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Spatial and Temporal Characteristics of Bike-Sharing Trips at Street Scale: A Case Study of Chengdu City

Tian Fangzhou*, Chen Binglang, Zhang Lu, Fei Ningyuan

College of Architecture, Southwest Jiaotong University, Chengdu, 610000, Sichuan, China
sjkwxn@163.com
**Corresponding author*

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Abstract: In the context of the policy goal of "carbon neutrality and carbon peaking", bicycle sharing, as a low-carbon and convenient way to travel, not only effectively meets the demand of the "last mile" of urban public transportation system, but also is one of the main ways to solve the problem of urban carbon emissions. It is also one of the main ways to solve the problem of urban carbon emission. This paper takes five urban areas in the center of Chengdu as an example, and uses Mobike order data and multi-source urban open data to conduct statistical analysis and spatial distribution visualization of shared bicycle data through Python and GIS, summarizing the spatial and temporal characteristics of shared bicycle travel activities at the street scale, and providing some data reference and theoretical basis for the placement and management of shared bicycles in the streets. It is of great significance to improve the efficiency of shared bicycle travel, achieve the goal of "carbon neutrality and carbon peaking" and improve the urban public transportation system.

1. Introduction

The rapid development of urban and motorized transportation has brought about serious traffic congestion and environmental pollution problems, and with the introduction of the goal of "carbon neutrality and carbon peaking", the concept of low-carbon travel has begun to re-emerge in cities. Among them, the bicycle-sharing mode of travel, which is represented by bicycle sharing, has contributed to the reduction of motorized traffic and urban transportation carbon emissions[1] . Public transportation is another effective way to alleviate urban traffic problems, and cycling is a powerful supplement to the "last mile" of urban public transportation. According to statistics, bicycle sharing accounts for a large proportion of public transportation arrivals or subsequent transportation choices[2] .Therefore, it is important to study the travel pattern of bicycle sharing for the improvement of urban public transportation system. In the context of the chaotic management of shared bicycles, the study of the travel characteristics of shared bicycles at the street scale is conducive to the management and placement of shared bicycles, improving the efficiency of shared bicycle travel and improving the travel environment within the streets.

Domestic and international studies on the characteristics of bike-sharing trips have relatively consistent findings, and the results all indicate that bike-sharing trips have obvious morning and evening peak characteristics and spatial aggregation characteristics. In a study of bicycle sharing in Hangzhou, Liu Bing et al. found that users' riding lengths were concentrated in the range of 6-10 min, proving that bicycle sharing is the main choice for people to travel short distances [3]. Shen et al.'s study of bicycle sharing in Singapore showed that bicycle sharing usage peaks during specific hours on weekdays, and the main purpose of users' riding is commuting, while weekend riding peaks are not obvious[4]. Chen conducted a nuclear density analysis of bicycle sharing coordinate points and found that riding activities are mainly concentrated in the core of the city. A kernel density analysis found that cycling activity is concentrated in the urban core [5].

This paper first pre-processes the bike-sharing order data in five urban areas of Chengdu by screening and cleaning, then performs statistical analysis and spatial visualization of the bike-sharing order data to visually reflect the spatial and temporal distribution characteristics of cycling behavior at the street level, identifies cycling hotspot areas [6], and conducts detailed analysis of weekday and weekend cycling volumes respectively.

