



Article Exploring Spatial Distribution of Urban Park Service Areas in Shanghai Based on Travel Time Estimation: A Method Combining Multi-Source Data

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Abstract: Due to a growing appreciation for the ecological and recreational benefits of public green spaces, the evaluation of urban parks' service efficiency, as well as citizens' behavioral preferences for daily recreation, have become an increasing academic focus. However, due to the lack of empirical approaches, existing research on exploring park service areas has been simplified by their use of Euclidean distance or buffer sets by simulation, ignoring the fact that the likelihood of citizens visiting urban parks is time sensitive. Utilizing mobile signaling data and web map services, this study proposes an approach to estimating the travel times of park visitors and analyzing the characteristics of park service areas from the perspective of actual time consumption. Taking Shanghai as a case study, this research firstly identified the time-cost decay of parks with different areas and locations. A comparison analysis was then used to examine the spatial relationship between park service areas and their accessibility defined by time consumption. The results show that (1) urban parks in Shanghai have larger mean service radii than existing planning guidelines, and park service areas were significantly influenced by park locations; (2) people have a great preference for urban parks whose travel times by public transit are under 40 min, and they have no desire to visit parks located within or outside the Middle Ring Road when the travel times reach 60 min and 75 min, respectively; (3) the shapes of park service areas are consistent with the high-accessibility districts defined by time thresholds, in spite of some differences caused by citizens' choices. These findings provide an effective tool for evaluating the actual characteristics of park recreational services, along with direct implications for policymakers aiming to establish effective strategies for improving the accessibility and vitality of urban parks.

Keywords: park service area; travel behavior; accessibility; multi-source data; Shanghai

1. Introduction

The urban park system is one of the most important components of the urban public service system, providing both physical and psychological health benefits for residents while also positively impacting the social, economic, and ecological development of urban areas [1–4]. Due to the rapid development of transportation systems and the functional differentiation of urban public parks, residents' recreational choices have become more diverse, resulting in a spatial imbalance between supply and demand [5,6]. Meanwhile, in the past few decades, rapid urbanization has transformed how people live in developing countries, minimizing urban dwellers' access to natural recreational activities because of a lack of green space and high urban population density [7,8]. To resolve such problems, it is



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). important for policymakers and urban planners to determine how efficiently urban parks are used and to then provide residents with sufficient public green spaces [6,9].

Given the uneven distribution of green spaces in urban areas, their functionality depends not only on their availability but also on their accessibility, which represents the ease with which residents can reach green spaces [10,11]. As an indicator of a park's ability to provide recreation services, accessibility is based on the spatial distribution of regions which are able to access park services through a transportation network [12,13]. A growing body of research has explored the accessibility of urban parks in order to identify urban areas lacking recreational opportunities in green spaces, which may contribute to environmental injustice and poor health outcomes [14–16]. As a result of improved GIS features, the spatial measurement of accessibility to green spaces, based on theoretical simulations, has greatly evolved. Because of the limited availability of traffic network data, some scholars have simplified park service areas as radii based on Euclidean distance [14,17–19] or delineated it by Thiessen polygons [20]. Both methods, however, fail to take into account actual access routes, ignoring the spatial differences caused by various factors, such as road networks and urban morphology. Thus, in order to estimate residents' recreation activities more accurately, calculating accumulative resistance or cost distance between parks and residents by a network analysis tool has been widely applied to determine park service areas [15,21–23]. Nevertheless, subjective defaults cannot be avoided in network analysis, such as the design speed for different road grades, particularly when several modes of transportation are taken into consideration. Additionally, all methods of measuring park service areas are arbitrary, since it is not easy to figure out at what level different types of parks will no longer offer services [19,23,24]. For instance, Xiao et al. defined 1.6 km (15 min walking distance) and 3.2 km (15 min cycling distance) as the criteria for park access in Shanghai, China [16], while Rosa considered 300 m and 600 m as the distance thresholds for a walking travel mode in Catania, Italy [25]. In recent years, some computational models have been developed based on gravity models or two-step floating catchment area models that consider spatial decay and assume that visitor distributions depend on Euclidean distances [26,27], which seem to avoid the delineation of particular service spheres. However, there is a pre-set assumption for all of these methods, that residents prefer nearby parks for recreation, failing to reflect actual park usage due to the ignorance of distant visitors. For citizens to satisfy their diverse demands, they may need to travel a much greater distance to reach a particular park [28]. Therefore, traditional spatial measures are not as accurate as they might seem when reflecting actual park usage. Given the difference between actual recreation behavior and idealized accessibility measurement methods, it is necessary to answer the question as to where the boundaries of the potential influence of a park recreation service can be established when considering the actual traffic situation and visitors' travel preferences.

Traditionally, researchers have used survey questionnaires and field observations to investigate citizens' recreation patterns [29-33]. These researchers built the foundation for demonstrating the relationship between the features of urban green spaces and their service areas. For example, Liu et al. utilized questionnaires to assume that visitors' geographic distributions of 12 sample parks were significantly influenced by a combination of factors, including park size, transport facilities, and visitors' attributes [30]. Nevertheless, this method cannot be generalized because of the difficulty of data collection, as well as the limited samples. Currently, the widespread use of information communication technologies provides a low-cost and efficient way to gain access to citizens' spatial and temporal behaviors [34–36]. Among the significant big data, mobile signaling data have been applied to identify visitors' mobility patterns in order to examine park use efficiency. These data allowed for the identification of each of the park's visitors and their residences by tracing their trajectory [19,37,38]. According to the distribution of visitors' homes, home-park Euclidean distance [19] and standard deviation ellipse (SDE) [13] have both been utilized to describe actual park service areas. Through a classified statistical analysis and regression model, the service distance threshold of different parks has been found to

be associated with the hierarchical structures of urban park systems, which are mainly set by park size or location [19,38]. However, these studies have paid little attention to the travel routes and time consumption of visitors for recreation, instead only looking at their origin–destination lines from the park to home as an actual supply-and-demand service flow. In fact, the likelihood of visiting urban parks for citizens is time sensitive, and varies depending on their travel mode, location, and traffic conditions [39,40].

