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Shared Management of Non-Motorized Vehicles at Yangzhuang Station: An Analysis Based on Spatial Optimization and Collaborative Governance during Peak Hours

CAI Bingjie, LIU Yuxi, LI Yijia, MA Xiangyu, LIU Zihan

(College of Architecture and Art, North China University of Technology, Beijing 100144, China)

Abstract With the expansion of urban rail transit networks, subways have become the primary mode of commuting for residents, leading to a growing demand for non-motorized vehicle connections during the "last mile". This study focuses on Yangzhuang Station in Shijingshan District of Beijing, analyzing the distribution of non-motorized vehicle parking spaces in the station's forecourt, the management mechanisms in place, and user behavior patterns. Research indicates that during peak hours, the number of non-motorized vehicles is substantial, their parking spaces are dispersed, and the parking order is disorganized. The existing model, which combines "enterprise dispatching with community supervision", faces challenges in achieving comprehensive coverage and dynamic management. Based on this analysis, three strategies are proposed: utilizing green and underused spaces, implementing intelligent parking guidance systems, and optimizing management mechanisms. These approaches aim to enhance the spatial capacity of the station's forecourt, standardize parking practices, and promote low-carbon travel. The findings of this study offer valuable references and practical insights for the management of non-motorized vehicles at comparable subway stations.

Keywords Subway station, Forecourt, Non-motorized vehicle, Shared bike, Low-carbon travel

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With the enhancement of urban transportation networks, subways have become the primary mode of commuting for residents, leading to a rapid increase in demand for non-motorized vehicle connections during the "last mile". The policies promoted by China, including "one station, one policy" and "refined governance", prioritize the development of a safe and orderly parking system surrounding subway stations. The *Beijing Urban Master Plan (2016–2035)* aims to enhance the integration between the slow traffic system and rail transit, thereby encouraging green travel. Similarly, the *Shijingshan District Zoning Plan (2017–2035)* explicitly mandates the optimization of slow traffic facilities around subway stations and the improvement of transportation space quality. In recent years, significant deficiencies have been observed in the scale and planning quality of non-motorized vehicle parking facilities. These deficiencies are characterized by inadequate space and infrastructure, suboptimal site selection, insufficient safety measures, and limited user convenience. Consequently, the rational allocation of non-motorized vehicle parking facilities within constrained spaces, the improvement of management efficiency, and the assurance of travel safety have emerged as pressing issues in urban traffic management[1].

Yangzhuang Station serves as a critical transfer hub in the western region of Beijing, facilitating transportation between the central urban area and the suburbs. Following the inauguration of Line 6 and Line 11, regional travel demand has escalated markedly, resulting in a substantial increase in the demand for non-motorized vehicle parking facilities. Although an "enterprise dispatching and community supervision" management model has been established, challenges such as spatial congestion and disorder during peak hours persist. Achieving dynamic adjustment and optimized co-governance within limited spatial constraints has become a critical issue for implementing the principles of comprehensive urban planning and improving the travel experience of residents.

The contradiction between the rising demand for "last mile" connectivity near subway stations and the insufficient provision and outdated management of non-motorized vehicle parking facilities has become increasingly evident. In recent years, bicycle travel has encountered challenges including limited space and facilities, suboptimal site selection, safety concerns, and user inconvenience[2]. The *Interpretation of the 2023 Annual Statistics and Analysis Report on Urban Rail Transit* indicates a continuous increase in travel demand surrounding subway stations, accompanied by substantial pressure on non-motorized vehicle parking during peak hours[3]. Consequently, investigating the management and spatial optimization of non-motorized vehicles in the forecourt of subway stations is essential. Such research can enhance orderliness and travel efficiency at station entrances, while also facilitating the development of a novel collaborative governance model between shared bicycles and rail transit. This approach offers valuable insights for promoting green, low-carbon travel and supporting the sustainable development of urban transportation.

