Optimisation of non-motorised facilities in urban fringe sheltered housing areas: Transport Accessibility and Equity Enhancement Based on Supply and Demand Analysis

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Abstract:
As affordable housing developments continue to expand toward the urban fringe, limited public transportation connections and extended commuting distances have intensified mobility challenges for residents. Owing to their affordability and flexibility, non-motorized vehicles have become a key solution for bridging the "last mile." However, the current supply of parking facilities for such vehicles is inadequate, leading to reduced travel efficiency and increased inequality in the distribution of transportation resources. This study examines 13 affordable housing communities on the outskirts of Xi'an, utilizing 473 valid survey responses to develop a supply-demand assessment and travel behavior model. Findings reveal that demand for non-motorized vehicle parking is 1.8 times the current capacity, particularly among low-income and long-distance commuters. In response, the study proposes a set of optimization strategies: dynamic adjustment of parking layouts, implementation of intelligent management systems, enhancement of public transit connectivity, and repurposing of underutilised motor vehicle spaces. The results offer practical insights for promoting transportation equity in peripheral urban areas.

Keywords: Affordable Housing; Urban Fringe; Non-motorized Vehicle Facilities; Transportation Equity; Supply-Demand Analysis

I. Introduction

With the continuous enhancement of China's urban housing security system, the spatial distribution of affordable housing has increasingly extended to the urban periphery (Vinda et al., 2023). While these emerging areas have helped alleviate residential pressure in central urban districts, they are also confronted with underdeveloped transportation infrastructure and inadequate public service systems (Chen, 2023). In particular, factors such as limited rail transit coverage, sparse distribution of bus stops, and generally long commuting distances have significantly increased both the travel costs and time burdens for residents. Against this backdrop, non-motorized vehicles—valued for their flexibility, affordability, and adaptability—have gradually become the primary mode of transport for last-mile commuting in affordable housing communities.

However, the growing share of non-motorized travel has not been matched by corresponding improvements in supporting infrastructure. In many peripheral affordable housing areas, insufficient parking space for non-motorized vehicles, imbalanced facility distribution, and outdated management practices have led to frequent issues of "parking difficulty and disorder" during peak commuting hours. These challenges not only reduce travel efficiency but also disrupt the order of shared community spaces, further exacerbating inequalities in transportation resource allocation and reinforcing the stratification of urban social space.
Moreover, the high usage rate of non-motorized vehicles reflects the income sensitivity of residents in their travel mode choices. Due to financial constraints, this population often lacks access to private vehicles (Zhao and Zou, 2025), while inadequate public transportation coverage fails to provide viable alternatives—rendering non-motorized vehicles a form of "passive adaptation." This structural disparity in access to transportation resources reveals the essence of transport equity issues: not in the vehicles themselves, but in the unequal rights to mobility (Currans et al., 2020).

Therefore, optimizing the non-motorized vehicle facility system is both a practical necessity for improving commuting efficiency and a strategic approach to promoting transportation equity and spatial justice in peripheral affordable housing areas (Linlin et al., 2022). A systematic analysis of facility imbalances from the threefold perspective of "infrastructure supply–resident behavioral response–spatial equity" helps address the structural oversight of "prioritizing housing over mobility" in current urban planning, and advances a people-oriented, green, and low-carbon transition in urban transportation systems.

This study selects 13 typical affordable housing communities located in five districts of Xi'an—High-Tech Zone, Qujiang, Xincheng, Lianhu, and Weiyang—as empirical cases. Through questionnaire surveys and field observations, a total of 473 valid samples were collected. A facility supply-demand ratio model is employed to assess configuration tension, and a binary Logit model is used to analyze the determinants of non-motorized commuting behavior. Based on the empirical findings, this paper proposes an optimization strategy for non-

motorized vehicle facilities that targets both "livability" and "equity," focusing on total capacity expansion, spatial layout refinement, smart management mechanisms, and public transport system enhancement. The study aims to provide empirical support and policy recommendations for transportation planning and resource allocation in peripheral affordable housing areas.

The structure of the paper is as follows: Section II reviews the relevant literature and theoretical foundations; Section III introduces the study area, data sources, and model specifications; Section IV presents the empirical results and diagnostic analysis; and Section V offers countermeasures and planning implications.

II. Literature Review

2.1 Commuting Challenges Faced by Residents of Affordable Housing in Urban Peripheries

The siting of affordable housing projects in urban peripheries often places them far from city centres, leading to limited public transportation coverage and significantly extended commuting distances (Deng, 2021). These areas are mainly inhabited by young people and low-income groups, whose travel behavior shows a high dependence on non-motorized vehicles (Han, 2022). Cheng pointed out that even when housing projects are located near rail transit stations, the absence of continuous connecting routes and pedestrian infrastructure results in relatively low actual accessibility (Cheng, 2024). These studies collectively indicate that the commuting disadvantage faced by residents in peripheral affordable housing areas is both widespread and structural.

