Time Window Delineation for Shared Parking in Urban Center

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ABSTRACT: The key to solving parking problem in urban centers using shared parking strategy lies in parking demand prediction and time window delineation for shared parking spaces. By analyzing the temporal distribution of parking demand for different land types, the influence of public transport on the demand for private car trips, and the analysis of residents' behavior of parking sharing, a behavioral choice-parking generation rate prediction model for shared parking demand is constructed. And on this basis, the study also lays emphasis on the principles and methods of parking time windows, predicts the number of available parking spaces and reserved parking spaces during the parking sharing period, and identifies the time windows for shared parking in the urban center.

1. INTRODUCTION

To alleviate the difficulties in parking in urban centers, shared parking has become one of the solutions for many cities. Shared parking enables sharing of the available parking spaces between different sites based on the differences in the temporal and spatial distribution of parking demand in adjacent areas of the city.

At present, shared parking is still under exploration, and many experts and scholars have studied it from various aspects, expecting to fully utilize the potential value of parking resources by realizing complementation of the parking time with the focus of helping users having the long-term parking sharing demand [1]. Yao Enjian et al [2]. made a thorough analysis on the time constraints and allocation principles of parking sharing, improved the graph coloring model and established an optimal allocation model of parking sharing resources, which effectively realizes optimal matching of the parking spaces for vehicles to be parked, but the study made less elaboration on the level of network deployment. Duan Manzhen et al [3]. found that complementarity exists in parking demand between residential areas and other types of places. Duan et al [4]. conducted a detailed study on the temporal characteristics of parking spaces in residential areas, and solved the problem of uneven parking allocation by establishing a two-level planning model, but they did not analyze and study the time constraint of matching. Similar two-level planning model has been improved by many scholars. Chen Jun et al [5]. applied the two-level model to the allocation of rental and sharing for college parking spaces, analyzed a variety of parking space usage scenarios, and also considered the solution in case college parking spaces could not meet the parking demand. In addition, Chen et al. classified the demand for parking sharing, determined the influencing factors of parking for different parking purposes, and established two parking choice models [6].

Most of the previous studies on parking sharing matching take the number of the available parking spaces as the research object, but ignore the strict time constraints in parking sharing matching, so they have certain limitations. Therefore, it is of practical significance to study the time window delineation of parking sharing and accurately determine the sharing period and number of vacant parking spaces so as to improve the utilization rate of parking spaces.

2. Parking Demand Prediction

Under the condition of shared parking, the demand for parking spaces is usually affected by factors such as time, development level of public transport, and parking charging policy [7]. Therefore, on the basis of the original model of parking generation rate, it is necessary to add the corresponding adjustment coefficients to correct the forecast of shared parking demand [8].

Herein, τ_j is used to represent the adjustment coefficient for parking demand in Type j land during peak hours [9]. The expression is as Equation 1:

$$\tau_j = \frac{d_j^T}{d_j^{T_j}} \tag{1}$$

Where, T is the peak hour of parking demand in a day in the mixed-use land, d_j^T is the parking demand of Type j land at T time, T_j is the peak hour of parking demand in a day for Type j land, and $d_j^{T_j}$ is the peak hour of parking demand for Type j land.

For the adjustment coefficient of public transportation [9], the number of bus stops (including conventional bus and rail stops) are taken as the influence factor to construct

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the correction factor ρ of demand of public transportation for parking spaces. The expression is as Equation 2:

$$\rho = 1 - PR^k \tag{2}$$

Where ρ is the adjustment coefficient of public transportation, PR represents the growth rate of the proportion of public transportation trips, and k is the number of public transportation stops in the region.

In the behavior analysis of choice on shared parking spaces, the parking options for decision making can be divided into two categories, i.e., shared parking lot and non-shared parking lot [10]. V_{1n} denotes the parking sharing utility and V_{2n} refers to the non-parking sharing utility, and the utility function can be expressed as Equation 3 and Equation 4 below:

$$V_{1n} = f(\boldsymbol{\theta}_1, \ \boldsymbol{X}_{1n}) \tag{3}$$

$$V_{2n} = f(\boldsymbol{\theta}_2, \ \boldsymbol{X}_{2n}) \tag{4}$$

Based on the behavior analysis of parkers' choice on parking lot, the ratio of non- shared parking utility to shared parking utility is defined as the adjustment coefficient of choice on parking lot, denoted by μ. The expression is as Equation 5 :

$$\mu = \frac{V_{2n}}{V_{1n}} = \frac{f(\boldsymbol{\theta}_2, \ \boldsymbol{X}_{2n})}{f(\boldsymbol{\theta}_1, \ \boldsymbol{X}_{1n})} \tag{5}$$

Then the quantity demanded for shared parking spaces considering residents' choice on parking lot P_s' can be obtained by the following Equation 6:

$$P_s^{'} = \mu P_s = \mu \sum_{j=1}^{N} (P \times \tau_j \times \rho \times \eta) \tag{6}$$

The behavioral choice-parking generation rate demand prediction model for shared parking is based on the parking generation rate model, and considers the comprehensive effects of parking time, parking cost, development level of public transport and residents' parking choice on parking demand under the condition of shared parking, which can more accurately achieve the demand prediction of parking sharing.

