.82     | 0.90     | 0.95     | 212    | 302    |
| School        | 0.82     | 0.79     | 0.95     | 51     | 83     |
| Total         | -        | -        | -        | 1582   | 1195   |

### 4. Conclusion

In this study, the traditional parking generation rate model is optimized according to the analysis of residents’ shared parking selection behaviour. A SPBSG model is established by analysing the shared parking selection adjustment coefficient \( \mu \), parking time distribution adjustment coefficient \( \tau \), and public transportation adjustment coefficient \( \rho \). Therefore, the comparison of the results between SPBSG model \( P_s \) and parking generation rate model \( P \) is shown in Tab.5.

### Table 5. Analysis of forecast results of shared parking demand

| Type          | \( P \) (pcs) | \( P_s \) (pcs) | \( P_s - P \) (pcs) | Value (pcs) | Ratio |
|---------------|--------------|----------------|---------------------|-------------|-------|
| Residential   | 1197         | 932            | -265                | -22.10%     |
| Commercial    | 302          | 212            | -90                 | -29.89%     |
| School        | 83           | 51             | -32                 | -38.46%     |
| Total         | 1582         | 1195           | -387                | -24.45%     |

Calculating by 30 m² per parking slot, a total of 387 parking slots are reduced compared with the traditional parking generation rate model, thus saving a construction area of 11610 m², and reducing the allocated parking space by 24.45%.

The SPBSG model takes shared parking behaviour selection, parking time, parking fee and public transportation development into consideration, which is closer to the reality of the parking slot demand. The use of the SPBSG model can effectively reduce the quantity of parking slots, and improve parking slot utilization, thus saving urban land use resources.
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References
[1] Smith M S. Shared Parking [M]. 2nd ed. Washington DC: Urban Land Institute, 2005.
[2] ZHANG Wen-hui, SU Yong-min, DAI Jing, WANG Lian-zhen. Distributing Model for Shared Parking in the Residential Zones [J]. Journal of Transportation Systems Engineering and Information Technology, 2019, 19(01): 89-96.
[3] CHEN Jun, WANG Bin, ZHANG Chu. Parking Resource Sharing and Matching Methods for Appertaining Parking Facilities Based on Space-time Capacity [J]. China Journal of Highway and Transport, 018, 31(03): 96-104+115.
[4] Xiao H, Meng X. How to restrain participants opt out in shared parking market? A fair recurrent double auction approach [J]. Transportation Research Part C: Emerging Technologies, 2018, 93: 36-61.
[5] SU Xiu, Meng Cheng. Private parking slot sharing [J]. Transportation Research Part B, 2016, 93: 596-617.
[6] HE P, CHEN J, ZHEN J H, et al. Parking Choice Behavior for Shared Parking Based on Parking Purposes [J]. Applied Mechanics and Materials, 2015, 743: 439-444.
[7] RAN Jiang-yu, GUO Xiu-cheng. A Method of Parking Demand Analysis Based on Shared Parking Strategy in Developed Regions [J]. Journal of Transport Information and Safety, 2015, 33(03): 9-15.
[8] HAN Xue, WANG Di. Behavior Analysis on Choices of Urban Residents on Shared Parking [J]. Journal of Hebei University of Water Resources and Electric Engineering, 2019(03): 57-60.