The Journal of Transport and Land Use jtlu.org
Vol. 17 No. 1 [2024] pp. 603–623

JTLU

The distribution of shared parking use in time and space: A case study in Guangzhou, China

Juan Wang
Guangzhou HKUST Fok Ying Tung Research Institute; Hong Kong University of Science and Technology
juanwang@ust.hk

Pengyu Zhu (corresponding author)
Hong Kong University of Science and Technology
pengyuzhu@ust.hk

Abstract: Shared parking enables private parking owners to share their parking spaces during idle time. In recent years, increasingly more research investigated people's intentions to participate in shared parking schemes as well as optimization algorithms to match shared parking supplies and demands. However, little research has investigated the distribution of shared parking use in time and space in implementation. To fill this gap, this study uses the transaction records of 121 shared parking lots in Guangzhou, China, and applies a quasi-Poisson regression model to analyze the influence of a set of explanatory factors on the total number of transactions. The results show that the number of parking transactions is significantly influenced by implemented duration, parking lot capacity, land use of shared facility, number of POIs (point of interest), and transit stations within a range of 750 meters from the shared parking lot. This study also applies a linear regression model to analyze the effect of a set of explanatory variables on the average parking duration at shared parking lots. The results show that the average parking duration is significantly influenced by the land use of a shared facility, number of office buildings within 750 meters from the shared parking lot, and peak time of the shared parking lots.

Keywords: Shared parking lots, distribution in time and space, total number of transactions, average parking duration

Article history:
Received: July 10, 2023
Received in revised form: April 1, 2024
Accepted: April 24, 2024
Available online: August 13, 2024

1 Introduction

Parking difficulties have caused great distress to citizens and transport authorities, particularly in large cities. In an attempt to reduce these problems during the last two decades, intelligent parking management, such as real-time reservation and pricing, has been applied to increase parking allocation efficiency (e.g., Mei et al., 2019; Teodorović & Lučić, 2006). However, most of these parking management initiatives are applied to public parking, aiming at increasing the utilization rate of public parking spaces. Privately-owned parking by households, companies, universities, and governments, remains to have low utility rates during their lengthy idle time (e.g., Jiang et al., 2021;

https://doi.org/10.5198/jtlu.2024.2408
ISSN: 1938-7849 |

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

Taylor, 2020). Thus, as a large proportion of urban parking resources is privately owned, a substantial contribution to a reduction of parking shortage would be possible by developing and implementing shared parking policies.

The core idea of shared parking is that private owners share their parking space during their idle time (e.g., Liang et al, 2019; Niu et al., 2021). People who need parking can reserve, use and pay for their shared parking use using intelligent platforms. Consequently, more parking space is provided to alleviate urban parking pressure, while private parking owners gain some economic benefit (e.g., Abbott & Bigazzi, 2017). Shared parking, as an innovative and sustainable way to alleviate urban parking pressures, has caught the attention of researchers. To investigate the feasibility of shared parking, two main streams of research to date can be identified: assessment of participation intentions of consumers and suppliers, and optimization of supply and demand (e.g., Ardeshiri et al., 2021; Liu et al., 2021; Ye et al., 2020). Despite their relevance, the implementation of shared parking has remained limited. To date, only several shared parking platforms have been established worldwide, such as Airparking[1], the Chinese largest shared parking platform with more than two million users, covering a variety of land use types of shared parking facilities, such as residence, office, and retail. Another example is Parkalot[2], an office-based shared parking platform in the United States. Due to the little implementation of shared parking, research regarding the spatiotemporal use features of shared parking lots is also rare.

Our study, therefore, aims to fill this research gap by using 418,635 transaction records data of 121 shared parking lots in Guangzhou, China from November 2020 to October 2021. The study data derives from the Chinese largest shared parking platform - Airparking. More specifically, the following three research questions will be addressed. (i) What are the spatial distribution features of the shared parking lots? When do the shared parking transactions start in a day and how long do they last? (ii) How do the features of shared parking lots and urban spaces influence the total number of transactions at different shared parking lots? (iii) How do the features of shared parking lots and urban spaces influence the average parking duration at different shared parking lots?

To answer these research questions, first, the spatial characteristics of the shared parking lots, such as location, land-use type, implementation duration[3], and the total number of transactions, are displayed on GIS maps and discussed. Next, shared parking transaction temporal characteristics, such as start time and duration, are compared among land-use types of shared parking lots, respectively during weekdays and weekends. After that, a quasi-Poisson regression model is estimated to understand how the total number of transaction is influenced by shared parking lots' implemented duration, capacity, land-use type, construction type, number of POIs (point of interest) and transits within a range of 750 meters. Finally, a linear regression model is estimated to understand how the average parking duration of the shared parking lots is influenced by shared parking lots' land-use type, number of POIs within a range of 750 meters, and parking peak time. Our study contributes to the existing body of knowledge in two respects. First, to the best of our knowledge, our study is the first to investigate the shared parking use characteristics in space and time using big data of real transactions. It supplements extant shared parking research that only discussed shared parking feasibility in the hypothetical context. Second, the results of our study help municipalities predict potential shared parking

[1] https://airparking.cn/indexEN.html

[2] https://parkalot.io/

[3] The shared parking implemented duration refers to how long the parking lots have been used for shared parking, counting from its first shared parking transaction.

transactions of shared parking lots and when the transactions intend to happen, and therefore make shared parking implementation policies in terms of shared parking allocation planning and management advice.

This paper is organized as follows. Followed the introduction, an overview of existing literature is presented. After that, section 3 introduces the data resource and describes the data. In Section 4, the shared parking spatiotemporal characteristics are presented and discussed. In section 5, a quasi-Poisson regression model is estimated to understand influential factors on the total number of transactions at different shared parking lots. And a linear regression model is estimated to understand influential factors on shared parking lots' average parking duration. Finally, a broader view of this work is discussed including conclusions, limitations, and future work.

2 Literature review

The concept of shared parking can be traced back to the 1980s, first studied by Lalani (1984). The initial ideas of shared parking suggested the possible combinations of land-use types that can share parking lots due to the temporal dislocation of parking demands, such as entertainment and commercial venues. Nevertheless, the initial shared parking concept substantially differs from the re-emerged shared parking concept in recent years which rises with the deepening of sharing economy and the maturity of information communication technology (ICT). The re-emerged shared parking concept emphasizes that idle parking spaces can be shared in real-time by private owners and the shared parking use can be reserved and paid online using intelligent platform.

2.1 Research interest of shared parking

The academic interest in shared parking re-emerged in 2019. The extant research has focused on two dimensions of shared parking feasibility, including the intention to participate in shared parking by both users and owners, and the optimization matching algorithm between shared parking provision and demands.

The study of shared parking participation intention plays a core role in estimating the potential markets of shared parking. From the user perspective, Liang et al. (2019) and Niu et al. (2021) investigated the influence of perceived variables on peoples' willingness to participate in shared parking. They found that perceived behavior control, self-efficacy (e.g., usefulness and ease of use), technology acceptance, and perceived risk are the key variables influencing the intention to use shared parking spaces. Ardeshiri et al. (2021) explored the monetary values of different shared parking features in terms of willingness to pay. They found that pricing (shared parking cost per hour) has a dominant influence on people's intention to use shared parking, followed by non-pricing variables, such as egress time, parking suitability for a specific car type, access period of parking lots, and availability of external facilities (e.g., CCTV, security gates, car wash). From the owner perspective, Xie et al. (2020) found that risks, such as parking facility investment, safety threats, privacy invasion, and management pressure have the dominant adverse effects on the intention to participate in shared parking. Yan et al. (2020) considered the uncertainty of shared parking revenue. They found that socio-demographics, revenue uncertainty, and psychological concerns influence the parking owners' propensity to engage in platform-based shared parking schemes.