This study focuses on Yangzhuang Station, located in Shijingshan District of Beijing, as the primary research subject. The scope of the research encompasses the land within an approximate 200 m walking radius surrounding the station's four entrances and exits. This includes the travel node of the residential area near the northwest entrance, the intersection connecting the main road and commercial street at the northeast entrance, the living space adjacent to the community green space at the southwest entrance, and the transfer area leading to the bus terminal at the southeast entrance (Fig.1). This study examines the distribution characteristics, facility utilization, and order variations of non-motorized vehicle parking under different spatial configurations of entrances and exits. The research primarily encompasses three aspects: first, conducting on-site observations and data collection to document changes in supply volume and order status during peak and off-peak periods; second, analyzing the operational mechanisms and challenges associated with the current "enterprise dispatching and community supervision" model; and third, based on the connectivity requirements

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between subway transfers and the slow traffic system, proposing spatial governance strategies tailored to local conditions. Through a comprehensive analysis of the multiple exit scenarios at Yangzhuang Station, this study aims to identify common challenges and optimization strategies in the management of non-motorized vehicles surrounding urban subway stations. Furthermore, it seeks to offer replicable experiences and insights for the governance of non-motorized vehicles at subway stations in Beijing and comparable urban contexts.

1 Analysis of the current situation of Yangzhuang Station

1.1 Parking volume and spatial pressure

The vicinity of Yangzhuang Station is predominantly residential, while Pingguoyuan Station has not yet been fully operational. This situation has resulted in a substantial increase in the demand for non-motorized vehicle parking at the station. On-site observations indicate that the number of non-motorized vehicles during the morning peak hour is approximately 1,500, decreasing to about 1,000 during the evening peak hour. The absence of large centralized parking lots capable of accommodating vehicles results in their dispersion along the roads in front of the station, auxiliary roads, and sidewalks. This encroachment on motor vehicle lanes and pedestrian pathways leads to widespread, dispersed parking. Such spatial constraints not only reduce traffic efficiency but also elevate the risk of conflicts between pedestrians and cyclists during peak hours.

1.2 Governance mechanism and order status

To alleviate congestion during peak hours, bike-sharing companies and community managers have deployed personnel to collect and relocate bicycles during the morning and evening rush periods, while community volunteers offer on-site guidance. Although these governance measures have partially standardized parking order, the absence of a unified, large-scale parking area near the station results in bicycles being dispersed across multiple locations, thereby complicating comprehensive management coverage. At certain entrances, exits, and auxiliary areas, there is an absence of clear parking and directional signage. The pathways for cyclists and pedestrians often intersect, resulting in localized disorder and safety risks. This issue is especially pronounced during peak hours. The existing management approach predominantly depends on empirical scheduling and manual guidance, lacking a systematic design framework and adaptable regulatory mechanisms.

1.3 Potential problems and peak risks

Despite the implementation of current dispatching and guidance measures, the number of non-motorized vehicles parked during peak hours continues to exceed the management capacity, resulting in prominent challenges. The spatial load-bearing pressure is substantial, and instantaneous accumulation can obstruct entrances, exits, and pedestrian pathways. Dispersed parking patterns cause frequent intersections between cycling and pedestrian routes, thereby increasing the likelihood of traffic conflicts. Governance responses are delayed, and both manual and enterprise scheduling efforts struggle to provide comprehensive coverage, leading to significant management gaps during peak periods. In the absence of systematic flexible space design and intelligent control measures, excessive parking of non-motorized vehicles may become prevalent. This situation not only diminishes the travel experience of residents but also escalates urban management costs, thereby exerting ongoing pressure on environmental order and traffic safety in the forecourt of subway stations.

At Yangzhuang Station, three primary issues characterize the parking of non-motorized vehicles during peak hours: excessive quantity, dispersed spatial distribution, and disorderly arrangement. Although current measures, including enterprise dispatching and community guidance, alleviate some pressure, achieving comprehensive coverage and dynamic management remains challenging. To address these structural and peak-time conflicts, it is imperative to develop more targeted solutions by optimizing spatial layout, flow line design, and multi-party collaborative governance. Such interventions aim to enhance the capacity and operational efficiency of the station's forecourt and provide a foundation for subsequent strategic planning.