2. Overview of the study area and research methodology

2.1. Overview of the study area

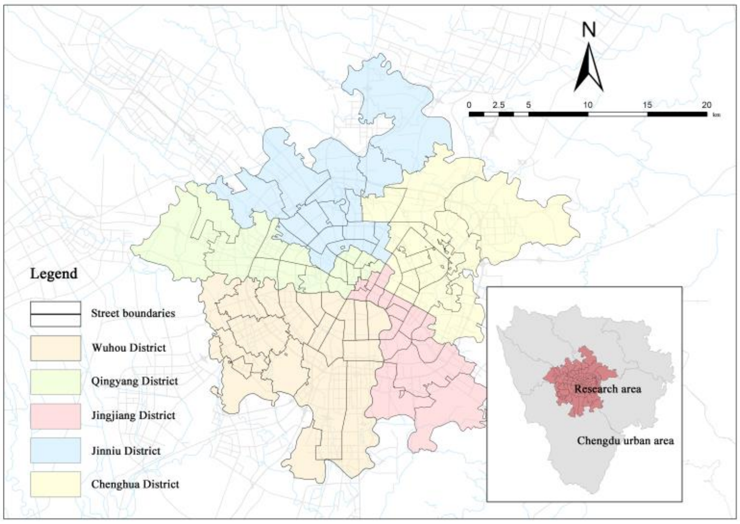


Figure 1: Scope of the study area

Chengdu is the central city in the southwest region and an important gateway to the west of the country for external connections, and its strategic position is very prominent. Currently, Chengdu is vigorously promoting TOD construction, and the high-density construction around bus stops will inevitably generate greater demand for transportation connections, and shared bicycles are one of the main ways of public transportation connections [7]. Chengdu has been putting out shared bikes since 2016, and by July 2018, the number of shared bikes in Chengdu was among the top three in the country. Among them, the five urban areas are the areas with the largest number of bicycle sharing and trips, and the number of bicycles in this range has exceeded 800,000[8]. The five urban areas include Chenghua District, Jinniu District, Qingyang District, Jinjiang District, and Wuhou District. This area is the spatial core of Chengdu and the earliest divided urban area of the city, with high economic level, well-constructed facilities, and dense activities of various people[9], which has a huge demand for shared bicycle trips and can provide sufficient samples for the study. Based on this, an area with a total area of about 463.7km^2 in the central five urban areas was selected as the research scope of the article. The study area and the administrative division of 62 streets in the five urban areas of Chengdu city streets are shown in the figure (Figure 1).

2.2. Data Sources

2.2.1. Data selection

The 2019 Mobike (now Meituan Bicycle) data showed that the number of Mobikes in the five urban areas of Chengdu city center had reached 400,000 by the end of 2018, which is a large amount of placement compared with other bicycle platforms, so the Mobike order data was selected as the base data for this study. The order data of the consecutive week from September 3 to September 9, 2018 in Chengdu city were crawled from the open port of Mobike using Python programming language, and the data collection frequency was once every 5 min. The data contains information of in-use and unused bicycles, totaling about 270 million data, and each data contains vehicle number, collection time, and vehicle latitude and longitude coordinates.

2.2.2. Data processing

(1) Data cleaning

The original data in the collection interval may be missing information in some fields of the order caused by manual transfer of shared bicycles, delay in information transmission, failure of vehicle positioning system and mistakes in the process of data aggregation, resulting in data displaying as garbled or empty values, so the data with such missing information are first identified and deleted.

(2) Data filtering

Since the original order data contains invalid data of unused bicycles, it is necessary to filter the data of bicycles where riding actually occurs. The approach is to sort the raw order data by bike number, and then sort the bike data of the same vehicle number in ascending order by data collection time information, and use Python's shift() function to compare the same numbered bikes in each

	DATA_TIME	BIKE_ID	LONGITUDE	LATITUDE	HOUR	DATE_TIME2	BIKE_ID2	LONGITUDE2	LATITUDE2	HOUR2
1525778	2018-09-09 00:49:23	0200037379#	104.098267	30.692250	0	2018-09-09 01:00:24	200037379#	104.098253	30.692254	1
3123480	2018-09-09 01:41:45	0200037379#	104.098253	30.692254	1	2018-09-09 01:52:48	200037379#	104.098276	30.692245	1
5037582	2018-09-09 02:44:03	0200037379#	104.098276	30.692245	2	2018-09-09 02:56:36	200037379#	104.098234	30.692257	2
6964714	2018-09-09 03:48:48	0200037379#	104.098234	30.692257	3	2018-09-09 03:59:07	200037379#	104.098259	30.692215	3
8888424	2018-09-09 04:51:09	0200037379#	104.098259	30.692215	4	2018-09-09 05:01:23	200037379#	104.098245	30.692254	5

Table 1: Data on orders for shared bikes where rides actually occurred

Segment collects the coordinate information of the first and last time point of the interval, and filters out the data whose coordinate position has changed, i.e., the data of the actual order being used (Table 1). For each data, compare its coordinate information with that of the previous data, and if there is a change, the coordinate will be regarded as the end point of this ride, so that the starting and ending coordinates of each bike-sharing order are obtained by this law. Finally, a total of 18,779,000 pieces of cycling track data were obtained for one week within the study area.