The study of shared parking optimization matching algorithms aims at finding efficient ways to allocate parking demand and idle shared parking spaces. The First-Come-First-Served (FCFS) serves as the basic matching algorithm that matches the idle shared parking space with the car that comes first with the parking time demand falling into the free time window of private parking space. Thus, FCFS applies the principle of saving drivers' time as much as possible (e.g., Han et al., 2019). The more complicated shared parking matching algorithms consider more matching goals. For instance, Zhang et al. (2020) proposed a double-objective shared parking algorithm to increase the occupancy rate of shared parking lots and reduce drivers' walking distance. Li et al. (2019) considered the drivers' credit in the shared parking matching algorithms to alleviate the nuisance that some drivers may not leave the private parking lots on time. Zhang et al. (2020) proposed a shared parking matching algorithm that owners first sell the right-of-use of private parking space to shared parking platforms by considering different pricing strategies. After that, based on private parking owners' choices, the algorithm matches the parking needs and supplies to maximize the profits of operators.

To summarize, extant shared parking research on people's intention to participate in shared parking helps to estimate the potential shared parking market, while the research on optimization matching algorithms improves shared parking efficiency. However, this research is mostly about hypothetical scenarios.

2.2 Shared parking implementation

Despite the increasing number of studies on shared parking feasibility, relatively little is known in the academic literature regarding the use characteristics of shared parking. A major reason for this result is that the implementations of shared parking schemes overall remain at the planning stage. Although some residents' self-organized shared parking schemes have been implemented but were confronted with legalization disputes due to the lack of support from local governments. Only in a small number of counties or regions, local governments have legislated initiatives to support the development of shared parking, and shared parking platforms have been established and achieved a considerable number of users.

Abbott and Bigazzi (2017) came up with the shared parking scheme for West End, a high-density residential neighborhood in Vancouver, Canada. By comparing the inventory and occupancy imbalance between on-street and off-street parking, they proposed to incorporate off-street parking into residential parking permits (RPP) via shared parking. They found that this scheme has the potential to reduce on-street parking congestion, improve existing parking utilization, and generate revenue for building owners. Despite the potential benefits, in practice, the implementation of shared parking generated a legalization dispute. In the capital region of Ottawa, Canada, local residents shared private parking with federal employees who suffer from office parking shortages. This shared parking action received no praise but legal warnings because the local governments thought shared parking may convert residential parking into commercial parking lots, and thus lead to additional traffic and nuisance. Westerlund (2020), analyzing comments on the local news about this event, argued that local residents opposed governments' decisions and believed the governments are overly restrictive and conservative in solving social problems in an innovative way. Compared with the conservative attitude towards shared parking in Ottawa, China leads the way in shared parking legislation and implementation, particularly in big cities where parking shortage is severe. Since 2017, more than 20 major cities in China, such as Beijing, Guangzhou, Shanghai, and Qingdao, have successively promulgated shared parking planning and management regulations to encourage households and companies to share privately-owned parking spaces (e.g., Cheng & Xie, 2017; Yuan, 2020). A variety of shared parking platforms, such as Airparking, Chengdu shared parking, and Hangzhou shared parking, experienced a rapid increase since 2017 (Nicholas, 2017).

As discussed above, the implementation of shared parking remains at the initial stage. Due to the limited implementation, no research yet has revealed the characteristics of shared parking use.

2.3 Parking choice and spatiotemporal use characteristics

Although research regarding shared parking use is rare, a body of research has investigated spatiotemporal characteristics of traditional parking use. Fundamentally, parking choice behavior was found related to location, proximity to the destination, time of day, and pricing policy, which impact the parking use in time and space. These findings help to predict parking demand and availability.

In particular, Rajabioun and Ioannou (2015) studied parking use characteristics in San Francisco, CA. They found that parking characteristics are seasonal, temporally correlated with parking location and spatially correlated with neighboring areas. Based on the findings, they developed a spatiotemporal auto-regressive model to predict parking availability at the estimated arrival time of drivers. Fiez et al. (2018) studied the spatiotemporal characteristics of parking demand in the Belltown neighborhoods in Seattle. Their research also recognized seasonal parking characteristics. Namely, parking occupancy from Monday to Friday are similar, increasing from the opening time to the peak near lunchtime, then decreasing during the afternoon and increasing again near dinner time. However, parking occupancy patterns are different on Saturday, increasing throughout the day continuously. Besides, their research found that parking occupancy varies with accessibility to restaurants on weekdays, but varies with city tourist attractions on Saturdays. Gao et al. (2019) used the data of NYC parking violation tickets and trained multiple machine learning models to understand the factors influencing illegal on-street parking. They found that it is highly related to four types of POIs, retail, health care, accommodation, and food services. A body of studies has investigated the influence of parking pricing on parking use. Based on their results, parking pricing was overall effective in reducing parking demands (e.g., Chang et al., 2014; Tsai & Chu, 2006). However, some studies argued that imprudent parking pricing, such as increasing hourly parking price when parking dwell time is elastic, can increase parking demand (Nourinejad & Roorda, 2017).

As discussed above, traditional parking use has been found highly correlated with parking location, time of the day, and parking policies. However, it is yet unknown how these factors influence shared parking use.

3 Data

3.1 Data source

The empirical shared parking data stems from Airparking, the largest Chinese shared parking company. The study area is Guangzhou, covering 7424 km² and 11 administrative districts with a population of 18 million. As the fourth largest and the earliest city to implement shared parking policies in China, Guangzhou is to date the only city in China, as well as in the world, that has a large number of shared parking users and transactions. Therefore, as the study area, Guangzhou is representative of the shared parking use study.

The data consists of two datasets, a dataset of 121 shared parking lots and a dataset of 434,564 shared parking transaction records from November 2020 to October 2021. In the shared parking lot dataset, each shared parking lot record contains the information of parking lot name, coordinates, land use, construction type, implemented duration, and capacity. In the shared parking transaction dataset, each transaction record contains the information of parking lot name, car type, reservation placing time, waiting time, parking start time, parking end time, timeout duration, transaction grading, and open comments for the transaction. The explanation for each variable is given in Table 1. The transaction and shared parking lots records can be joined by the common variable - parking lot name. Since the shared parking transactions are anonymous, users' demographics are unknown.

Table 1. Explanation of variables

Variable name	**Explanation**
Parking lot name	The name of the parking lots.
Coordinates	The longitude and latitude of the parking lots.
Land use	The land-use type where the shared parking lot is located includes five types: residential, commercial retail, office, mixed, and public parking.
Construction type	The structure of shared parking lots, including two types: underground, ground-level.
Implemented duration	Implemented duration refers to how long the shared parking services have been provided in a shared parking lot, counting from the first recorded shared parking order.
Capacity	Capacity refers to the total parking spaces, including shared parking spaces and non-shared parking spaces. Ideally, it would be better only to count the shared parking spaces. However, the data provider didn't get approval from parking management to provide the shared parking provision data.
Car type	The car types of shared parking users include three types: fuel, electric, and hybrid.
Reservation placing time	To use the shared parking space, users need to reserve the parking space at least 15 min in advance. Reservation placing time refers to the time that the users place the reservation.
Waiting time	Time from placing the reservation to parking start time.
Parking start time	The time when the parking starts.
Parking end time	The time when the parking ends.
Timeout duration	To use shared parking lots, the drivers need to reserve the parking lots based on the available time slot claimed by shared parking providers. If the drivers park longer than their reservation length, the exceeded time will be recorded as timeout duration and charged three times higher than the reservation time.
Transaction grading	Shared parking users can grade the service after they complete each parking order. The grading ranges from 1 to 5, indicating an acceding satisfaction level of the services.
Open comments	Shared parking users can supplement text comments after they grade the service.