2 Design strategy: spatial optimization and co-governance model

In response to the challenges of excessive parking demand, dispersed spatial arrangement, and disorderly management of non-motorized vehicles during peak hours at Yangzhuang Station, three optimization strategies are proposed to improve the forecourt's capacity and management efficiency.

2.1 Utilizing green and underused spaces

During the morning peak hour, approximately 1,500 non-motorized vehicles are present around Yangzhuang Station, while the evening peak hour sees about 1,000 such vehicles. However, the existing standardized parking spaces

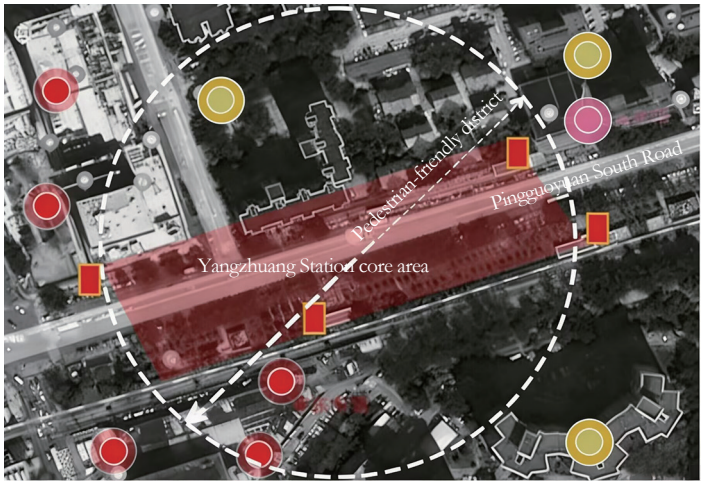

Fig.1 Research area near Yangzhuang Station

Fig.2 Temporarily available green spaces around Yangzhuang Station

number only between 800 and 900, resulting in a structural deficit exceeding 600 spaces during peak periods. To mitigate the issue of concentrated overflow during these times, a precise calculation was conducted to determine the temporarily available green spaces within the four areas of the station. The respective areas of these green spaces are 2,500, 1,100, 2,640, and 925 m^2, amounting to a total of 7,165 m^2(Fig.2).

In light of the need to preserve green spaces and the flexibility required for peak demand adjustments, the parking capacity of green spaces was calculated using three different ratios: 30% (conservative), 50% (recommended), and 70% (emergency). The capacity estimates were based on three commonly applied standards for shared bicycle land occupation: compact (1.2 m^2/vehicle), standard (1.5 m^2/vehicle), and including passageways (2.0 m^2/vehicle) (Table 1).

Calculations indicate that, even under the most conservative model of 30% available and 2.0 m^2/vehicle, four green spaces can sustainably accommodate 1,074 parking spaces. Under the recommended scene of 50% available and 1.5 m^2/vehicle, an additional 2,388 parking spaces can be provided. This capacity fully meets the demand of 1,500 vehicles during the morning peak hour, offers a sufficient buffer, and significantly exceeds the demand of 1,000 vehicles during the evening peak hour. The capacity configuration of the four green spaces at Yangzhuang Station facilitates the implementation of a dynamic regulation system characterized by "elastic expansion during peak hours and restoration during off-peak periods". Specifically, during morning and evening rush hours, the green space parking area can be utilized as a temporary centralized parking facility. Conversely, during off-peak hours, it reverts to its original function as a public green space, thereby maintaining its daily landscape and recreational activities.