(3) Data extraction within the study area

Import the cleaned csv format order data into GIS, select "LONGITUDE" and "LATITUDE" field information as latitude and longitude coordinates respectively, and convert them into vector shp. format data with wgs84 coordinates for spatial analysis. The vector data of the study area was superimposed, and the coordinate points of the shared bicycle order data within the study area were selected and exported, and finally about 14,689,000 data were extracted, which were used as the basic data for analyzing the characteristics of shared bicycle trips.

The specific data extraction and weather conditions for each day are shown in the table (Table 2). To avoid the influence of climatic factors on the study findings, the two days without rainfall on September 6 (Thursday) and September 8 (Saturday) were selected as representatives of weekdays and weekends, respectively, to screen the data of bike-sharing orders where riding occurred within the study area.

Date	9/3	9/4	9/5	9/6	9/7	9/8	9/9
Amount of raw data	2779812	2841529	2494336	2831913	2832306	2737078	2263435
Amount of valid data	2202999	2253047	1947863	2229299	2216086	2109875	1730038
Weather conditions	shower	moderate rain	light rain	cloudy	cloudy	cloudy	shower

Table 2: Valid data collection by day and weather conditions

2.3. Research Methodology

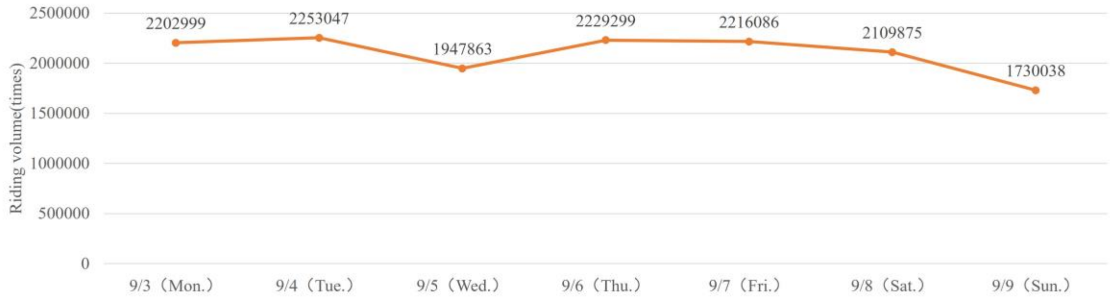
This paper adopts literature research method for basic theory research and literature review, and the collected bike-sharing data are screened and cleaned by Python and other tools, and statistical analysis is conducted to grasp the overall characteristics of users' cycling hours and travel distance. The processed bike-sharing data are connected to the faceted street space, and their travel trajectories are visualized on the street space scale using density analysis and spatial autocorrelation of GIS spatial analysis, and their spatial distribution hotspots, aggregation patterns and other characteristics are analyzed to intuitively reflect the spatial distribution characteristics of bike-sharing trips and provide scientific basis for cycling management and optimization of cycling environment.

3. The General Characteristics of Shared Bicycle Travel

3.1 Number of shared bicycle trips by day

A statistical summary of bike-sharing order data for each day of the week shows that the number of rides in Chengdu's five urban areas on each day of the week is concentrated between 2 and 2.03 million, with a daily average of 2.098 million rides (Figure 2). In general, the number of rides on weekdays is greater than that on weekends, and the difference between the number of rides per day on weekdays is small, indicating that there is a stable and large demand for bicycle sharing on weekdays. The difference between weekday and weekend rides may be due to the fact that a large number of people have more rigid commuting travel demand on weekdays, while commuting demand decreases on weekends and the overall number of trips is smaller than on weekdays, making both weekend bike-sharing demand and rides decrease.