The transaction records were screened by omitting the outliers in terms of parking duration based on two principles. First, transaction records with a parking duration shorter than 5 min were omitted. This principle is suggested by Airparking managers who suggest that a too short parking duration often indicates a parking failure due to occupied parking lots, poor indoor navigation systems, etc. Second, transaction records with a parking duration longer than 1837 min were omitted based on the Rosner test that applies the extreme studentized deviation test for potential outliers in the dataset (Rosner, 1975). After data screening, 418,635 transaction records remained for analysis, accounting for 96.33% of the raw dataset.

Moreover, geodata of the study area, Guangzhou, were extracted from online open source data. Particularly, the district borders and road networks were extracted from

OpenStreetMap[4]. The POI information (e.g., tourism attractions, office buildings, art centers, hospitals, education institutions, and shopping centers/streets) and transit stops were extracted from amap[5].

3.2 Data description

The features of 121 shared parking lots are summarized in Table 2. The geographic-related features of shared parking, such as land use, the number of POIs and transits within a range are obtained by combining the dataset of shared parking lots with city Geodata. To count the number of POIs and transit stops within a certain walking distance, the shared parking lots are loaded into QGIS based on their coordinates. Following this, service areas with a radius of 750m (approximately 10-min walking) are generated based on the road networks of each shared parking lot. It is important to note that the 750m is defined as the shard parking service area, as a 10-min walking is considered as a suitable service radius for public facilities according to various design standards in Chinese urban and rural planning regulations. For example, guidelines such as the ‘Guidance of shopping center tenant mix strategy’[6] and the ‘Standard for urban residential area planning and design’[7] recommend a 10-min walking as a norm for good accessibility design norm for public facilities. Additionally, considering a normal walking speed ranging from 60-90m/min, we used an average walking speed of 75m/min to calculate the service distance, which equates to 750m. The POIs and transit stops are counted if they fall into the service area polygons. The transaction-related features, such as the total number of transactions, and average parking duration are aggregated based on the dataset of shared parking transactions by the name of shared parking lots.

Overall, the key features of shared parking lots vary greatly. To start with, the shared parking lots are categorized into five types based on the land-use type of their location. Shared parking lots located in residential neighborhoods where residents share privately-owned parking spaces during parking idle time, account for the largest shared at 44.63%, termed residential shared parking lots. Shared parking lots located in commercial retail lands where shops, restaurants, gyms, etc. share their dedicated parking space, account for the second-largest shared at 22.66%, termed commercial shared parking lots. Shared parking lots located in office land use where the companies share their parking space, account for the third-largest shared at 15.70%, termed office shared parking lots. The fourth-largest types of shared parking lots are located in mixed land use where at least two land-use types, for instance, residential and commercial or residential and offices, are officially planned. This type of shared parking lot accounts for 9.92%, termed mixed shared parking lots. At last, shared parking lots located in public parking land use where management-used parking spaces are shared during idle time, account for the smallest shared at 9.09%. This type of shared parking lot is termed public shared parking lots. Based on the construction, the shared parking lots are categorized into two types, underground parking and ground parking. The majority of shared parking lots are underground, accounting for 82.64%. The remaining 17.36% of the shared parking lots are ground parking.

[4] https://www.openstreetmap.org

[5] https://lbs.amap.com/api/webservice/summary

[6] National Development and Reform Commission of the People's Republic of China. (2012). Guidance of shopping center tenant mix strategy (SB/T 10813-2012). Beijing, China: China Planning Press.

[7] Ministry of Housing and Urban-Rural Development of the People's Republic of China. (2018). Standard for Urban Residential Area Planning and Design (GB50180-2018). Beijing, China: China Architecture & Building Press.

Regarding the implemented duration of shared parking lots, it ranges from 1 to 82 months, with a mean of 49.81 months (appropriately 4 years) and a standard deviation of 22.66. Regarding the capacity, it ranges from 24 to 2312 among the shared parking lots. The majority of shared parking lots, accounting for 84.30%, have less than 500 parking spaces. By aggregating the shared parking transactions by shared parking lots, the total number of transactions of each shared parking lot is obtained, ranging from 1 to 37174 in the observed year. Most shared parking lots, accounting for 74.38%, have less than 3000 transactions. The average total number of transactions is 3460, with a standard deviation of 7100.49. The average parking duration of transactions is also aggregated by shared parking lots, ranging from 0.93 to 12.89 hours. The average parking duration for the majority of the shared parking lots is between 2 to 8 hours, accounting for 77.69%. The mean of shared parking lots' average parking time is 5.50 hours, with a deviation of 2.50.

Table 2. Summary of shared parking lot features

Categorical variables	**Frequency**	**Proportion**
Land use		
Residential	54	44.63%
Commercial retail	25	20.66%
Office	19	15.70%
Mixed (residential, commercial, and/or business office)	12	9.92%
Public parking	11	9.09%
Construction		
Ground parking	21	17.36%
Underground parking	100	82.64%
Continuous variables	**Mean**	**Standard Deviation**
Implemented duration (month)	49.81	22.66
Capacity	329.90	397.71
Total number of transactions	3460	7100.49
Average parking duration (hours)	5.50	2.50
POIs (within 750m)		
Tourism attractions	2.34	2.78
Office buildings	19.17	16.25
Art related buildings (museum/theater/gallery)	4.76	4.23
Hospital and affiliates	1.62	2.53
Education departments (primary and high schools/university departments)	5.27	4.55
Shopping malls	1.76	2.66
Transportation transit (within 750m)		
Metro station entrances	4.00	4.81
Bus stops	9.17	4.43

4 Spatiotemporal distribution features

4.1 Spatial distribution features

The spatial distribution of shared parking lot features is shown in Figure 1a to 1d. According to Figure 1a, the majority of shared parking lots, accounting for 78.51%, are clustered in city central districts, i.e., Tianhe District (35.54%), Yuexiu District (21.49%), and Haizhu District (21.49%). Such distribution fits the urban space characteristics as city central districts have higher urbanization rates and population density, thus higher parking demands. According to Figure 1b, residential shared parking lots are most widely distributed, early in every district. In contrast, the business office shared parking lots mainly cluster in central administrative districts. Regarding the implemented duration of shared parking lots, no notable spatial difference is observed according to Figure 1c. Based on interviews with Airparking managers, the shared parking business was initiated by cooperating with one of the largest local real estate developers whose projects are well distributed in the city. All real estate projects managed by this developer in different administrative districts started shared parking at a similar time. This fact may explain why residential shared parking lots are most widely distributed, and the distribution of implemented duration is relatively evenly distributed in space. Last but not least, shared parking lots with more than 500 transactions in the observed year are mostly clustered in central administrative districts, see Figure 1d. It is correspondent with the high parking demands in city center areas.

