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2025 Volume 3, Issue 7
Contemporary Education Frontiers
ISSN (Online): 3029-1860 ISSN (Print): 3029-1879

An Empirical Study on the Characteristics of the Number of Bicycles Parked on Blind Paths in Beijing and the Optimization of Urban Road Distribution Based on Mathematical Models

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Abstract: To address the issue of the lack of protection of the rights of visually impaired people due to the occupation of blind paths by shared bikes in Beijing, this study, based on spatial analysis and mathematical modeling methods, integrates multi-source data to explore the spatio-temporal characteristics and distribution patterns of bike parking on blind paths. Through comparative analysis of different areas such as the core area, suburbs, and areas around subway stations, the spatial differences and key influencing factors of the occupancy rate of blind paths were identified, and a three-dimensional optimization model of "demand-facility-policy" was constructed. The study found that the occupancy rate of blind paths within 1 km of metro hubs and CBDS was recorded 47–62% higher than in other areas, and the rate of illegal parking in areas covered by electronic fences decreased by more than 80%. Based on the empirical results, a road optimization plan of "zoned control + technology empowerment + supply and demand matching" is proposed to provide theoretical support and practical paths for balancing barrier-free access and the development of shared bikes.

Keywords: Road space optimization; Government-enterprise collaborative governance; Barrier-free access guarantee

Online publication: August 26, 2025

1. Introduction

1.1. Research background

Blind paths, as a core component of urban accessibility facilities, are the "lifeline" for safeguarding the travel rights of visually impaired people. Since the implementation of the Law on the Construction of Barrier-Free Environment, the coverage rate of blind paths in Beijing has reached a relatively high level, with the coverage rate of blind paths on main and secondary roads in the core area reaching 98% [1].

However, with the popularization of shared bikes, although the "last mile" travel problem has been solved, the problem of random parking has not been completely solved, and the occupation of blind paths has become a common occurrence - the occupancy rate of blind paths at stations such as Qianmen Subway Station and Huixin West Street South Entrance Station often reaches 100%, which seriously neglects and threatens the safety of the visually impaired.

Current research has mostly focused on a single dimension, either on the standardization of the blind path facilities themselves, or on the optimization of shared bike scheduling, lacking a systematic empirical analysis of the spatial conflict between the two [2].

This study quantifies conflict features through mathematical modeling, providing a new perspective for the refined allocation of urban road space resources, with dual values of social equity guarantee and traffic efficiency improvement.

1.2. Subjects and scope of study

Focusing on the spatial relationship and management system of blind paths and shared bikes within the Beijing metropolitan area, it covers the functional areas of six major urban districts (Dongcheng, Xicheng, Chaoyang, Haidian, Fengtai, Shijingshan). A range of 500 meters around 42 key subway stations (such as Xizhimen Station and Qingnian Road Station) and 1km around core business districts such as Wangfujing CBD and Financial Street, covering high-density office and commercial POI clusters. Daily data for typical quarters of 2024 (March to May, September to November) were also selected to focus on the differences in parking during peak hours (7:00–9:00, 17:00–19:00) and off-peak hours, in line with the need to track trends in the occupancy rate and complaint rate of the blind path, taking into account both the typicality of the problem and regional differences.

1.3. Research methods and data sources

A combined approach of data research and modeling was adopted: New vehicle and usage data were obtained through publicly available government data and census data of blind path facilities from the Chinese Academy of Sciences and Beijing University of Civil Engineering and Architecture; real data were obtained by measuring occupancy rates at 42 key subway stations in different time periods from 2023 to 2025 and by analyzing parking volume and illegal parking rates in governance cases such as Songjiazhuang Hub and Jiuxianqiao Sub-district. Use Excel and Python Scikit-learn to organize the data and build a model quantified by the distribution trend factor.

2. Distribution data of shared bikes and blind paths

2.1. Data on the distribution of blind paths

According to **Figure 1**, the distribution of blind paths in Beijing shows a significant gradient of urban functions, forming a decreasing pattern of "core - near suburbs - far suburbs", which is highly matched with the regional population density and the concentration of core functions. This difference is in line with the orientation of "Priority for barrier-free access in the core area" in urban planning and is highly matched with the regional population density and the concentration of core functions.