With the advancements in information technology, online platforms such as Google, Yahoo, and Facebook have made their databases easily accessible to users through Application Programming Interfaces (APIs). Time costs with related distances and routes can be accurately obtained by using APIs offered by online maps, such as Google Maps in Western countries, and Baidu Map and AMap in China [41–43]. In contrast to network analysis by ArcGIS, the latest road networks will no longer need to be established ahead of time. By inputting the latitude/longitude coordinates of the origin and destination with APIs, we could easily obtain detailed travel routes and the corresponding travel costs calculated by AI technology for different transportation modes, such as driving, public transit, walking, and biking [44–46]. Scholars have begun to use web map APIs in their studies, such as those on the dynamic efficiency of traffic networks [47] and the spatial equity of public facilities [48,49]. An innovative method was developed in this study to determine residents' travel times by combining web map APIs with mobile network signaling data.

This study proposed that park service areas should be analyzed by actual time consumption to identify and investigate visitor patterns and preferences in contrast to the conventional use of a single radius or road distance. Meanwhile, it is essential to answer the question of whether basing the accessibility metric on time consumption is consistent with park service areas according to the actual behavior of residents statistically and spatially. To achieve this objective, we chose Shanghai, one of the municipalities directly under the central government, as the case study for empirical examination via a big data approach. The findings of this study can provide new insight into the impact of traffic facilities on the recreation choices of citizens for individual parks, along with an optimized threshold for real-time transportation used in park planning.

The remainder of the paper is organized as follows: Section 2 introduces the study area, datasets, and the methods used to analyze urban park service areas based on the time costs. Section 3 shows the spatial characteristics of park visitors from the perspective of time-cost decay and the relationship between park service areas and accessibility calculated by the web map. Section 4 discusses the data results and outcomes.

2. Materials and Methods

In this section, we first described the study area and introduced the multi-source data involved in our research. Then, for the empirical examination, as mentioned in Figure 1, we took three main steps. Firstly, park visitors identified from mobile signaling data were used to determine the park service areas based on park-residential lines and hotspots of park visitors' homes. We performed both descriptive statistics and spatial distributions describing actual travel preferences of park visitors, which allowed us to make inferences about the relationship between park service areas and park attributes. As a second step, to determine the time–cost threshold for citizens' behavior, we computed the time consumption for each leisure trip between homes and parks using the web map APIs and ran a time–cost decay analysis for each park category. Finally, an analysis comparing hotspots of park visitors' residences with the potential accessibility of the entire study area based on the thresholds identified above was conducted to evaluate their spatial consistency.



Figure 1. Research frame.

2.1. Study Area

As one of the leading central cities in China, Shanghai is located at the alluvial plain of the Yangtze River and the western coastline of the East China Sea. In 2020, the population of permanent residents was 24.87 billion, and its gross domestic product was USD 593.1 billion. Along with its continuous population growth and economic development, the urban constructed area was raised to about 3100 km². In order to enhance the quality of citizens' lives, the latest Urban Master Plan (2017-2035) places great emphasis on providing better green infrastructure for leisure and entertainment and attempts to promote the green space supply to 13 m² per capita by 2035. Hence, in recent years, the Shanghai government has been committed to optimizing the urban green space system and improving recreation service efficiency. Combined with 352 urban public parks in the metropolitan area, the whole area reached 21.4 million ha in 2019.

In this study, we defined our study area as the high-density urban region within the Outer Ring Road of Shanghai City, which covers 662.51 km², including 117 sub-districts (Jiedao or Zhen). According to the Urban Master Plan (2017-2035), our target area also contained the main city zone of Shanghai, also regarded as the Central Activities Zone, which contains the major commercial, leisure, and residential areas for a wide variety of activities. Due to its dense population and multiple functions, the demand for public green space in this area is extremely high. Therefore, Shanghai is a representative case for illustrating the contemporary interactions between residents and urban parks. Figure 2 depicts the geographic area of the study.



Figure 2. Study area and sampling parks.

2.2. Data Preparation

2.2.1. Sampling Park Data

In order to derive the shapefiles of urban parks, their boundaries were obtained from the area of interest (AOI) data provided by the Baidu web map and were georeferenced by ArcGIS 10.7 to export their polygons. Then, we used the list of urban parks and green land published by the Shanghai government to exclude golf courses and private resorts that may have been identified as public green spaces. Given that some public parks outside the Outer Ring Road may also provide recreation services for residents in our study area, the green spaces adjacent to the Outer Ring Road were also selected.