Regarding the activation time mechanism, it is advisable to implement a dual-track system comprising "peak-hour timed activation and a saturation trigger". Specifically, the regular activation periods should correspond to the morning rush hour from 07:00 to 09:30 and the evening rush hour from 17:00 to 19:30. Concurrently, the saturation level of the main parking area should be established between 80% and 85% to serve as a dynamic trigger threshold. When the primary parking area reaches the threshold, the enterprise will coordinate with local sub-districts and communities to activate temporary parking zones. Users will be directed to available spaces via LED signage, temporary guiding lines, and App push notifications. Vehicles will be removed, and temporary facilities dismantled within 20–60 min after the peak period concludes, facilitating the prompt restoration of green spaces.

Through a systematic quantitative analysis of four green spaces and the development of a time-based management model[4], this strategy proposes the establishment of a non-motorized vehicle parking system in the forecourt of subway stations that is "expandable, detachable, and highly adaptable", without permanently occupying green spaces. This approach not only significantly enhances the peak carrying capacity of Yangzhuang Station but also considers the long-term maintenance of urban refined management and the quality of public spaces.

2.2 Implementing intelligent parking guidance systems

To mitigate the issues of disorderly parking and local congestion resulting from the concentrated influx of non-motorized vehicles during peak hours, it is essential to implement an intelligent parking guidance system at Yangzhuang Station, utilizing real-time data. This system depends on data provided by shared bicycle enterprises, including vehicle positioning, area occupancy rates, and inflow and outflow volumes. It dynamically assesses the usage status of each parking area with an update interval ranging from 1 to 5 min and establishes a congestion warning threshold between 80% and 85%. When the primary parking area nears full capacity, the system will automatically activate the guidance mechanism. Real-time information regarding the number of available parking spaces, their locations, and walking distances will be displayed through LED information boards at the station entrance and along the main cycling flow routes, as well as via saturation warning lights and ground guidance markings, thereby directing cyclists to divert promptly (Fig.3). For temporarily designated green space parking areas, QR code prompt signs may be installed at the entrance, enabling users to scan and access information about remaining parking spaces and guided routes. This approach further mitigates instances of cyclists lingering and parking indiscriminately near the station entrance.

The shared bike App facilitates interaction between the user and dispatching ends by recommending designated parking areas when users approach within approximately 100 m of a station entrance. If the primary parking area is at capacity, the App offers navigational guidance to alternative parking locations. Additionally, small incentives, such as points or mileage rewards, may be provided to encourage users to comply with proper parking protocols. Enterprise dispatchers are required to respond promptly to system prompts. Upon identifying persistent congestion in a specific area, they must implement local traffic diversion and vehicle coordination within 10-15 min. While temporary parking spaces are in use, patrols should be conducted every 15-30 min, and vehicles should be retrieved, with facilities removed promptly after peak hours. The closed-loop mechanism, established through data monitoring, on-site guidance, user prompts, and dispatch patrols, significantly enhances parking order. This approach facilitates a transition from manual management to a real-time regulatory management model and effectively integrates with the flexible parking space strategy of green spaces[5].

2.3 Enhancing the connectivity of slow traffic systems

Currently, the management of non-motorized vehicles at Yangzhuang Station primarily depends on the temporary cooperation between enterprise dispatchers and community volunteers. This approach lacks a unified organizational framework and a fixed division of labor, often resulting in issues such as insufficient management and delayed responses in various areas during peak hours. Therefore, it is imperative to establish a straightforward and well-defined "collaborative management mechanism" at the sub-district level, ensuring that enterprises, sub-district

Table 1 Calculation of parking space capacity under different available ratios in four green spaces

Scene	Available area m^2	Compact vehicle	Standard vehicle	Including passageways vehicle
30% Available	2,149.5	1,791	1,433	1,074
50% Available (recommended)	3,582.5	2,985	2,388	1,791
70% Available (emergency)	5,015.5	4,179	3,343	2,507

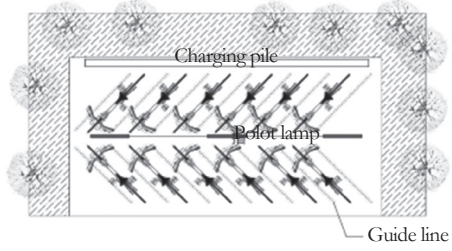

Fig.3 Intelligent parking schematic diagram

authorities, communities, and urban management officers clearly understand their respective responsibilities. For instance, the sub-district authority is responsible for overall coordination and the activation of temporary parking spaces. The enterprise is tasked with data provision, vehicle sorting, and recycling. The community oversees maintaining order at entrances and exits. The urban management officer supervises and addresses issues related to improperly parked vehicles. This division of responsibilities helps mitigate problems arising from inconsistent information and untimely responses, enabling all parties to operate in accordance with established procedures during peak hours.