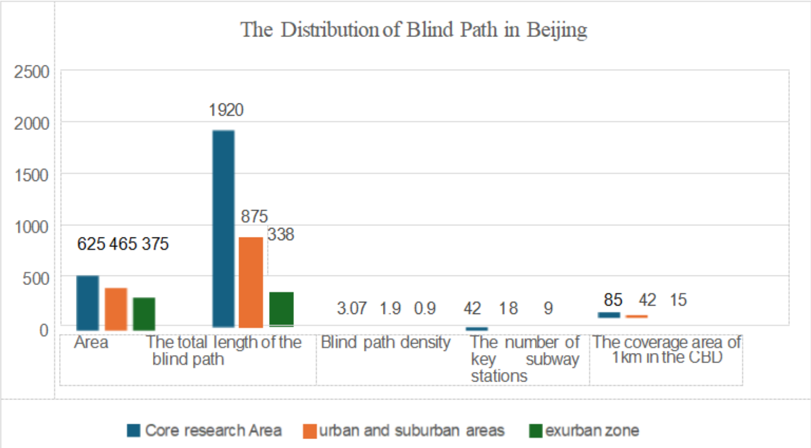

Figure 1. The distribution of blind path in Beijing.

2.2. Shared bike distribution data

There is a total of three operating enterprises in the city (Meituan, Hellobike, and Didi Qiguo). In 2024, the cumulative number of rides throughout the year reached 1.144 billion, with an average daily riding volume of 3.1258 million, representing a year-on-year growth of 5.12%. In 2024, the average daily turnover rate of vehicles was 3.31 times, with an average daily operation and maintenance force of 2,791 people and an average daily vehicle dispatch of 177,000 times.

3. Distribution trends

3.1. Time dimension

3.1.1. Intraday fluctuations

Two peaks are formed during the morning rush hour (7:00–9:00) and the evening rush hour (17:00–19:00), and the occupancy rate of the blind path is 3–4 times higher during the peak period than during the off-peak period. Take Songjiazhuang subway station as an example. During the morning rush hour, there are more than 1,400 bicycles parked around the blind path, and more than 30% of them occupy the space of the blind path [3].

3.1.2. Annual changes

Over the past five years, the problem of occupation of the blind path has shown a trend of "first worsening and then improving". From 2019 to 2022, the proportion of unpressurized blind paths in the core area dropped from 78% to 65% due to the surge in the number of bicycles deployed [4]. After 2023, with the promotion of electronic fence technology and the launch of the "100-day Campaign", the proportion of unpacked bikes rebounded to 72%, and the number of complaints dropped by 23.9%.

3.2. Spatial dimensions

3.2.1. Circle distribution

With CBD as the core, it presents a "dense core-decreasing periphery" circle structure. The average occupancy rate of the blind path within 1 km of the CBD was 58%, dropped to 32% within 1–3 km, and was less than 15% beyond 3 km, confirming the significant impact of commercial activity intensity on parking behavior [5].

3.2.2. Node aggregation

High-value clusters formed around transportation hubs and public service facilities. Within 500 meters of 42 key subway stations, the occupancy rate of blind paths is 62% higher than that in non-node areas, with the most prominent problem being at hub points such as Songjiazhuang Station and Xizhimen Station where the three rail lines converge.

3.2.3. Regional differences

The occupancy rate of blind paths in the core areas (Dongcheng and Xicheng) (47%) is significantly higher than that in the suburbs (Tongzhou and Daxing) (18%), but the combined problem of "dead-end" and occupation of blind paths in the suburbs is more prominent.

4. Overview of the differences and reasons

4.1. Regional parking differences

Table 1. Regional parking differences

Comparison dimensions	Core area	Suburban areas (Tongzhou, etc.)	Far suburbs (DaxingHuangcun, etc.)
Blind path density km/km^2 3.2		1.8	0.9
Occupancy rate of blind paths at subway entrances (%)	68	41	23
Frequency of illegal parking within 1 km of CBD	12.3 times per day	5.7 times a day	2.1 times a day
Electronic fence coverage (%)	92	65	38
Response time (minutes)	15–30	30–60	60–90

4.2. Analysis of key causes of regional parking differences

4.2.1. Imbalance between supply and demand

The parking space gap around the subway entrances in the core area is 40–60%, and the seven exits of Songjiazhuang Station can only meet 50% of the parking demand, causing users to "squeeze in" the blind paths [6]. While there is ample space in the suburbs, there is both insufficient and uneven distribution of bicycles, which leads to illegal parking in some areas.