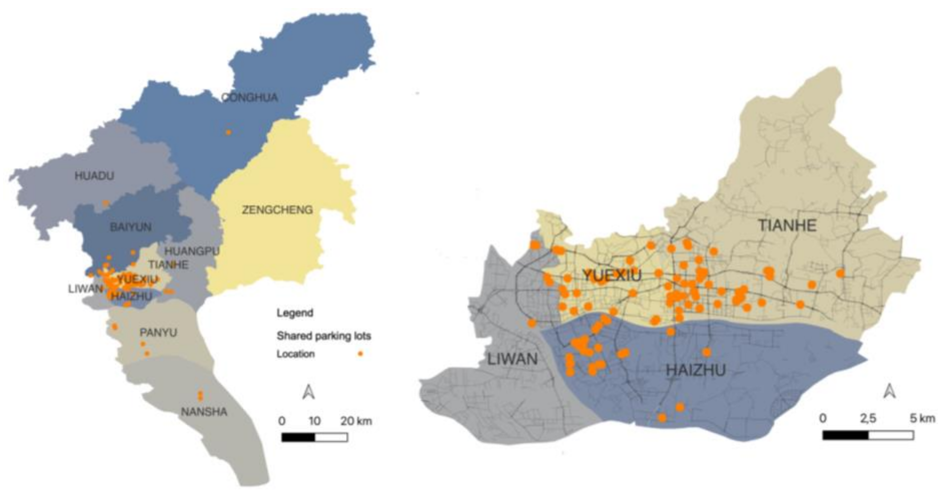


Figure 1a. Location of shared parking lots in the city (left) and central districts (right)

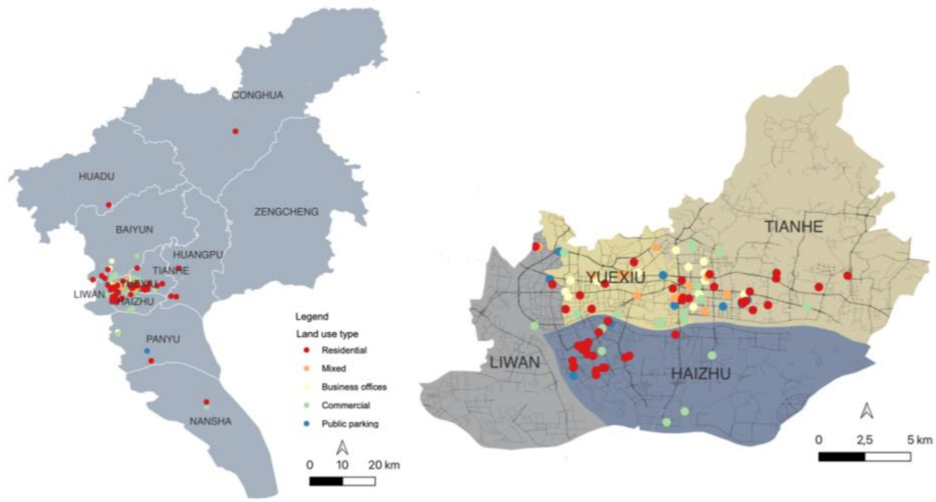


Figure 1b. Land use type of shared parking lots in the city (left) and central districts (right)

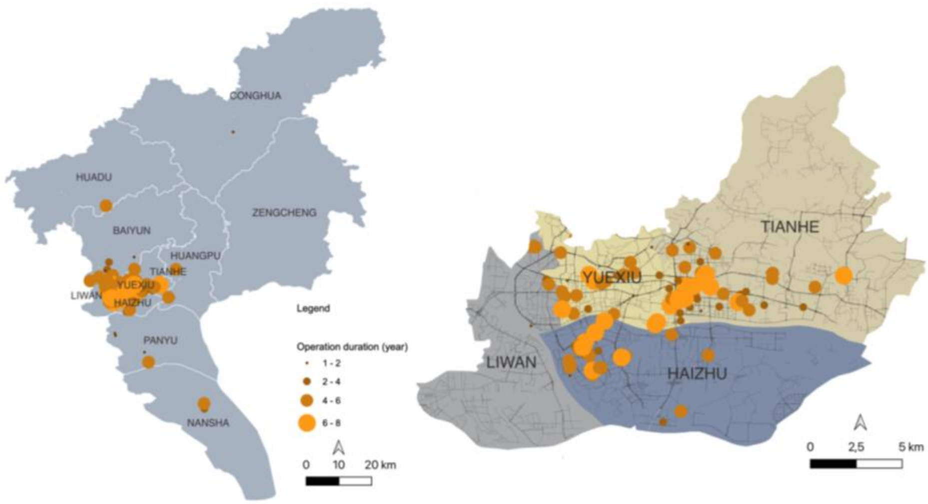


Figure 1c. Implemented duration of shared parking lots in the city (left) and central districts (right)

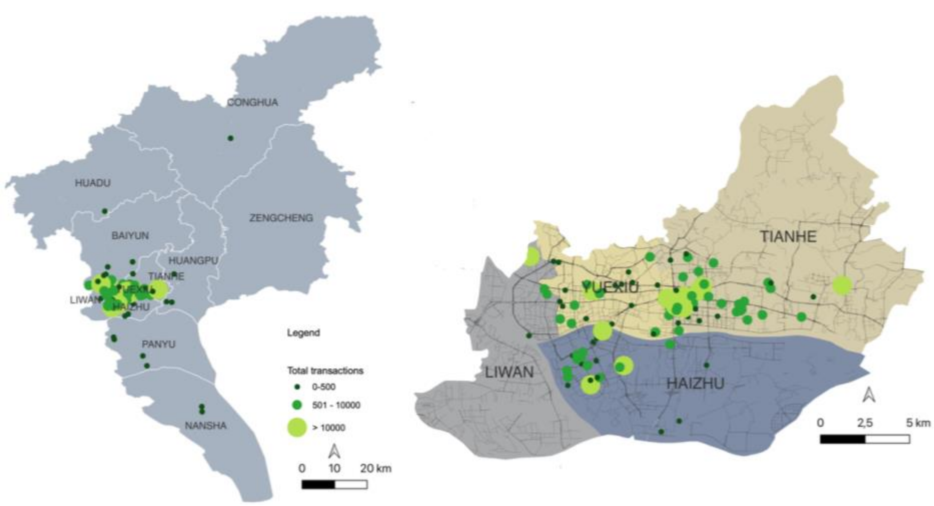


Figure 1d. Total number of transactions of shared parking lots in the city (left) and central districts right)

4.2 Temporal distribution features

The shared parking transaction temporal features at different shared parking lots are shown in Figure 2 in terms of the average number of transactions at different hours of the day and the percentage of transactions with different parking duration. These two features are clustered and aggregated by the land-use types of shared parking lots, respectively on weekdays and weekends. Based on the results, the operation temporal features vary greatly among the land-use types of shared parking lots.