In practical operations, it is advisable to establish a "standardized response protocol for peak hours" to facilitate rapid coordination among all parties. When the primary parking area approaches capacity (typically between 80% and 85% occupancy), the enterprise's data system should prompt the activation of a temporary parking area. The enterprise dispatcher is required to arrive on-site within 10−15 min to manage vehicle organization. Additionally, community volunteers assist in directing pedestrian and vehicular traffic to prevent congestion at the station entrance. Following the conclusion of the peak period, enterprises are required to complete vehicle retrieval and the removal of temporary facilities within 20−60 min. The restoration status will then be verified by the sub-district authorities. This straightforward and well-defined mechanism enhances forecourt management organization and facilitates a more rapid response to the concentrated parking demands experienced during peak hours[6].

2.4 Optimizing management mechanisms

It is essential to establish a "co-governance mechanism at the station level", led by the sub-district authorities, coordinated by enterprise dispatching, and supported by community supervision. This mechanism should clearly define the responsibilities of all stakeholders and outline the process for information sharing. Enterprises should adjust the timing of release and recovery activities based on peak demand forecasts. Community volunteers are tasked with maintaining on-site order, while government departments are responsible for supervision and policy guidance. By leveraging data support and multi-party collaboration, a management model transitioning from passive response to proactive early warning is established, thereby rendering governance more systematic and sustainable. In practical application, it is imperative to further enhance the mechanisms for information sharing and dynamic supervision. Additionally, the development of a digital management platform is necessary to facilitate real-time data collection, analysis, and feedback, ultimately improving the scientific rigor and responsiveness of governance. Simultaneously, a public participation mechanism may be implemented to encourage interaction and feedback among residents, enterprises, and management departments, thereby facilitating the collaborative construction and governance of the station forecourt space. By leveraging technological advancements and innovative mechanisms, refined and intelligent management of non-motorized vehicle parking can be realized, effectively improving space utilization efficiency and environmental order[7]. The three strategies function synergistically to mitigate peak pressure, standardize parking arrangements, and ensure a safe and convenient travel environment for residents within the existing spatial constraints. Additionally, they provide replicable and scalable models for managing non-motorized vehicles around Yangzhuang Station and comparable subway stations.

3 Conclusions

The forecourt area of a subway station serves as a critical nexus between urban traffic and public life, characterized by complex circulation patterns and high pedestrian volumes. Effective management of this space directly influences travel experience and efficiency. This study focuses on Yangzhuang Station in Shijingshan District, Beijing, specifically addressing the issue of non-motorized vehicle parking congestion during peak hours. Findings indicate that vehicle numbers exceed the designated capacity, resulting in dispersed spatial organization and disorderly conditions. Moreover, the existing management model, which combines "enterprise dispatching with community supervision", proves insufficient to comprehensively oversee all areas. Based on this analysis, four strategies were proposed: utilizing green and underused spaces, implementing intelligent parking guidance systems, enhancing the connectivity of slow traffic systems, and establishing a co-governance system within the station area. These strategies collectively form a solution that integrates "spatial optimization with mechanism innovation". The challenges faced by Yangzhuang Station are representative of those encountered by stations in older urban areas. The proposed strategies align with green travel policies and offer a viable approach for addressing the "last mile" problem at similar stations. This research contributes to the refined governance of transportation systems. Future work may involve expanding the sample size, advancing technological applications, and improving the universality of the proposed framework.

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