According to existing research, the distance between two neighboring mobile base stations in the central city varies from 500 m to 3 km [16,19]. If we assume that their distribution is in the form of a grid, the base stations roughly have a service area of more than 2.5 ha. The considered parks were only those larger than 2.5 ha, because, if a park's area is smaller than the minimum service area, the base stations may have difficulty distinguishing green access from activities taking place on residential or commercial land nearby. Finally, a total of 58 public green parks, with an area ranging from 2.59 ha to 190.77 ha, were obtained, as shown in Figure 2. We divided green spaces into four domains, according to their geographical relationships with three ring-shaped roads: within the Inner Ring Road, between the Inner Ring Road and the Outer Ring Road, and beyond the Outer Ring Road (Table 1).

Location	Park ID	Park Name	Area (ha)	Location	Park ID	Park Name	Area (ha)
	A1	Tianshan Park	6.51		B1	Hongqiao Central Park	16.19
	A2	Zhongshan Park	27.12]	B2	Changfeng Park	34.67
	A3	Kaiqiao Park	6.11	1 -	B3	Kangjian Park	13.13
	A4	Panyu Park	4.33	1 -	B4	Shanghai Arboretum	86.08
	A5	Fuxing Park	8.94	-	B5	Nayuanbinjiang Park	9.36
	A6	Xujiahui Park	14.36		B6	Xuhuibinjiang Park(South)	11.49
	A7	Guangchang Park (Luwan)	6.84	B—Between	B7	Shibo Park	37.26
	A8	Penglai Park	4.10	the Inner Ring	B8	Shangnan Park	5.01
A—Within the – Inner Ring _ Road _ –	A9	Putuo Park	2.66	Road and the Middle Ring	B9	Xuhuibinjiang Park(North)	17.64
	A10	Mengqing Park	10.85	Koad -	B10	Caoxi Park	5.04
	A11	North Sichuan Road Park	6.54	1 -	B11	Wuning Park	8.71
	A12	Yan'an Park	5.01	1 -	B12	Dahuaxingzhi Park	6.82
	A13	Taipingqiao Park	4.12		B13	Daninglingshi Park	68.76
	A14	Guangchang Park (Huangpu)	11.33		B14	Quyang Park	6.82
-	A15	Jing'an Sculpture Park	9.18	-	B15	Zhabei Park	13.25
-	A16	Meiyuan Park	2.59	1	B16	Siping Park	4.96
-	A17	Century Park	190.75	1	B17	Huangxing Park	41.38
-	A18	Jingnan Park	3.57	1	B18	Yangpu Park	22.78
-	A19	Gucheng Park	6.58	1	B19	Biyun Sport Park	12.62
=	A20	People's Park	16.46		C1	Shanghai Zoo	97.60
	A21	Buyecheng Park	4.84]	C2	Lingnan Park	5.00
	A22	Lujiazui Central Park	11.14]	C3	Zhili Park	6.73
	A23	Heping Park	19.62	C—Between the Middle Ring Road and	C4	Songnan Park	9.38
	A24	Jiangpu Park	5.62		C5	Jiangwancheng Park	18.34
	A25	Luxun Park	25.32		C6	Puxing Cultural Park	8.41
D—Beyond the Outer Ring Road -	D1	Minhang Sport Park	103.47	Road	C7	Gongqing Forest Park	180.71
	D2	Li'an Park	28.37		C8	Zhangheng Park	8.43
	D3	Gucun Park	190.77]	C9	Jinqiao Park	12.19
	D4	Huaxia Park	25.44		C10	Yangguang Park	42.06

Table 1.	. Summary	of the	sampling	parks.

2.2.2. Identifying Park Visitors and Their Residential Locations

First, mobile phone signaling data, with private information removed, were acquired from a dataset called Smart Steps Core Insight Platform, provided by China Unicom, one of the largest mobile companies in China. Considering the impact of weather on residents' willingness to travel outside, the signaling data involved in this study are from the data captured by mobile base stations during the period of a week, from May 6th to May 12th, 2019, where the weather was either sunny or cloudy. The coordinates and states of users were recorded by the base stations, which were employed to identify citizens' trajectories and activities by several particular criteria.

The process of identifying park usage can be simplified to the following four steps. First, users whose mobile phones connected to the base stations for more than 15 min and less than 8 h during the opening hours of parks (6:00–22:00) were extracted. Second, workers whose workplaces were close to the parks were defined and excluded from the data set if their mobile phone data were captured for more than five days during the working day (10:00–16:00). Third, we excluded the data belonging to the surrounding permanent residents, whose locations were still the service areas of particular base stations during the night (00:00 and 05:00), as it was too difficult to determine whether they were visiting the parks or staying at home. Finally, all identified park users' homes were defined as their locations, recorded by base stations, between 00:00 and 05:00 for more than 20 days in May 2019. Through the method demonstrated above, we successfully identified a 217,339 origin–destination matrix of urban park visitors in Shanghai over a period of a week.

2.3. Analytical Strategy

2.3.1. Delineation of Park Service Areas

As a first step, descriptive statistics were calculated for Euclidean distances between park destinations and residences to roughly illustrate the differences in recreation service quality. Considering the non-normal distribution of distance variables [30,50], average, median, quantiles, and standard deviation were calculated to demonstrate the variation of distribution. Then, with the help of SPSS software, we checked the correlations between park–residence distances and park areas, as well as the distance to the city center, to investigate which influencing factors had the strongest connections with the spatial distribution.