Based on the user data counted in the Mobike Development Report, the number of rides per capita per day was calculated (Figure 3). From the overall analysis results, the number of rides per capita on each day is lower than 3 times. According to relevant studies, the shared bicycle turnover rate of about 5 times per day is conducive to maximizing urban transportation efficiency. It can be seen that the current status quo has a low utilization rate of shared bicycles, and the average daily use efficiency of individual vehicles has more room for improvement. From the average daily cycling frequency data of user groups, users use shared bicycles more frequently on weekdays than on weekends, which may be due to the fact that users use shared bicycles more often on weekdays for commuting. Looking at the full week data, rides in cloudy weather on both weekdays and weekends are higher than their rides in rainy weather, and has a larger difference, proving that weather factors have a greater influence on whether users choose to travel by shared bicycle.



Date	9/3（Mon.）	9/4（Tue.）	9/5（Wed.）	9/6（Thu.）	9/7（Fri.）	9/8（Sat.）	9/9（Sun.）
Riding volume(times)	2202999	2253047	1947863	2229299	2216086	2109875	1730038

Figure 2: Bike-sharing travel statistics by day

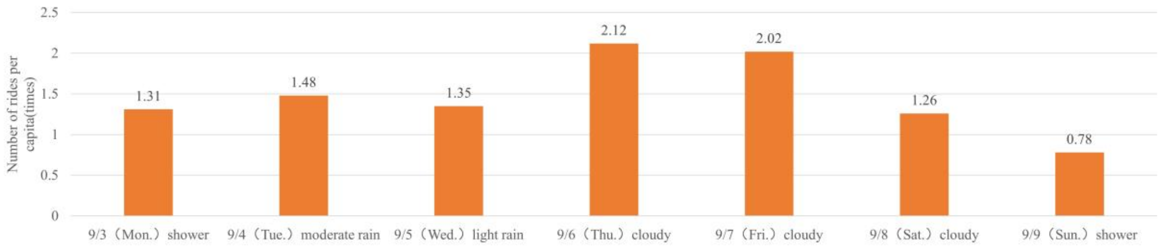


Figure 3: Statistics of daily per capita rides by day

3.2. Distribution characteristics of riding hours

The difference between the end time and the start time of each order was calculated by Python language as the riding time of the order, and the average riding time of the shared bicycle was counted for each day of the week (Figure 4). This indicates that users use bicycle sharing on weekdays for commuting purposes, where the cost of travel time is more rigid, and on weekends for leisure purposes. This indicates that weekday users mostly use bikes for commuting, which has a hard limit on travel time cost.

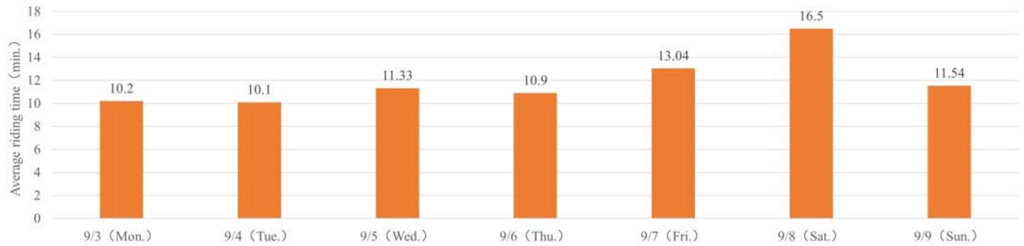


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Figure 4: Average riding hours by day

The average ride length alone is not enough to reflect the concentrated distribution of users' ride length, so probability density distribution analysis was conducted on weekday and weekend ride lengths, and histograms of ride length density distribution were drawn from weekday and weekend data (Figure 5). The majority of orders on weekdays were within 15 min, with orders of 6 min-8 min accounting for 37% of the total number of orders on weekdays. Most orders on weekends are concentrated within 20min, with orders of 10min-15min accounting for about 35% of the total number of all-day orders on weekends. This further indicates that the demand for short commutes is greater on weekdays, while the demand for travel on weekends is more flexible.