3. Time Window of Shared Parking

3.1. Setting principle for time window of shared parking

The parking demand in the region shall be regarded as the basis to determine the time window under the condition of shared parking, matching the parking demand with the number of the available parking spaces in the available buildings to ensure that there is no overflow of parking demand during the period of parking sharing.

Besides, the needs of the parking space owners as well as the users of the shared parking spaces shall be taken into account as well to identify the time window for parking sharing, so as to ensure that the parking interests of the parking space owners are not infringed upon, and simultaneously meet the parking needs of the users of the shared parking spaces. Hence, the following principles must be followed when determining the time window for parking sharing to ensure that the implementation of the program will ensure that the interests of all parties are protected [11].

3.1.1. Security for meeting parking needs

When setting the time window, it is necessary to consider the parking needs of both the owner and user of parking space [12]. Taking residential areas as an example, the owners act as the main body of parking spaces in residential areas, and the owners' own needs shall be prioritized during the implementation of shared parking. In addition, when setting the time window, it shall be guaranteed that the idle parking resources in the specified area can meet the demand for shared parking, so as to avoid parking problems such as indiscriminate parking of vehicles caused by the unsatisfied parking demand due to the reduction of the total parking supply.

3.1.2. Stability of the time window

The time window of shared parking shall be reliably stable. In other words, the number of the available parking spaces in the specified area is sufficient to meet the parking demand within a relatively long period of time. Too short time window of shared parking or a fragmented patchwork of time window will result in confusion for parkers and, in turn, exacerbate the mismatch between parking supply and demand. Consequently, the time window of shared parking must be continuous and stable and span a large period of time.

3.2. Time window setting of shared parking

When setting the time window for parking sharing, it is necessary to compare and match the prediction results with the number of the available parking spaces in the area based on the behavioral choice-parking generation rate prediction model for shared parking demand constructed above, and come up with a time window that can meet the shared parking demand. When matching the available parking spaces with parking demand, a certain number of parking spaces must be set aside in case the building itself encounters unexpected parking demand. The residential area where the shared parking is implemented must also meet the condition of acceptable walking distance for vehicle owners, which is selected as 300 meters for this study.

4. Examples

4.1. Date analysis

The Baijiahu area in Jiangning District, Nanjing City, Jiangsu Province, is located in the center of Dongshan sub-city, forming a comprehensive hub area integrating functions such as commerce, business, culture, administration and residence. This paper investigates the use of parking facilities in this area to obtain basic data

and study and analyze the mechanism of shared parking. The survey area is centered on the intersection of Shuanglong Avenue and Tianyuanzhong Road and radiates outward for about 1 km, including commercial area (Jingfeng KINGMO), residential area (21st Century Modern City Apartments), work place (Nanjing Phoenix Contact Co., Ltd.) and other land types of different nature.

There is a clear regularity of parking demand in residential area, work place and commercial area, and the peak hour are relatively stable. The peak parking demand in residential area is concentrated in the time periods of 0:00-7:00 and 19:00-24:00, that in commercial area is mainly around 19:00 in the afternoon, and that in work place is mainly between 9:00 and 17:00. It can be seen that differences exist in the peak parking demand of the three land types, and the parking spaces in commercial area and work place are not saturated throughout the day. The parking demand characteristics of residential, shopping malls and office buildings are different, which makes it possible to provide and share the available parking spaces in shopping malls and office buildings. Parking volume of different sites on weekdays is presented in Figure 1.

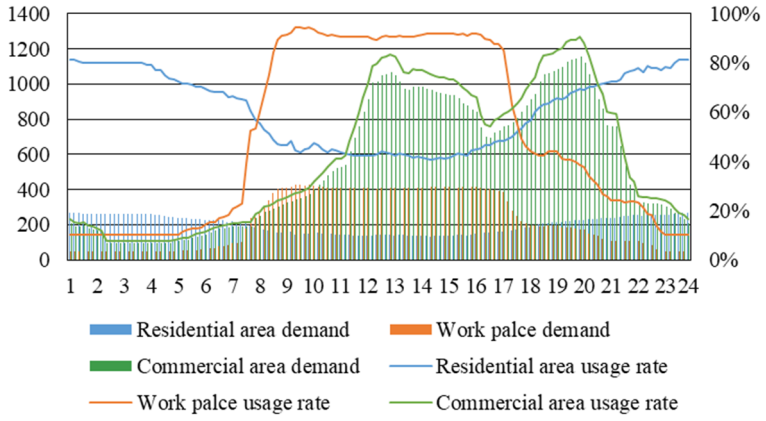

Figure 1. Parking volume of different sites on weekdays

4.2. Parking demand prediction

This example uses the parking data of Baijiahu area in Jiangning District, Nanjing, and predicts the parking demand of 21st Century Modern City Apartments in this district from 8:00 to 20:00 on weekdays by combining the behavioral choice-parking generation rate prediction model for parking sharing demand constructed in the previous section. The parking demand for each time period Xi is shown in the second column of Table 1.