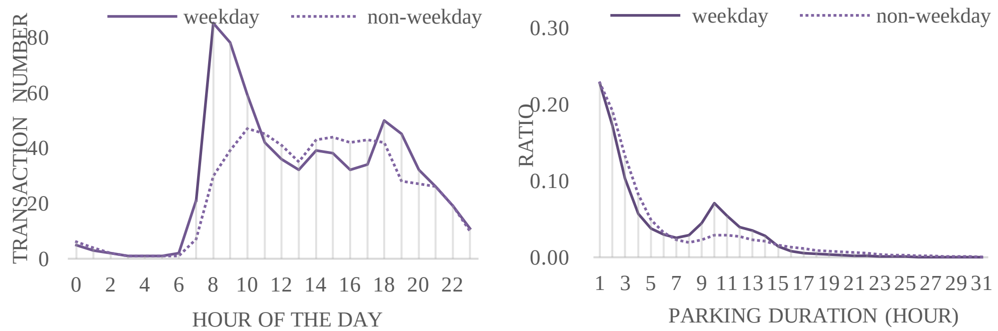
First, residential shared parking lots have the largest number of daily transactions. According to Figure 2, the number of transactions varies with day types and the hour of a day. Notably, on weekdays, the number of transactions surges from 7 am, arriving at the first peak time around 8-9 am. This peak time may result from two aspects. First, residents leave home around 8-9 am for work, leaving their parking spaces available to start sharing. Second, 8-9 am on weekdays is the morning traffic peak when a lot of people have parking demands. The increasing provision and demand for shared parking spaces thus co-contribute the first peak time of residential shared parking lots. Followed by an abrupt drop, the number of transactions fluctuates until 17 pm, reaching a second smaller peak time at 18 pm. After that, the number of transactions keeps dropping until the second day at 6 am. However, on weekends, the number of transactions slowly increases from 6 am, arriving at its peak around 10 am, then fluctuating until 18 pm before dropping down. On both weekdays and weekends, the largest percentage of parking duration is less than 1 hour, respectively accounting for 22.72% and 22.80%. The parking duration between 8-11 hours on weekdays doubles that of weekends, respectively accounting for 16.89% and 8.00%.

The mixed shared parking lots have the second largest number of daily transactions. On weekdays, the number of transactions increases rapidly from 7 am, reaching the peak at 9 am, then steadily drops. However, on weekends, the number of transactions increases rather slowly from 7 am, with a peak at 15 pm, then gradually drops. Regarding the parking duration, on both weekdays and weekends, the largest percentage of parking duration is 1-2 hours, respectively accounting for 16.90% and 23.09%. On weekdays, the percentage of parking duration between 8-11 hours is notably higher than on weekends.

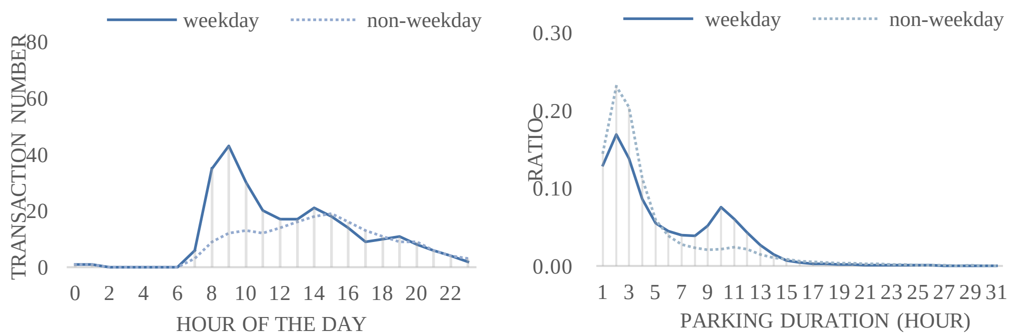
The office shared parking lots have the third largest number of daily shared parking transactions. During weekdays, two peak hours with a similar number of transactions occur respectively at 9 am and 14 pm. On weekends, peak hours coincide with weekdays, however, the first peak hour has fewer transactions. In terms of parking duration percentage, the distribution of parking duration percentage on weekdays and weekends is similar. The largest percentage of parking duration is both 1-2 hours, respectively accounting for 29.27% and 31.39%. Transactions with parking duration longer than 5 hours account for a small share, approximately 12.69%.

Commercial shared parking lots have a small number of daily transactions, fluctuating less than ten transactions from 8 am to 22 pm. The distribution of parking duration percentage on weekdays and weekends is overall overlapped. The largest percentage of parking duration is both 1-2 hours, respectively accounting for 18.81% and 19.75%. Besides, on both weekdays and weekends, there is a notable amount of transactions with long parking duration between 9-13 hours, respectively accounting for 24.10% and 18.71%.

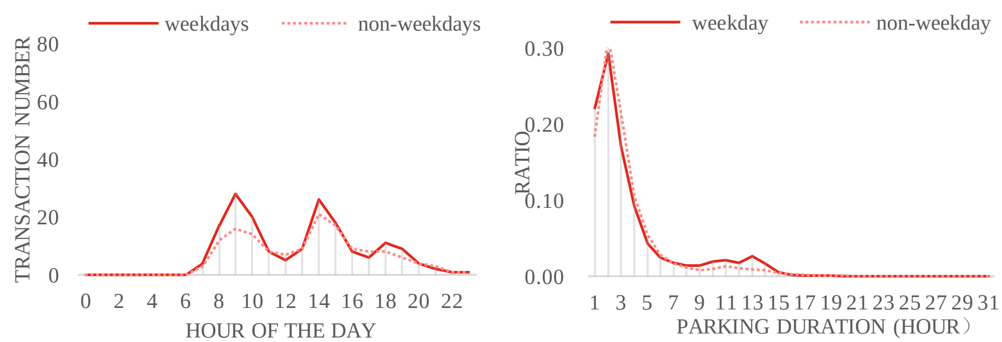
Public shared parking lots have the smallest number of daily transactions with only one peak time on weekdays at 8 am when the transaction number is up to seven. During the rest of the hours, the number of transactions is very small, around one or zero. However, compared with all other land-use types, public shared parking lots have the largest share of transactions with long parking duration between 9-12 hours, accounting for 41.16% on weekdays.



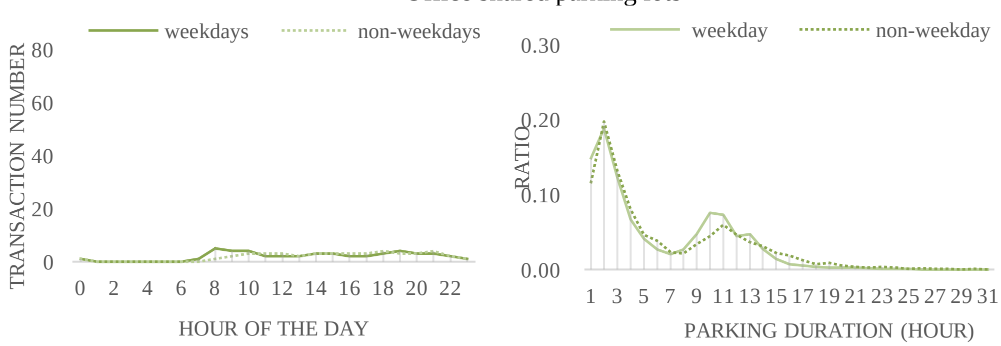
Residential shared parking lots



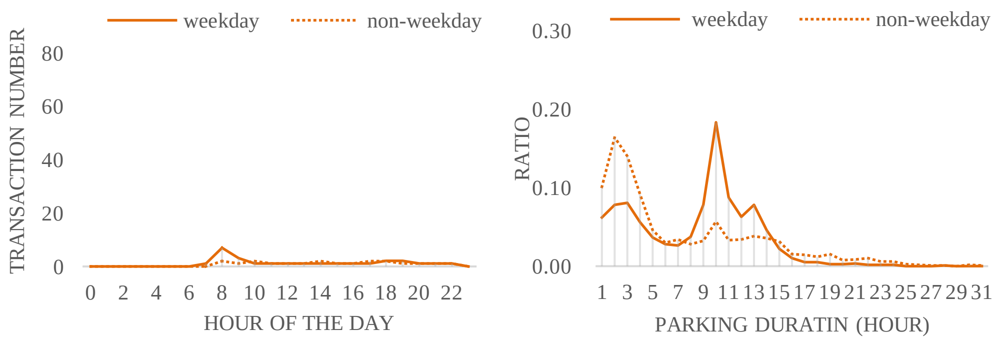
Mixed shared parking lots



Office shared parking lots



Commercial shared parking lots



Public shared parking lots

Figure 2. Transaction number at different hour of a day (left) and ratio of parking duration (right)