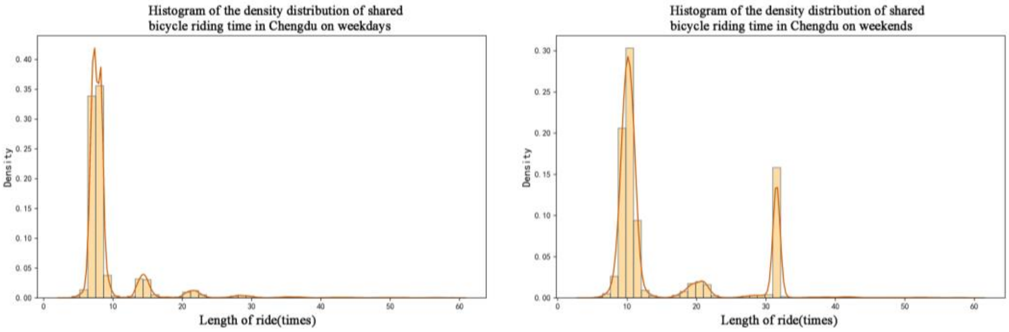

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Figure 5: Histogram of the density distribution of shared bicycle riding hours on weekdays and weekends

3.3. Riding distance distribution characteristics

Based on the starting and ending coordinates of the order data using ArcMap's XY to line tool to generate the riding OD line for each order and calculate the OD line length as the distance of each ride, which is a straight line distance connecting the starting and ending points (Euclidean distance) and is smaller than the actual riding distance. Considering the influence of bicycle positioning error or manual scheduling, the data with moving distance less than 200m were deleted and the valid data were counted and the results are shown in Table 3. The median riding distance on weekends is about 3 times higher than that on weekdays in general, which is mainly due to the difference in travel purpose between weekday and weekend riding.

Date	Mean (m)	Standard deviation (m)	Minimum (m)	Median (m)	Maximum (m)
Weekday	1022.57	927.81	200.00	748.79	25509.40
Weekends	1651.95	886.6	200.00	2259.52	27297.70

Table 3: Distribution of all-share bicycle riding distance density on weekdays and weekends

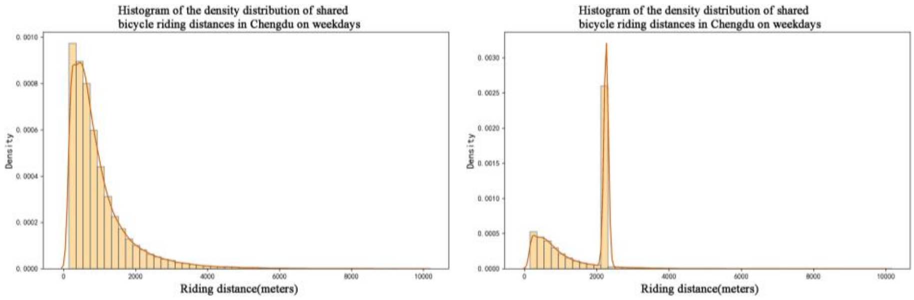
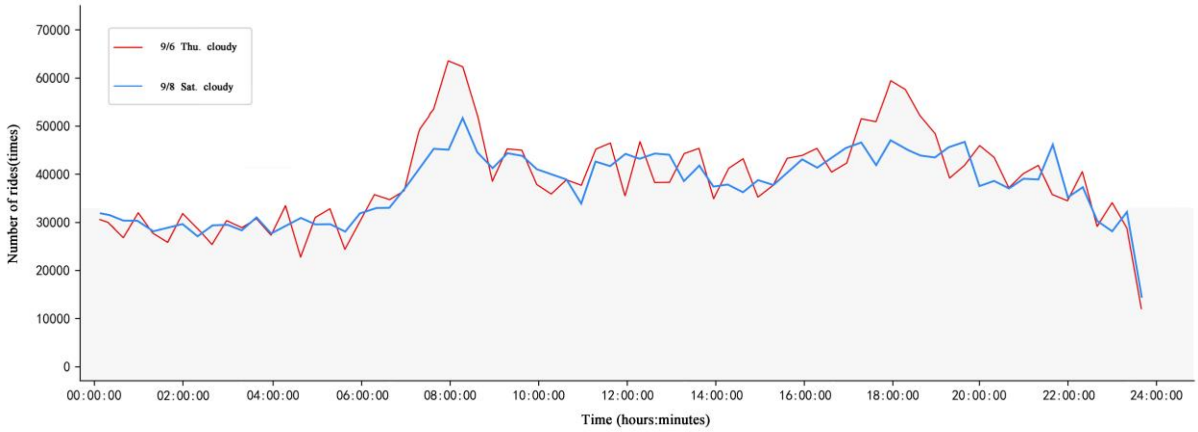