Then, with the kernel density estimation method (KDE) on ArcGIS 10.7, which has been widely used to describe the spatial distribution of point data [30,51], the hotspots were projected by fitting a smoothly continuous density surface with scattered residence points. Considering the actual distribution of mobile phone base stations in Shanghai, we employed a kernel with a bandwidth of 1200 m to clearly display the pattern of spatial clustering. Due to the difference in sample size, it is meaningless to distinguish the service areas of parks by absolute density value. Therefore, the quantile method was used for classification, and we determined grids with density values in the top 20% to be the core hinterlands, which contained most of the park visitors' residences.

2.3.2. Travel Time Estimation of Each Trip

We developed a method that utilized the Baidu web map to assess travel times and routes, and which could add travel trajectories on the basis of mobile phone signaling data to improve the accuracy of trip estimation. The Baidu web map is a web-based navigation map in China that provides API services for the public similar to those provided by Google Map APIs. Through the Route Planning API of Baidu Map, routes between two locations can be calculated based on different scenarios and travel modes. Considering both walking and public transportation are important means of getting to green spaces [52–54], we chose both of them as the two transport modes in our research. Moreover, as traffic conditions may influence the routes and time expense calculations for public transport, we set the travel times to be between 8:00 and 20:00 on weekdays and assumed that citizens would prefer the shortest routes in regard to time.

Based on the predetermined rules mentioned above, Python programs were used for deriving the duration and distances of the shortest routes from the origin points to the urban parks in batches by invoking the Route Planning APIs of Baidu Map. We calculated the time cost for each trip based on the origin–destination matrix, as described above, taking visitors' residences as the origin points, and the park entrances obtained from the web maps and field observations as the destinations, assuming that a visitor would pick the shortest path when several route options were given. This value represented the actual time consumption of visitors' trips to the urban parks (Figure 3).



Figure 3. Travel time estimation by Route Planning APIs for an identified trip to Daninglingshi Park (B13).

2.3.3. Time-Cost Decay Analysis and Indicators of Time Thresholds

In order to examine the relationship between the use of green parks and the actual costs of transportation, we applied the probability distribution function and cumulative distribution function, with time intervals as independent variables, both for the overall situation and every pair of groups of parks with different areas and locations. With this method, we observed variations in the proportion of residents visiting a given park in each time interval compared to the total visitors as the time cost increased, avoiding the influence of the sample size on the research. Histogram and optimal fitting models were used to fit the above data.

Based on previous studies [42], we assumed that there were two kinds of reasonable threshold values of time consumption for public green space in the time–cost decay functions. The first threshold is the maximum point, which represents the time period which residents prefer over all others. The second threshold is the time period in which the cumulative distribution of people (the integral of time-cost decay function) has reached 80%, regarded as the longest time duration beyond which people are unwilling to visit an individual park.

2.3.4. Definition of Park Potential Accessibility and Comparative Analysis

In order to assess the traffic convenience of each park, we created a raster map of the study area with a 250×250 m grid unit, and, after removing inaccessible areas, such as rivers and mudflats, set the center point of each pixel as the starting point. Then, the minimum time cost for each pixel, from the origin points to every sampling park, can be obtained based on Route Planning APIs, which can be converted to an isochron map for the accessibility of every park. To depict the public green space accessibility of the study area, we used Kriging interpolation to transform the origin points into a polygon. Moreover, for each residence point, the time required to reach a park can be obtained through spatial interpolation. Compared with the Euclidean distance and the network

distance used in previous research, the actual time cost value can more clearly reflect actual traffic conditions.

Moreover, we conducted a comparative analysis to explore the relationship between the actual service areas of urban parks and the potential accessibility, based on time consumption, according to actual traffic conditions and visitors' preferences. The potential accessibility was derived from different time intervals according to people's travel patterns, observed above. With the increase in the time–cost value, we checked the overlapping area between the isochronous circles and the hotspots of visitors' residences to find out the optimal value at which the two have the closest morphologies. Together, all these statistics provide a comprehensive measurement of urban park service areas according to their time–cost decay patterns.

3. Results

3.1. Characteristics of the Park Service Area

3.1.1. Park–Residence Distance

We calculated the Euclidean distance between each park visitor's residence and the park they visited. For each park, the number of identified park users, mean, median, and 75th percentile of park-residence distances were determined (Table 2). First, the overall statistics showed a power-law distribution of the number of people visiting individual green park spaces, which meant that few parks received a large number of visits, but the number of parks with a small number of visits was large, and the difference was significant. Meanwhile, considering the non-normal distribution of distance variables, the median park-residence distance of recreational parks and green spaces was more suited to being regarded as an indicator reflecting the service radii of the parks. This was negatively correlated with the distance from the city center (r = -0.367, p < 0.01), but it was not significantly associated with the park areas (r = 0.107, p > 0.01). Thus, there was a minor relationship between service radii and park sizes, but the geographic location made a significant difference. Additionally, the median park-residence distance of each park was far beyond the existing guidelines for green space across the world. These correlations indicated that, as a traditionally used criterion to divide the scope of services in parks, area scale has obvious limitations.

Additional examination of this relationship was conducted by investigating how parks with different locations differed in their distances from their visitors' residences. We divided all parks into four categories according to the three ring-shaped roads in the study area: (1) parks within the Inner Ring Road; (2) between the Inner Ring Road and Middle Ring Road; (3) between the Middle Ring Road and Outer Ring Road; (4) beyond the Outer Ring Road. Then, we calculated the mean service radii of each category, proving that this correlation was not simply linear. The results revealed that the radii of parks located within the Inner Ring Road were significantly larger than the other three categories, followed by the parks outside the Outer Ring Road. The parks within the Outer Ring Road illustrated the rule that a radius of service becomes larger as a park gets closer to the city center. It is probably due to the fact that the area within the Inner Ring Road is the center of employment and public activities in Shanghai, that this area's green space is not only for the surrounding residents, but also attracts a large number of people who come to the central city for work and recreation.