4.2.2. Location and function differences

The core area is densely populated with commercial and office POIs, with an average daily footflow of 30,000 to 50,000 people. The shared bike turnover rate is 2.8 times that of the suburbs, and the short- term parking pressure far exceeds the carrying capacity of the facilities. Hospitals, scenic spots and other locations have peak occupancy periods due to concentrated dwell times [7].

4.2.3. Policy implementation gradient

More than 90% of key locations in the core area have been covered by electronic fences, and illegal parking will face non-lock-up and joint disciplinary actions; In the suburbs, the coverage rate offences is less than 40%, and the human operation and maintenance force is weak, resulting in the weakening of policy binding force.

4.2.4. Facility planning flaws

The blind paths in some areas are unreasonably designed (e.g., the blind path at Heping West Bridge subway station turns 6 times every 5 meters), which overlaps with the parking demand area and poses an inherent conflict risk; The lack of connection between the new and old urban blind paths further exacerbates the parking chaos.

5. Discussion and suggestions

5.1. Core findings

5.1.1. Effectiveness of technical means

Electronic fence systems play a decisive role in regulating parking. After the implementation offence management in Jiuxianqiao Sub-district, the occupancy rate of blind paths dropped from 67% to 12%; Songjiazhuang Hub has achieved a fundamental improvement in the problem of random parking through the "fence + sniffing + operation and maintenance linkage" model, confirming that technology empowerment is the core path to conflict mitigation.

5.1.2. Significance of impact factors

Geodetector analysis shows that the number of residential POIs (explanatory power $q = 0.68$), distance from subway stations ($q = 0.62$), and coverage of electronic fences ($q = 0.57$) are the three dominant factors affecting the occupancy rate of blind paths, consistent with the research conclusion of the Institute of Geography of the Chinese Academy of Sciences on the characteristics of shared single vehicle sources [8].

5.1.3. The significance of policy coordination

The "100-day Campaign" of the Municipal Commission of Transport and the implementation of enterprise operation and maintenance responsibilities have formed a synergy, achieving a favorable situation where "the number of rides increased by 3.84% while the number of complaints decreased by 23.9%", indicating that single governance is difficult to be effective and a multi-subject coordination mechanism needs to be established [9].

5.2. Future urban spatial planning optimization scheme

5.2.1. Zoned and classified layout of parking spaces

Within 1 km of the CBD in the core area, adopt the "densified electronic fence + three-dimensional parking" model, referring to the experience of Tiantan East Gate Station, add one dedicated parking area every 50 meters, with capacity configured 1.2 times the peak demand [10]. In the suburbs, the "dispersed layout + shared parking space" model is adopted, and tidal parking spaces are set up in the idle spaces of residential areas and commercial complexes.

5.2.2. Separation of blind paths from parking spaces

Re-plan blind path routes to avoid high-frequency parking areas such as subway entrances and shopping mall entrances [11]. For built sections, a rigid protective boundary is formed by physical isolation measures such as adding barrier posts and raising the edge of the blind path [12,13].

5.2.3. Special design for hub nodes

For a three-rail junction hub like Songjiazhuang, a "bicycle parking area at the station exit" is planned to be setup, with multiple bicycle racks 3 meters away from the blind path and an operation and maintenance dispatch center for real-time dredging.

5.2.4. Technology in coordination with parking control

Promote the "Bluetooth Road studs + high-altitude sniffing" system, and implement non-lock-up, charging and credit punishment mechanisms for parking in no-parking zones.

5.2.5. Reward system to stimulate public participation

Promote the "clearing illegal parking for cycling vouchers" mechanism and setup a "barrier-free supervision" mini-program to receive citizens' reports.

5.3. Limitations of research

5.3.1. Data availability constraints

There is a lack of continuous monitoring data on blind path parking across the city. Existing analyses rely on typical site surveys and historical data inferences, making it difficult to achieve refined spatio-temporal modeling. The publicly available Mobike data only covers a short-term sample from 2017 and does not reflect the policy impact in recent years.

5.3.2. Model simplification

Quantification of commuting demand uses an average assumption of "40 km/day", without considering travel differences among different occupations and age groups; The influence of random factors such as weather and holidays on parking behavior was not included [14,15].

5.3.3. Insufficient scheme validation

The optimization proposals are based on the generalization of existing cases and model deduction, lacking empirical tests from large-scale pilot projects, and their suitability in different regions needs further validation.

Disclosure statement

The author declares no conflict of interest.

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