Figure 6: Density distribution of all-share bicycle riding distance on weekdays and weekends

The probability density analysis of cycling distances throughout the day (Figure 6) shows that the differences in cycling purposes make the cycling distances vary significantly between time periods and days on the same day. 300m-1500m is the main shared bicycle travel distance on weekdays, and the number of orders in this cycling distance range accounts for about 72% of the total number of orders, while weekend cycling distances are generally longer than weekdays, concentrated in the 500m-2000m range, accounting for 62% of the total number of weekend orders. The distance of weekend rides is generally longer than that of weekdays, concentrated in the range of 500m-2000m, accounting for 62% of weekend orders. The difference in travel distance between weekdays and weekends is mainly due to the difference in the intensity of travel time constraints and travel purpose between the two. Overall, the distance traveled on each day is concentrated within 4km, indicating that bicycle sharing is mainly used for short-distance travel.

3.4. Time distribution characteristics



Bottom map source: BIGEMAP map downloader

Figure 7: Distribution of bike-sharing usage on weekdays and weekends

Using Python programming to integrate all the data for a week, we counted the weekday and weekend bike-sharing usage and obtained its time distribution (Figure 7). The data analysis results show that bike-sharing trips have obvious morning and evening peak characteristics, and the amount of rides during peak hours on weekdays is significantly higher than that on weekends. The peak hours of shared bicycle ridership on weekdays are basically the same as the peak hours of urban traffic, and the ridership during all hours is higher than that on weekends, which indicates that shared bicycles are mainly used for commuting on weekdays. The change in cycling volume at all hours on weekends is smoother than on weekdays, and the peak characteristics of cycling volume are not as obvious as on weekdays, but the peak hours of shared bicycle travel on weekends are basically the same as those on weekdays, indicating that there is still a certain amount of commuting demand on weekends.

4. Spatial Distribution Characteristics of Shared Bicycle Trips at Street Scale

The study area's street surface data were connected to the weekday and weekend order riding trajectories using python programming, and the riding density of each street was calculated and visualized in ArcMap. From the visualization results, it can be seen that there are more obvious spatial clustering characteristics of bike-sharing travel activities at the street scale (Figure 8), and the hot streets for weekday and weekend rides are more consistently concentrated within the second ring road and the southern Tianfu New Area, but there are some differences in the amount of rides, and the specific travel characteristics of bike-sharing at the street scale are as follows.

(1) The spatial agglomeration characteristics of cycling activities are obvious, with high cycling density in streets with mainly commercial and employment functions

The hot streets for cycling on each day are mainly located within the third ring, and the cycling is especially intensive in the streets with dense commercial and leisure facilities such as Chunxi Road Street, XiYuhe Street and Shuyuan Road Street within the first ring. This is due to the fact that these streets are located in the core of the city, with dense business districts and rich types of service facilities, and are the main destinations for residents to spend their daily lives for leisure and work. Higher cycling densities are also found in areas near the periphery of the city, such as Shiyang Street and Guixi Street, at the southern end of the study area. These areas are new urban areas with more dense work sites and therefore have a high demand for commuter cycling.

(2) The distribution of cycling activities on weekends is more concentrated than on weekdays

The distribution of cycling activity density on weekdays shows a characteristic of evenly increasing from the third ring to the first ring, forming a core of cycling density in the center of the city. Weekend cycling activity, on the other hand, shows a stronger pole-core characteristic, with a large number of cycling activities clustered in Guixi and Shiyang streets in the south, where cycling density is significantly higher than in other areas. This is probably due to the fact that these streets are Chengdu's high-tech industrial clusters, which still have a large commuting demand on weekends, and the fact that the area is a new district with a more complete slow walking system than the old city, and has more green parks equipped with a complete cycling system, such as Guixi Ecological Park and Jincheng Park. These parks have slow flow routes across the city roads (Figure 9) and are more continuous and have better scenery than the slow flow routes in the north, providing a better slow walking experience and attracting a large number of users to ride for leisure and fitness purposes.