Location	Park ID	Area (ha)	Park Lears -	Euclidean Distance between Parks and Residences (m)			
		nicu (iiu)	Tark Osers	Median	Average	75% Percentiles	
	A1	6.51	2316	12,013.83	8676.62	15,974.19	
	A2	27.12	7054	10,768.42	8169.91	14,968.45	
	A3	6.11	3444	11 292 59	8986 22	15 409 79	
	A4	4.33	1210	10,436.89	8211.55	14,601.86	
	A5	8.94	5856	11,162.02	8765.70	15,360.66	
	A6 A7 A8	$14.36 \\ 6.84 \\ 4.10$	2398 3149 219	10,127.22 12,857.37 10,296,31	7478.55 10,027.90 7788 14	14,017.68 16,866.30 15 194 51	
	A9	2.66	238	11,218.47	7571.09	15,211.23	
	A10	10.85	1006	11,025.10	8604.46	15,144.58	
	A11	6.54	1058	14,078.57	6743.41	10,642.19	
A—Within the Inner Ring	A12 A13 A14	5.01 4.12 11 33	679 754 3100	14,308.48 10,621.11 11,898.53	10,657.90 7888.16 9109.70	18,676.84 14,943.98 15 971 54	
Koad	A15	9.18	4968	13,062.64	10,514.20	17,066.81	
	A16	2.59	170	10,696.39	7642.95	14,298.6	
	A17 A18 A19	3.57 6.58	417 272	10,727.33 12,537.41 11,964.26	9528.37 9227.71	14,001.32 15,465.34 14,142.74	
	A20	16.46	10,743	14,207.67	11422.68	18,696.62	
	A21	4.84	4715	11,497.24	9008.98	16,159.55	
	A22	11.14	46,085	13,434.50	10,885.31	18,013.39	
	A23	19.62	4393	7662.67	4318.30	8778.64	
	A24	5.62	240	10,714.85	6875.57	15,619.51	
	A25	25.32	5687	9110.23	5458.03	11,887.67	
	B1	16.19	6710	10,775.09	8033.95	15,105.71	
	B2	34.67	2400	9730.78	6225.85	13,120.54	
	B2	12.12	294	10,688.11	7174.60	14,786,20	
	B3 B4 B5	13.13 86.08 9.36	4577 948	9178.85 11,739.94	5349.58 8951.92	14,788.20 13,303.87 16,602.25	
B—Between	B6	11.49	714	9770.60	6182.99	13,751.83	
	B7	37.26	598	12,542.56	10,219.01	16,619.43	
	B8	5.01	411	9007.60	6102.50	11,747.76	
the Inner Ring	B9	17.64	607	10,209.93	7313.15	14,453.64	
Road and the	B10	5.04	2552	10,063.03	7050.39	14,745.38	
Middle Ring	B11	8.71	358	11 513 49	7985.68	15 368 75	
Road	B12 B13 B14	6.82 68.76	1493 2388	7945.37 9102.20	4301.11 5882.70	10,898.43 11,953.95	
	B14	0.82	430	9552.27	5860.39	12,413.52	
	B15	13.25	7107	9152.97	5894.94	12,336.23	
	B16	4.96	363	13,956.61	9009.22	18,353.05	
	B17	41.38	14,628	9669.79	5106.69	13,305.82	
	B18	22.78	1643	10,892.47	7050.15	15,314.67	
	B19	12.62	387	10,192.24	6501.20	13,808.12	
	C1	97.60	5025	14,497.82	12,277.51	20,987.18	
	C2	5.00	609	7758.97	4224.45	9350.94	
	C3	6.73	796	9439.07	5413.27	11 390.08	
C—Between the Middle Ring Road	C4 C5	9.38 18.34	345 1044	9475.72 10,355.96 7126.00	4817.23 5620.91	12,498.44 14,038.24 7087.74	
and the Outer	C7	180.71	6292	12,972.72	9282.64	18,646.77	
Ring Road	C8	8.43	570	11,352.41	7343.78	15,471.29	
	C9	12.19	1126	6867.96	3828.68	7783.15	
	C10	42.06	3536	10,807.71	6906.33	14,329.79	
D—Beyond the Outer Ring Road	D1 D2 D3 D4	28.37 190.77 25.44	11,265 300 11,687 2647	12,547.95 8153.71 14,424.55 14,582.45	4591.84 7504.71 10,142.61	18,530.58 9735.92 10,941.26 21,605.54	

 Table 2. Descriptive statistics of Euclidean distance (m) between parks and visitors' residences.

3.1.2. Hotspots of Park Visitors' Residences Calculated by KDE Method

The spatial patterns of actual urban park service areas were observed using a continuous density surface that showed where the visitors were mainly from. We addressed the area and shapes of each park to demonstrate the degree of spatial connection and accumulation among the sampling parks. Figure 4 shows the area of the top 20% tourist density values for each park. For all parks, the hotspot areas varied from 26.59 km² (C6), the smallest, to 461.48 km² (A20), the largest. Generally, parks close to employment centers or with a unifying theme may have larger service areas, such as People's Park (A20) near the Municipal People's Government, Lujiazui Central Park (A22) located in the Pudong CBD, and Shanghai Zoo (C1). For parks in different location categories (Table 3), we observed that the order of service areas was the following: parks within the Inner Ring Road (181.83 km²) > parks beyond the Outer Ring Road (126.12 km²) > parks between the Inner Ring Road and the Middle Ring Road (122.10 km²) > parks between the Middle Ring Road and the Outer Ring Road (119.02 km²). These results showed that citizens were willing to spend more time on the road when visiting parks located downtown or those with natural landscapes.