5 Modeling influential factors on shared parking lot spatiotemporal operation features

5.1 Methodology

To understand how shared parking lot features and urban spatial features influence the number of total shared parking transactions and average parking duration, the Generalized Linear Regression (GLM) models are applied. The GLMs are chosen to estimate the data for two major reasons. First, GLMs have the flexibility to allow for a wide range of probability distribution, including Normal, Poisson, and Gamma distribution (e.g., Dobson & Barnett, 2018; Nelder & Wedderburn, 1972). This feature is applicable to our data types, where shared parking transaction is count data applying to Poisson regression. Second, GLMs are capable of handling overdispersion count data with more accurate estimation results. In our case, the total transactions of the shared parking lots, serving as the dependent variable, are over-dispersed (see Table 2). Therefore, the quasi-Poisson regression model from GLMs is chosen for the estimation.

The general form of GLMs is given as:

$$g(\mu) = X\beta \tag{1}$$

$$y \sim Distributuion\ (\mu,\phi) \tag{2}$$

where g(μ) is the link function that relates the independent variable to the expected value of the dependent variable. X is the matrix of independent variables. β is the vector of coefficients. Different GLMs use different link functions, and the choice of the link function depends on the nature of the response variable. y is the dependent variable. Distribution specifies the probability distribution of the dependent variable. μ is the expected value of the dependent variable. ϕ is the dispersion parameter, which accounts for variability not explained by the independent variables (e.g., Nelder & Wedderburn, 1972).

5.2 The number of total shared parking transactions

A quasi-Poisson regression model, employing the logarithmic function as the link function and assuming a Poisson distribution, is applied to estimate how shared parking lot features and urban spatial features influence the number of total shared parking transactions. The dependent variable is the number of total shared parking transactions. The independent variables are implemented duration, parking lot capacity, land-use type, parking construction, number of POIs (within 750m), and number of transportation transits (within 750m). The model shows decent goodness-of-fit, with a R squared of 0.629. The Chi-square p-value test on 15 degrees of freedom is 0.000. The variance inflation factor (VIF) of each independent variable is less than 5.00 (see Appendix B), indicating no multicollinearity issue exists in the model (Daoud, 2017). The signs of estimated coefficients are as expected. Note that, Incidence Rate Ratio (IRR) is displayed in the result to measure the incidence rates of events between different groups. IRR-1 is used to measure the change in the incidence rate associated with a one-unit change in the independent variable. IRR can be expressed as:

$$IRR = e^{\beta} \tag{3}$$

where β is the coefficient.

Based on the estimation results (see Table 3), implemented duration, parking lot capacity, land-use type, number of business office buildings, art-related POIs, and bus stations (within 750 meters) have a statistically significant impact on the number of total parking transactions. In particular, with each additional month of shared parking implemented duration, the mean of the number of total transactions increases by 5.3%. A possible explanation is that, on one hand, the longer the parking lot has been used for sharing, the more people are aware of the shared parking through advertisements, social networks, etc. As a result, the shared parking lot has more potential users and thus transactions. On the other hand, shared parking lots with a longer implemented duration is more likely to provide better services due to their operation experiences, which helps to attract more shared parking users. Regarding the influence of parking lot capacity, with each increase of 10 parking lots, the mean of the number of total transactions increases by 0.1%. This result is as expected that larger parking lots have the potential to provide more shared parking space, and thus are capable to cater to more shared parking needs. The land-use types of shared parking lots also have significant influence on the number of total transactions. To be specific, compared with mixed land use shared parking, commercial shared parking has 67.8% fewer transactions, and residential shared parking has 43.9% fewer transactions. Regarding the influence of POIs, with one more business office building within the shared parking walking distance area (750m, about 10min walking), the mean of the number of total transactions increases by 3.1%. This result is constant with the extant research findings that office buildings generally impose parking pressures in its vicinity due to insufficient parking supply in office buildings (e.g., Mingardo et al., 2015). As a result, urban areas with high density of office buildings have larger shared parking demands and thus transactions. In contrast, with one more art-related POIs located within walking distance of shared parking lots, the mean of the number of total transactions decreases by 10.7%. A possible explanation is that art-related buildings are less often visited compared with other basic functional buildings in China. Besides, newly built art-related buildings are more likely to have sufficient parking space, which may reduce the parking demands from surroundings. Last, but not least, regarding the influence of transportation transit, with one more bus station located within walking distance of the shared parking lots, the mean of the number of total transactions decreases by 9.4%. A possible explanation is that bus services can overall reduce the demand for car usage, thus the demand for shared parking.

Table 3. Estimation results of quasi-Poisson regression model

	Coefficients	Std.Error	t-value	IRR	IRR-1
Constant	5.305***	0.728	7.285	201.335	200.335
Shared parking implemented duration (month)	0.051***	0.009	5.669	1.053	0.053
Parking lots capacity (every 10 parking space)	0.001***	0.000	3.985	1.001	0.001
Shared parking land use					
Commercial	-1.134*	0.595	-1.906	0.322	-0.678
Residential	-0.578*	0.324	-1.784	0.561	-0.439
Business office	-0.239	0.388	-0.618	0.787	-0.213
Public parking	-0.516	0.777	-0.663	0.597	-0.403
Mixed of Residential and commercial (base)	0.000	-	-	-	-
Shared parking type					
Underground parking	-0.737	0.848	-0.869	0.479	-0.521
Ground parking (base)	0.000	-	-	-	-
POIs					
Tourism attractions	-0.005	0.068	-0.078	0.995	-0.005
Business office buildings	0.031***	0.008	3.694	1.031	0.031
Art related	-0.114**	0.048	-2.383	0.893	-0.107
Hospital departments	-0.014	0.059	-0.241	0.986	-0.014
Education departments	0.054	0.046	1.176	1.056	0.056
Shopping center/street	0.068	0.058	1.175	1.071	0.071
Transportation transit					
Metro station entrances	0.046	0.035	1.333	1.047	0.047
Bus stations	-0.098**	0.042	-2.319	0.906	-0.094

Note: Significance level: 0.01 '***'; 0.05 '**'; 0.1 '*'.
AIC = 382286.3, BIC = 292286.3, Log-likelihood = -186833.8.

5.3 Average shared parking duration

A linear regression model, a parametric mode assuming a Normal distribution, is applied to estimate the influential factors on the average shared parking duration of each shared parking lot. The dependent variable is the average shared parking duration of the transactions that occurred at each shared parking lot. The independent variables are shared parking lot land-use type, number of POIs (within 750m), and the peak time of the shared parking lots. The model shows decent goodness-of-fit, with R squared of 0.382. The p-value of the F-statistic is 0.000. The variance inflation factor (VIF) of each independent variable is less than 5.0 (see Appendix C), indicating no multicollinearity issue exists in the model.