(3) The clustering characteristics of cycling activities in urban centers on weekends are not obvious compared to weekdays

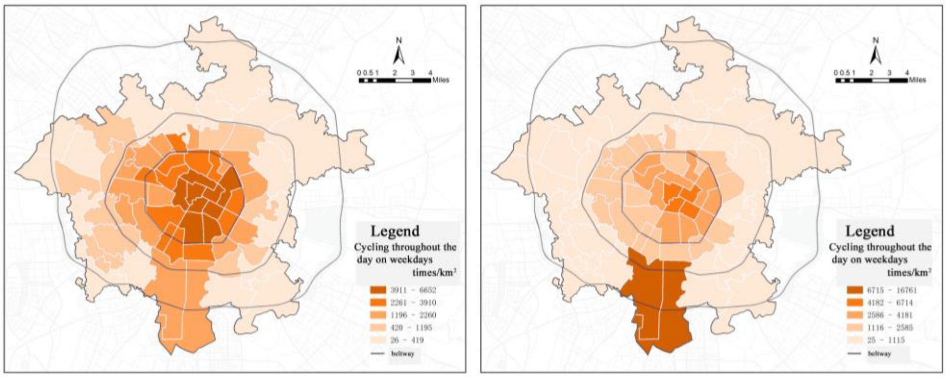


Figure 8: Street-scale weekday and weekend all-day cycling density distribution

Weekend cycling activity within the second ring has decreased significantly compared to weekdays, which may be due to the fact that weekend residents travel mainly for leisure purposes and have more flexible and rich choices in terms of travel time and travel mode.

Figure 9: Well-established slow walking system in the southern park of the study area

5. Conclusion and Discussion

This paper analyzes the spatial and temporal characteristics of bike-sharing trips at the aggregate and street scales to draw the following conclusions.

(1) On the overall characteristics of cycling trips, there is a higher demand for cycling on weekdays than on weekends, and the amount of cycling on weekdays is similar on all days. The average length of people's cycling trips is mainly distributed in the range of 10-13min, and the length of weekday cycling trips is shorter than that of weekends. The length of weekday cycling trips is mainly distributed in the range of 6-8min, while the length of weekend cycling trips is concentrated in the range of 10-15min, indicating that weekday travelers have more rigid time constraints. The analysis of cycling distance found that the main cycling travel distance was 300-1500m on weekdays and 500-2000m on weekends, both proving that cycling is mainly used for short distance travel.

(2) In terms of time distribution characteristics, there are morning and evening peaks in bike-sharing usage, with ridership peaking at 8:00-9:00 and 18:00-19:00. The bimodal distribution characteristics of weekday ridership in terms of time are more obvious than those of weekends. It is also found that weekday riders are less sensitive to weather than weekends.

(3) In terms of spatial distribution, the spatial distribution characteristics of cycling activities on the street scale indicate that areas with complex functions and dense facilities of various kinds and around bus stops will generate higher cycling volume, which shows a higher cycling density in the urban core area within the second ring and along the rail transit line, forming an obvious high-density cycling corridor on the north-south axis of the city.

In summary, the structure of the analysis of the spatial characteristics when sharing bicycle trips shows that there is a certain correlation between cycling activities and the dominant function and geographical location of streets. Streets with different positioning and construction types should develop different policies and approaches in the management and placement of shared bicycles. For example, streets dominated by commuting trips should have high-density and small-scale adequate placement at possible commuting interchange points, while streets dominated by leisure trips can have low-density and large-scale placement of shared bicycles. The chaotic situation of shared bicycle placement can be rectified to a certain extent, improving people's travel efficiency and enriching the demand for shared bicycle use, in order to achieve the goal of zoning and grading management of shared bicycles.

This paper only briefly analyzes and describes the travel characteristics of shared bicycles at the street scale, and the correlation effects between their characteristics and the values of the street itself have not been studied in depth, which can only provide a rough reference for the management of shared bicycles at the street level.

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