Figure 4. Spatial distribution of parks with different hotspot areas.

Table 3. The average hotspot areas of park visitors' residences for different categories of parks.

Location	Average Area of Hotspots of Park Visitors' Residences (km ²)
A—Within the Inner Ring Road	181.83
B—Between the Inner Ring Road and the Middle Ring Road	122.10
C—Between the Middle Ring Road and the Outer Ring Road	119.02
D—Beyond the Outer Ring Road	126.12

Regarding the shapes of the park service areas, overall, recreation services were primarily centered around parks with a high density of visitors and delivered outwards into various directions at varying rates of decay. According to this, each park's main service targets were still primarily surrounding residents, although some parks' hotspots presented multi-core or ribbon-shaped patterns. For example, as shown in Figure 5, the service area of Xuhuibinjiang Park (South) (B6) extended along the Huangpu River in the north–south direction for about 10 km, while it had a small east–west axis of influence. The recreation service area of Gucheng Park (A19) exhibited several core areas independent from each other in all directions around the park. Their morphological characteristics most likely differed due to the influences of traffic, facilities, park functions, and community



distributions, so citizens from long distances may have been able to access these parks or may have had a strong desire to visit them.

Figure 5. Hotspots of park visitors' residences calculated by KDE method.

3.2. Time-Cost Decay Analysis and Time Thresholds

In order to better understand how actual traffic conditions influenced the park service areas, travel time estimation was applied to analyze the time–cost decay. Figure 6 shows the results of the probability distribution, with time intervals for all sampling parks, using a box plot. As the time cost increased, the average percentage of visitors initially increased, then dropped inversely once the peak, in the range of 35 to 40 min, was reached. Moreover, the degree of dispersion within this range was also smaller than that of adjacent intervals. Therefore, the preference threshold for park visitors who relied on public transportation and walking was within 40 min.



Figure 6. Probability distribution of park visitors with time intervals.

In addition, we drew the cumulative distribution function for each category based on location, and this indicated that when the travel time to a park within the Middle Ring Road (Figure 7a,b) was greater than about 60 min, the proportion of visitors was less than 5%, and the cumulative service population already exceeded 80%. In other words, citizens were

less inclined to visit a park more than 60 min away. However, the parks in Category C and Category D (Figure 7c,d) showed much greater willingness thresholds, at 76.36 min and 77.03 min, respectively, which illustrated that visitors' time consumption when traveling to destinations located in the urban fringe was higher than other regions due to the imperfection of public transportation and the lack of green space resources. In comparison to other studies which did not use mobile phone data, this study's willingness thresholds were considerably higher, because those studies ignored the fact that people, for diverse reasons, are often willing to go to some parks far away from their homes, as long as multiple convenient transportation options are available.

It is interesting to note that the differences between parks within the same category became more notable with increases in the distance from the city center. The willingness thresholds of parks in Category A ranged from 47.79 min (A16) to 66.19 min (A22), but those in Category C ranged from 46.63 min (C9) to 90.23 min (C3). This may have been because some theme parks located beyond the Middle Ring Road, which target the special needs of visitors, attract tourists from far distances to visit, such as Gongqing Forest Park (C7), while the lack of employment opportunities in some large residential areas outside the Middle Ring Road resulted in some small parks simply attracting nearby residents. The parks within the Middle Ring Road, however, demonstrated little differences, because of their similar target visitors and mixed surrounding functions.



Figure 7. Cumulative distribution of park visitors with time intervals for different categories.

3.3. Spatial Relationship between Park Service Area and Accessibility Based on Time Thresholds

The isochrone maps were superimposed over the core service areas of the parks to determine how geographically similar they were. The efficient public transit network system in Shanghai made areas near metro or bus stations easily accessible, and the isochronous lines appeared to extend along subway lines and important traffic thoroughfares for all parks. In contrast, by simply calculating Euclidean distance and the time-consuming pattern, such results that highlight the effect of public transit points cannot be obtained.

For the parks located within the Middle Ring Road (Category A and Category B), the isochrone maps all showed a radius covering the majority of the central city within 60 min and with a radiation shape (Figure 8 and Appendix A). Generally, the main hotspots of each park corresponded roughly with the residents' 40-min traveling radii, which was consistent with the preference threshold we established. There were also some scattered hotspots within the willingness threshold, and the distribution was the same as the isochronous circle extension. These results indicated that the actual recreation services of the urban parks were significantly spatially influenced by transportation accessibility by public transit, which was concentrated within the preference thresholds, and then shrank within the willingness thresholds, hardly exceeding these.

There was, however, an obvious distinction between parks located at the three segmentations of the city that are separated by the Huangpu River and Suzhou River. Although the high accessibility areas were beyond the natural hindrance of the river due to the modern traffic network, the areas governed by the park services were almost exclusively in the interior of the geographic areas in which they were located. As an example, although a range of accessible areas within the 40-min traveling circle extended to the east side of the Huangpu River and the south side of the Suzhou River, the actual park service area of Heping Park (A23) was still limited in the north bank of the Suzhou River, hardly attracting visitors from the other two banks. However, the parks located in the city's Central Activity Zone (A14, A15, A20, A22) still had wide service areas serving most residents in the research area, since they could receive a high number of people visiting from long distances for public activities rather than for daily leisure. According to this result, the Central Activity Zone has already inherited the function of providing the city's essential public services.