Table 1. Demand prediction of parking sharing in residential area

Time period	Parking demand Xi	Free berth Yi	No. of shared berth	Time period	Parking demand Xi	Free berth Yi	No. of shared berth
8:00-8:20	114	116	113	14:00-14:20	146	248	216
8:20-8:40	145	147	141	14:20-14:40	141	255	222
8:40:9:00	150	153	148	14:40-15:00	139	251	218
9:00-9:20	147	176	153	15:00-15:20	137	251	218
9:20-9:40	152	184	160	15:20-15:40	131	246	214
9:40-10:00	161	196	170	15:40-16:00	132	243	211
10:00-10:20	170	209	182	16:00-16:20	139	238	207
10:20-10:40	163	209	182	16:20-16:40	143	231	201
10:40-11:00	151	212	184	16:40-17:00	150	222	193
11:00-11:20	154	237	206	17:00-17:20	147	212	184
11:20-11:40	161	244	212	17:20-17:40	146	202	176
11:40-12:00	156	246	214	17:40-18:00	160	190	165
12:00-12:20	152	254	221	18:00-18:20	142	174	151
12:20-12:40	153	256	223	18:20-18:40	143	176	153
12:40-13:00	151	258	224	18:40-19:00	131	156	145
13:00-13:20	142	258	224	19:00-19:20	140	135	137
13:20-13:40	151	256	223	19:20-19:40	146	114	125
13:40-14:00	158	255	222	19:40-20:00	130	102	113

4.3. Confirmation of the number of available parking spaces and reserved parking spaces

The availability of parking spaces in residential areas selected for this study was obtained from a preliminary survey. When setting the number of reserved parking spaces in residential areas themselves, the criteria for determining whether to implement parking sharing were made as per 85% of the vehicles parked during the peak parking period, and the number of reserved parking spaces C was determined as 5% of the number of idle parking spaces Yi. The number of available parking spaces and the number of reserved parking spaces for each time period in the area are shown in the third and fourth column of Table 1, respectively.

4.4. Confirmation of time window for parking sharing

As can be seen from Figure 3, the number of shared parking spaces in the residential area is increasing all the time from 8:00 a.m., and by 9:10 a.m. the shared parking spaces in the residential area are already equal to the parking demand. That is to say, from 9:10 a.m., there is a sufficient number of stably available parking spaces in the residential area to meet the demand for parking sharing in the area, and this time period lasts until 18:40 p.m. As the owners of the residential area gradually get back to home, the number of vacant parking spaces decreases as demand of parking spaces begins to rise, so the demand for parking sharing cannot be met. Since parking is an ongoing behavior, it cannot be ended immediately. Based on this, the time window for parking sharing can be determined as 9:00-18:30. Time window of parking sharing in residential area is presented in Figure 2.

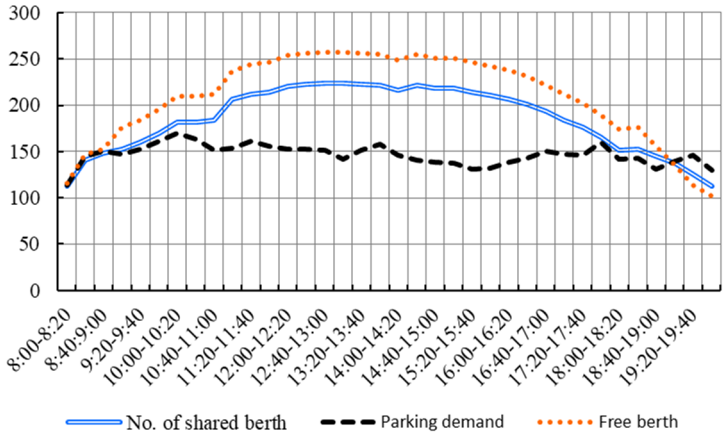

Figure 2. Time window of parking sharing in residential area

5. Conclusions

In this paper, the traditional parking generation rate model based on the concept of shared parking is improved by analyzing the residents' parking choice. Moreover, the research also respectively studies the differences in the temporal distribution of parking demand of different land types, the influence of public transport development on parking demand, the guiding role of parking charging policy on the demand for shared parking spaces, and the relation between residents' parking preferences and parking demand. Besides, a utility function of parking choice is established using BL model, based on which the adjustment coefficient of parking choice is introduced to construct a behavioral choice-parking generation rate prediction model for parking sharing demand. In addition, the study shows that the execution of regional shared parking requires both sufficient available parking spaces which can meet the shared parking demand within the walking range accepted by car owners, and the relatively continuous and stable period of time when the available parking spaces can be shared. With the two conditions satisfied, the time window setting for parking tide can be determined as per practical situation.

Acknowledgments

This work was financially supported by Academic Funding Program for top Talents of higher academic disciplines of Anhui Provincial Education Department （gxbjZD2022095） and by Anhui Provincial Natural Science Foundation of China (1908085QE240)

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