Based on the estimation results (see Table 4), the constant, land-use type, number of business office buildings, number of hospitals, and the peak time have a statistically significant impact on average parking duration in the sample size. Particularly, compared with commercial shared parking lots, the public shared parking lots have the largest mean of average parking duration (2.953 hours longer), followed by residential shared parking lots (1.888 hours longer), business office shared parking lots (1.604 hours longer), and mixed shared parking lots (1.584 hours longer). This result may be caused by the different shared parking provision features of different land-use types. For example, residential shared parking spaces are more likely to be provided during the owners' working hours lasting more than 8 hours. Thus, users with long parking duration demands are more likely to choose residential shared parking lots. However, commercial shared parking spaces are more likely to be provided during shops' non-busy periods which intend to be small time intervals. Thus, users with long parking duration demands are less likely to choose commercial shared parking lots. Another possible explanation is that the surrounding POIs near shared parking lots influence the users' parking purpose and thus parking duration. Based on the estimation results of POIs' influence, with one more business office building located within the shared parking lot walking distance, the mean of parking duration decreases by 0.032 hours; with one more hospital department located within the shared parking walking distance area, the mean of parking duration decreases by 0.187 hours. Last, but not least, the mean parking duration is influenced by peak hours of the shared parking lots. Particularly, the mean parking duration of shared parking lots with peak hours between 10-12 am on weekends, is 0.858 hours shorter than average. However, the mean parking duration of shared parking lots with peak hours between 18-20 pm on weekends is 1.488 hours longer than average. This result may be highly associated with users' parking purposes in a specific period.

Table 4. Estimation results of linear regression

	Coefficients	Std.Error	t-value
Constant	4.771***	0.567	8.408
Shared parking land use			
Residential	1.888***	0.542	3.484
Business office	1.604**	0.724	2.214
Public parking	2.953***	0.799	3.694
Mixed of Residential and commercial	1.584**	0.790	2.005
Commercial (base)	0.000	-	-
POIs			
Tourism attractions	0.013	0.100	0.128
Business office buildings	-0.032*	0.017	-1.840
Art related	-0.057	0.068	-0.826
Hospital departments	-0.187*	0.099	-1.884
Education departments	0.005	0.060	0.086
Shopping center/street	-0.103	0.093	-1.110
Peak time			
[8am - 10am) in weekdays	0.462	0.466	0.991
[18pm - 20pm) in weekdays	0.651	0.559	1.164
[10am - 12am) in weekends	-0.858*	0.484	-1.772
[18pm - 20pm) in weekends	1.488**	0.497	2.991

Note: Significance level: 0.01 '***'; 0.05 '**'; 0.1 '*'
AIC = 537.9, BIC = 582.7, Log-likelihood = -253.0.

6 Conclusion and discussion

Shared parking has become popular in recent years. To date, some research has investigated the intentions to participate in shared parking and the optimization of shared parking matching algorithms in a hypothetical context. However, little research has utilized big data of real shared parking transactions to investigate the use features. To fulfill this gap, our research retrieved the shared parking operation data in Guangzhou, the only city to date in China, as well as in the world, having a large number of shared parking users and transactions, from Chinese largest shared parking platform—Airparking—to analyze the shared parking use characteristics in time and space. By respectively applying a quasi-Poisson regression model and a linear regression model, our study estimates how shared parking features and urban spatial features influence the number of total transactions and the average parking duration at shared parking lots. The estimation results provide evidence of shared parking use of spatial-temporal features in large cities with high population density and underlying policy implications to promote the implementation of shared parking. The following policy implications are obtained from the estimation results.

First, our study found that shared parking lots with a longer implemented duration contributes to a larger number of total transactions. We infer that this is because shared parking lots with longer implementation duration exhibit better reputation and mature management, consistent with the prevailing notion in existing studies that extended implementation duration often serves as crucial predictors for the diffusion of innovative technological solutions (e.g., Drury & Farhoomand, 1999; Premkumar et al., 1994). Based on this result, we contend that providing management assistance to newly established shared parking lots may help to increase the transactions by improving their shared parking service quality. For example, installing the license plate recognition devices, designing the indoor navigation system, and helping parking lot managers become familiar with the shared parking process. Besides, we propose that advertising may help newly established shared parking lots to gain more transactions within a shorter operation time by facilitating the concept diffusion process. To fulfill this goal, both shared parking providers and users should be targeted for advertising to promote the shared parking space provision and usage. Meanwhile, considering the Chinese local governments are promoting shared parking development, the shared parking operators should take advantage of governmental policy advocacy to persuade citizens to participate in shared parking.

Second, our study found that the number of business office buildings located near shared parking lots has significant influences on both the number of total shared parking transactions and average parking duration. This result echoes prior studies, which explored factors and policies influencing parking demands in workplaces (e.g., Al-Masaeid et al., 1999; Rye & Ison, 2005). We extend this understanding by specifically linking the concentration of business office buildings to shared parking usage. Based on our result, we emphasize the importance of considering the influence of job density on shared parking site selection. Particularly, urban areas with high job densities should be considered as good candidates to implement a shared parking policy. Besides, considering the business office visits often occur during work hours, residential shared parking that often provides shared parking spaces during residents' working time should be considered as a suitable shared parking type to cater to the business parking needs.

Third, our study reveals varied operational features in different shared parking types, aligning with findings from existing studies that quantified the interaction between land use and features of conventional parking (e.g., Shen et al., 2020; Parmar et al., 2021). This finding reinforces and extends established knowledge, shedding light on the diverse characteristics that influence shared parking operations. In light of these results, we advocate tailoring implementation plans for diverse shared parking types. Specifically, consider residential parking lots where peak demand occurs around 8-9 am, a period already bustling with neighborhood traffic. To optimize shared parking services, strategic coordination is vital. This involves measures like designated shared parking lanes and parking space areas to segregate the traffic flows, ensuring an efficient and harmonized coexistence of original neighborhood traffic and shared parking activities. Such thoughtful design mitigates potential congestion and enhances the overall effectiveness of shared parking solutions, addressing the unique challenges posed by varying usage patterns and traffic dynamics.

Several limits exist in this study. First, our study year is one of the Covid-19 years which is not necessarily normal at the time. However, based on the Chinese Covid-19 policy, its greatest impacts occurred before our study year in the first national lockdown period from Jan 2020 to May 2020. After that, the lockdown policy became more swift, local, temporary, and moderate (see Appendix A). It is of great interest to use panel data before Covid-19, during Covid-19, and after Covid-19 to estimate total transaction numbers with a calibration parameter to bridge the different periods. Second, our study used the total parking capacity of the parking lots rather than shared parking space capacity in the transaction estimation model due to the limits of available attributes in the dataset. Although shared parking space capacity is more optimal for estimation, the practical consideration of shared parking space availability schedules also plays an essential role in estimating the number of shared parking transactions. Therefore, it is of great interest to elaborate on the complicated relationship between parking capacity, shared parking scheme participation, shared parking space availability schedule, and total shared parking transaction. This understanding is vital for urban planning and transportation management departments in calibrating land provisions to meet parking demands effectively.

Appendices

Appendices A-C available as supplemental files at https://doi.org/10.5198/jtlu.2024.2408.

References

Abbott, N. T., & Bigazzi, A. Y. (2017). Utilizing shared parking to mitigate imbalanced supply in a dense urban neighborhood: Case study in Vancouver, British Columbia, Canada. *Transportation Research Record, 2651*(1), 92–100. https://doi.org/10.3141/2651-10

Al-Masaeid, H. R., Al-Omari, B., & Al-Harahsheh, A. (1999). Vehicle parking demand for different land uses in Jordan. *ITE Journal, 69,* 79–84.