The parks in Category C and Category D appeared on the isochrone maps as ribbonshaped areas of high accessibility, radiating in the direction of the subway lines to the city center. Compared with the first two categories, there was a considerable reduction in the areas of high accessibility spaces. Similar to the pattern of willingness thresholds, the differences in the same group were expanded. The actual service areas of some parks were much smaller than the potential ones, based on the preference thresholds, while others formed much larger main hotspots or a new core beyond the willingness thresholds. There were at least two reasons for this substantial difference: (1) from the perspective of internal factors, the service areas of some comprehensive theme parks outside the Middle Ring Road, such as Shanghai Zoo (C1), were often larger than those of the community parks; (2) from the perspective of citizens' demands, visitors from some residential areas outside the Middle Ring Road had no choice but to spend more time seeking park recreation services due to their local areas' lack of green space resources and high population densities.



Figure 8. Comparative analysis between park service area and accessibility (Category A).

4. Discussion

4.1. Travel Distance and Time Thresholds of Park Service

In previous research, it has been shown that proximity to public service facilities is usually measured in terms of travel time or travel distance, and that there is an acceptable cost beyond which citizens may be unwilling to travel to reach a given facility [55,56]. In line with research in China [13,19], this study found that urban parks in Shanghai have a much larger service radii than those prescribed in existing planning guidelines for green spaces. Such a pattern might be attributed to the convenience of public transportation and the diversity of citizens' demands for recreation services. However, the results appeared to suggest that the locations of parks, rather than their areas, had a greater effect on the differences in median distances between parks and residences, a finding which may not be in accordance with existing research and guidelines [37,57]. Generally, visitors of urban parks within the Inner Ring road lived farther from the park than visitors of parks outside the Inner Ring Road. This might be attributed to the high population density in the central area and its great walkability. Meanwhile, because of the homogenization of the designs of different-sized parks, the recreation service quality of larger parks was not much better than that of smaller ones, which made the former ineffective at attracting users who lived further away. Therefore, a recommendation for planning would be to increase the amount of small multi-functional green spaces in the high-density, urban, built-up area as opposed to establishing huge urban parks with ordinary designs in the suburbs. This may allow a city to conserve scarce urban land and at the same time provide a better allocation of natural resources to its citizens.

Some studies have confirmed that citizens' actual routes and time consumption were more meaningful than Euclidean distance, and high travel costs may diminish residents' desire to visit parks [39,45]. Interestingly, we found that residents' usage patterns of the different parks were relatively consistent from the perspective of travel time consumption. Citizens' real-time behavior towards recreation in parks was most favorable within 40 min of their residences, and the frequency significantly declined beyond 60 min for parks within the Middle Ring Road and after about 75 min for the other parks. Although the traffic location conditions and functional themes among parks were different, this threshold showed strong consistency with small differentiation. The figure indicated that, through public transit, people can access public urban parks within a much more acceptable time, compared to the 15-min community life circle put forward in the latest Urban Master Plan (2017–2035), which was calculated by walking. Such guidelines may be more suitable for medium-sized cities with smaller built-up areas rather than metropolises where residents rely more on public transportation for travel [58]. For a metropolis such as Shanghai with a great number of citizens and a mass transit system, it may be possible to ameliorate the current imbalance between supply and demand for parks and green spaces by improving public transportation in high-density areas, especially for socioeconomically disadvantaged districts which may face social inequalities of park accessibility [11].

We further compared tolerance time thresholds for visiting parks with some research based on questionnaires [11,42], and found that the average actual travel time in Shanghai was larger than that reported in the latter, which was about 20–25 min for public transport. There seems to be, then, an inconsistency between subjective intentions and actual travel activities. Though the questionnaires in those prior studies were specifically designed to evaluate residents' tolerance time for independent travel to urban parks without incidental recreational behavior when working or shopping, which may underestimate the actual distances between residences and park destinations, this result still indicated that highquality parks were not distributed in a way that offered residents recreational options that were convenient enough. As mentioned earlier, since there were insufficient urban parks in Shanghai, residents might have had no choice but to spend more time at those parks, which was another reason for the longer time thresholds [16]. Communities' spending more time on trips to parks may not necessarily mean they have longer tolerance times than others, but rather that the insufficient supply of parks and green space in these areas causes residents to spend more time on travel. Thus, it is important for urban planners to keep in mind that longer actual time thresholds do not necessarily imply longer travel distances for citizens to reach recreation services. Different travel time thresholds among different neighborhoods can identify the regions with severe supply and demand imbalances, providing urban planners with strategies to optimize urban parks for the needs of these neighborhoods.

4.2. Relationship between the Park Service Areas and Potential Accessibility

The shape of a park service area can also be an indicator of external characteristics such as the land use and infrastructure around the park [37]. The results indicated that recreational services distributed in different directions with varying rates of decay, and parks adjacent to employment centers or those with multifaceted functions were found to have larger service areas. Thus, the surrounding vitality of citizens' activities and mixed land use might increase the visiting frequencies of parks located in the central city. For example, Guan et al. suggested that the activities of employees in the commercial district who may use green parks during the daytime for a break were ignored by the guidelines in park planning [31]. Based on our findings, we suggest that visitor groups and random travel behavior should be considered in landscape planning and design. It would be noteworthy to further determine the park visitors whose workplaces are nearby, instead of simply identifying their residences.

Furthermore, traffic convenience, as has been suggested in previous studies [9,59,60], was found to have a significant influence on park service areas. This demonstrated that citizens may be willing to go to parks far away if the time required for traveling is within the accessibility thresholds, as long as public transportation is readily available. The accessibility evaluation of public green space has been widely used to formulate urban planning strategies for planners, scholars, and administrators of cities [19,36]. Compared to other studies, we proposed a new method using a web map service to explore accessibility thresholds based on time consumption. This method took into account the actual patterns of citizens' self-movements and the influence of public transit, thus improving the accuracy of delineating park-based accessibility. As shown in the isochrone maps above, the potential accessibility calculated by time consumption, which included public transit and actual transportation conditions, was strongly correlated with the distribution of metro stations. Thus, a station-centered spatial distribution of high accessibility to urban parks was observed, which suggested that transit-oriented green space may significantly improve use efficiency and vitality.

Interestingly, our results revealed that apart from the actual time costs, natural hindrances such as the Huangpu River and Suzhou River tended to shape the park service areas, and that the distribution of visitors was sharply distinct between those on opposite sides of the rivers. A similar phenomenon was also observed by Zhang et al. and Ding et al., who both found that commuting flows of job-housing in Shanghai were split into two large clusters across the Huangpu River [50,61]. In their research, it was be attributed to the inconvenience of routes crossing the river traditionally due to the lack of methods to calculate the actual travel time. While we have found that, in spite of the similar time consumption for reaching the parks on either bank, citizens still showed little interest in visiting the park on the side opposite to them. According to some studies on tourists' destination choices [62,63], cognitive distance estimates, which were obviously different from real distances, may have had a significant impact on citizens' preferred destinations, which were spatially clustered. Citizens may overestimate the travel time to parks located on the other sides of the rivers in Shanghai and may then decrease their willingness to use recreation services from specific parks.

4.3. Limitations and Future Research

While the application of mobile phone data and web map services improved our understanding of the park service areas used for measuring accessibility, the limitations that can be addressed in future studies are the following. First, mobile signaling data in the present study were gathered during just one week, and these were used to calculate an average value for the overall situation. Thus, these data cannot be compared across multiple days, making it hard to accurately represent conditions over weekends or during large public festivals in which citizens are more willing to visit distant parks because of their time away from work. Future research should conduct a comparative analysis among multiple days and illustrate the differences in visitors' distribution patterns in order to explore the inherent complexity of spatial-temporal features. Second, park features such as water areas, park facilities, aesthetics, and differences in surrounding services that may influence the attraction of parks [30] were not considered in this study. Future studies should take into consideration other major factors and park attributes that affect the usage of public green spaces when comprehensively analyzing the service areas of urban parks. Third, due to the characteristics of the data involved in our research, we had to omit some selected sample parks and actual users of the parks. On the one hand, we ignored a great number of community-level green spaces whose areas were smaller than the coverage of the mobile base stations, even though they provided daily outdoor entertainment activities within walking distance for residents. On the other hand, the visitors who lived around the parks may have been excluded because they lived within the same base stations for the parks. Even if they were not within the service range of the same base station, their time consumption could have been sometimes overestimated because some walking and cycling paths may not have been recorded by the web maps. In the future, we will have to place more emphasis on the service efficiency of small community green spaces in residents' daily lives.

Nevertheless, using the web map APIs and mobile signaling data, our study could be very useful for future urban studies research, even for areas beyond that studied herein. This research frame could be widely applied in measuring the service areas of other facilities or urban functional areas. It may be possible, for example, to identify the hierarchical structure of different urban functional areas by studying the distribution of citizens during public activities and their time consumption. This may help guide planning that aims to meet residents' demands.

5. Conclusions

By combining mobile phone signaling data with web map services, this study identified park users and their residences and estimated their travel times in order to investigate their behavior patterns when visiting urban parks. The results indicated that the urban parks studied had much larger service radii than those identified in existing planning guidelines and research. On average, the parks located in the Inner Ring Road, which is the business center of the whole city, had the largest park service areas and attracted more visitors than any others. Furthermore, based on time–decay analysis, our study highlighted that the preference time threshold for reaching urban parks was about 40 min, and if the travel time to the parks within the Middle Ring Road was greater than about 60 min, citizens would be unwilling to travel to these distant parks. Meanwhile, it was proven that the shapes of park service areas were consistent with the regions with high accessibility values calculated by time consumption thresholds, and the metro lines were found to greatly influence the distribution of hotspots of visitors' residences. Interestingly, in spite of the actual traffic convenience, the park service areas still represented spatial clustering because of the impact of natural segregation.

For researchers, this study sheds light on an improved method of exploring citizens' actual behavior, from the perspective of time consumption, using multiple sources of big data. It minimized the error when measuring the park service areas and accessibility, and it can be further adapted to explore the distribution of other urban public facilities. Furthermore, the findings may assist city planners and policymakers to develop urban park systems within dense urban areas that are more efficient, without wasting land.

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Appendix A



Figure A1. Comparative analysis between park service area and accessibility (Category B).







Figure A3. Comparative analysis between park service area and accessibility (Category D).

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