Ardeshiri, A., Safarighouzhdi, F., & Hossein Rashidi, T. (2021). Measuring willingness to pay for shared parking. *Transportation Research Part A: Policy and Practice, 152*, 186–202. https://doi.org/10.1016/j.tra.2021.08.014

Chang, C. T., Chung, C. K., Sheu, J. B., Zhuang, Z. Y., & Chen, H. M. (2014). The optimal dual-pricing policy of mall parking service. *Transportation Research Part A: Policy and Practice, 70,* 223–243.

Cheng, Y., & Xie, C. (2017, Nov. 13). Parking lots are new stars of the sharing economy. *China Daily*. Retrieved from https://www.chinadaily.com.cn/business/2017-11/13/content_34466543.htm.

Daoud, J. I. (2017, December). Multicollinearity and regression analysis. *Journal of Physics: Conference Series*, *949*(1), 012009.

Dobson, A. J., & Barnett, A. G. (2018). *An introduction to generalized linear models*. Boca Raton, FL: CRC press.

Drury, D. H., & Farhoomand, A. (1999). Innovation diffusion and implementation. *International Journal of Innovation Management*, *3*(2), 133–157.

Fiez, T., Ratliff, L. J., Dowling, C., & Zhang, B. (2018). Data-driven spatio-temporal modeling of parking demand. *Proceedings of the American Control Conference,* 2757–2762. https://doi.org/10.23919/ACC.2018.8431681

Gao, S., Li, M., Liang, Y., Marks, J., Kang, Y., & Li, M. (2019). Predicting the spatiotemporal legality of on-street parking using open data and machine learning. *Annals of GIS*, *25*(4), 299–312.

Han, Y., Zhang, Q., & Huang, W. (2019). Optimal parking space allocation model based on the shared parking in residential areas. *CICTP 2019*, 2588–2599.

Jiang, Y. P., Shao, X. R., & Song, X. C. (2021). Matching model between private idle parking slots and demanders for parking slot sharing. *Journal of Transportation Engineering, Part A: Systems*, *147*(6), 04021028.

Lalani, N. (1984). Evaluating shared parking for new developments. *Public Works, 115*(2), 64.

Li, C., Tao, Y., & Liu, S. (2019). A shared parking space optimization model to alleviate China's parking problem Ccnsidering travelers' tiered credit risk. *Transportation Letters*, *13*(1), 45–52. https://doi.org/10.1080/19427867.2019.1700013

Liang, J. K., Eccarius, T., & Lu, C. C. (2019). Investigating factors that affect the intention to use shared parking: A case study of Taipei City. *Transportation Research Part A: Policy and Practice, 130*(September), 799–812. https://doi.org/10.1016/j.tra.2019.10.006

Liu, W., Zhang, F., & Yang, H. (2021). Modeling and managing the joint equilibrium of destination and parking choices under hybrid supply of curbside and shared parking. *Transportation Research Part C: Emerging Technologies, 130*(June), 103301. https://doi.org/10.1016/j.trc.2021.103301

Mei, Z., Feng, C., Ding, W., Zhang, L., & Wang, D. (2019). Better lucky than rich? Comparative analysis of parking reservation and parking charge. *Transport Policy*, *75*, 47–56.

Mingardo, G., van Wee, B., & Rye, T. (2015). Urban parking policy in Europe: A conceptualization of past and possible future trends. *Transportation Research Part A: Policy and Practice, 74,* 268–281.

Nelder, J. A., & Wedderburn, R. W. (1972). Generalized linear models. *Journal of the Royal Statistical Society Series A: Statistics in Society, 135*(3), 370–384.

Nicholas. (2017, July 17). Chinese shared parking startup Airparking receives millions in RMB of Pre-A Round. *Pandaily*. Retrieved from https://pandaily.com/chinese-shared-parking-startup-airparking-receives-millions-in-rmb-of-pre-a-round/

Niu, Z., Hu, X., Qi, S., Yang, H., Wang, S., & An, S. (2021). Determinants to parking mode alternatives: A model integrating technology acceptance model and satisfaction–loyalty model. *Transportation Research Part A: Policy and Practice, 152*(73), 216–234. https://doi.org/10.1016/j.tra.2021.08.010

Nourinejad, M., & Roorda, M. J. (2017). Impact of hourly parking pricing on travel demand. *Transportation Research Part A: Policy and Practice, 98*, 28–45.

Parmar, J., Das, P., & Dave, S. M. (2021). A machine learning approach for modelling parking duration in urban land-use. *Physica A: Statistical Mechanics and its Applications, 572*, 125873.

Premkumar, G., Ramamurthy, K., & Nilakanta, S. (1994). Implementation of electronic data interchange: An innovation diffusion perspective. *Journal of Management Information Systems, 11*(2), 157–186.

Rajabioun, T., & Ioannou, P. (2015). On-Street and off-street parking availability prediction using multivariate spatiotemporal models. *IEEE Transactions on Intelligent Transportation Systems, 16*(5), 2913–2924. https://doi.org/10.1109/TITS.2015.2428705

Rosner, B. (1975) On the detection of many outliers. *Technometrics, 17*(2), 221–227, https://doi.org/10.1080/00401706.1975.10489305

Rye, T., & Ison, S. (2005). Overcoming barriers to the implementation of car parking charges at UK workplaces. *Transport Policy, 12*(1), 57–64.

Shen, T., Hong, Y., Thompson, M. M., Liu, J., Huo, X., & Wu, L. (2020). How does parking availability interplay with the land use and affect traffic congestion in urban areas? The case study of Xi'an, China. *Sustainable Cities and Society, 57*, 102126.

Taylor, E. J. (2020). Parking policy: The politics and uneven use of residential parking space in Melbourne. *Land Use Policy, 91*, 103706. https://doi.org/10.1016/j.landusepol.2018.11.011

Teodorović, D., & Lučić, P. (2006). Intelligent parking systems. *European Journal of Operational Research*, *175*(3), 1666–1681. https://doi.org/10.1016/j.ejor.2005.02.033

Tsai, J. F., & Chu, C. P. (2006). Economic analysis of collecting parking fees by a private firm. *Transportation Research Part A: Policy and Practice, 40*(8), 690–697.

Westerlund, M. (2020). Citizen perceptions of government's resistance to shared parking. *Technology Innovation Management Review, 10*(5), 28–40. https://doi.org/10.22215/timreview/1354

Xie, J., Ye, X., Yang, Z., Yan, X., Lu, L., Yang, Z., & Wang, T. (2020). Impact of risk and benefit on the suppliers' and managers' intention of shared parking in residential areas. *Sustainability,12*(1), 268. https://doi.org/10.3390/su12010268

Yan, Q., Feng, T., & Timmermans, H. (2020). Investigating private parking space owners' propensity to engage in shared parking schemes under conditions of uncertainty using a hybrid random-parameter logit-cumulative prospect theoretic model. *Transportation Research Part C: Emerging Technologies, 120*(September), 102776. https://doi.org/10.1016/j.trc.2020.102776

Ye, X., Sui, X., Xie, J., Wang, T., Yan, X., & Chen, J. (2020). Assessment of the economic and social impact of shared parking in residential areas. *Information, 11*(9), 411. https://doi.org/10.3390/INFO11090411

Yuan, C. (2020, Nov. 27). Trending in China: Beijing tackles parking shortage with shared spaces. *CX TECH*. Retrieved from https://www.caixinglobal.com/2020-11-27/trending-in-china-beijing-tackles-parking-shortage-with-shared-spaces-101633168.html

Zhang, F., Liu, W., Wang, X., & Yang, H. (2020). Parking sharing problem with spatially distributed parking supplies. *Transportation Research Part C: Emerging Technologies, 117*, 102676.