2.2 Supply-Demand Imbalance and Facility Allocation Issues of Non-Motorized Vehicles

With the rising frequency of non-motorized vehicle use, the mismatch between supply and demand for related facilities in affordable housing communities has become increasingly prominent. Han found that many youth-oriented public rental housing projects in Xi'an face challenges such as a shortage of parking spaces, poor nighttime lighting, and lack of management, all of which negatively impact commuting experience and safety (Han, 2022). Lu Yuan et al. highlighted frequent conflicts between non-motorized and motorized vehicles in Shunyi District, Beijing, which reflect spatial mismatches in parking resource allocation (Lu et al., 2023). Notably, some affordable housing communities exhibit a phenomenon of facility mismatch: although the proportion of residents using private vehicles is low, the number of motor vehicle parking spaces often exceeds those for non-motorized vehicles. This reflects the continued application of commercial housing standards without due consideration of the travel needs of affordable housing residents. International studies have also shown that the travel intensity of motor vehicle use among low-income populations is significantly lower than that of the general public, and a lack of differentiation in development evaluations may lead to misallocation of resources (Amanda et al., 2018).

2.3 Theoretical Approaches to Accessibility and Transportation Equity

Recent research has gradually shifted from a narrow focus on individual travel behavior to more systematic investigations into infrastructure provision and transportation equity. Scholars widely agree that transportation equity involves not only freedom of mode choice but also travel capability, accessibility efficiency, and balanced spatial resource allocation (Geurs and van Wee, 2004). However, most of the relevant literature remains centreed on urban core areas and lacks systematic assessments of the equity of non-motorized vehicle facility allocation in peripheral affordable housing zones. Although some studies have attempted to measure equity through indicators such as supply-demand ratios, service radius, and facility density, there is still a notable absence of integrated application in the field of non-motorized transportation (Sun et al., 2021).

III. Research Design and Methods

3.1 Study Area and Sample Selection

As the affordable housing supply system in Xi'an has gradually improved, the spatial distribution of affordable housing communities has extended to the urban periphery. This has led to the formation of typical affordable housing clusters in areas such as the High-Tech Zone, Qujiang New District, Weiyang District, Xincheng District, and Lianhu District. During the site selection process, the planning orientation often followed the principle of "locating away from the core of the main urban area and closer to emerging industrial zones." While this approach has contributed to relatively high land-use efficiency, it has also brought about increasingly prominent issues related to lagging transportation infrastructure.

This study selected 13 representative affordable housing communities from the five aforementioned districts as the survey samples, covering various types of affordable housing, including public rental housing, housing coordinated through the housing provident fund, and resettlement housing. Specifically, the selected communities include:

Figure 1. Distribution of Sample Affordable Housing Communities in Xi'an

District	Community Name	Housing Type
Qujiang New District	Gongzuo I Public Rental Housing, Gongzuo II Public Rental Housing	Public Rental Housing
High-Tech Zone	Lanbo Apartment, Jinye Apartment, Software Apartment	Public Rental Housing
Xincheng District	Tianlun George Mansion, Qujiang Mingfu Jiayuan	Resettlement / Provident Fund Coordinated Housing (Mixed)
Lianhu District	Fenghefang, Vanke Golden Joy City, Yirun Garden	Provident Fund Coordinated Housing
Weiyang District	Xipu Tuozhai, Zhongpu Tuozhai, Xiaoli Provident Fund Community, Poly Wutongyu	Resettlement / Public Rental Housing (Mixed)

The selected communities are situated within the transitional zone between the central urban area and industrial new districts, typically exhibiting a pattern of "peripheral distribution along major rail corridors." Although some housing projects are located near rail transit nodes or arterial roads, their actual accessibility remains limited due to the absence of continuous pedestrian networks and convenient transfer pathways. This is particularly evident in the generally excessive walking distances to subway stations (often exceeding 2 kilometers), low-frequency bus services, and expansive service radii—factors that have significantly increased residents' reliance on non-motorized modes of transport.

From a spatial planning perspective, these affordable housing developments are commonly located beyond the control boundaries of rail-related land use and at the fringe of urban functional zones. While such locations benefit from low land costs and favorable policy support, they are often designated in higher-level planning documents as "development reserves" or "ecological control zones." Consequently, they lack adequate urban-scale public service infrastructure, resulting in mismatches in the provision of transportation, education, and healthcare services. In some cases, despite their proximity to transit corridors, barriers such as the lack of pedestrian crossings, indirect or fragmented walking paths, and steep elevation differences give rise to a planning paradox: **spatial proximity but functional disconnection**.

Regarding sample composition, a total of 500 questionnaires were distributed, yielding 473 valid responses—an effective response rate of 94.6%. Stratified random sampling was conducted based on housing unit quantity, population density, and administrative divisions. GIS verification was employed to ensure spatial coverage was evenly distributed, housing types were diverse, and commuting characteristics were representative.

3.2 Data Sources and Indicator Construction

(1) Data Sources and Collection Methods

The data for this study were primarily obtained through two channels: in-person questionnaire surveys and on-site observations conducted in selected residential communities. The survey was carried out between January and February 2025, covering both weekdays and weekends. Researchers visited 13 affordable housing communities to conduct face-to-face interviews and distribute paper questionnaires, supplemented by an online version. Respondents were permanent residents aged 18 or older who had lived in the community for at least six months. The survey focused on their daily commuting patterns, usage of transportation facilities, and perceptions of mobility and access.

Simultaneously, using a combination of street-view image analysis and field inspections, researchers recorded the quantity, spatial distribution, and saturation level of non-motorized vehicle parking facilities in each community. In some cases, video surveillance coverage was also used as a supplementary validation tool to enhance data accuracy and timeliness.

To ensure the scientific rigor and effectiveness of the questionnaire design, this study referenced the *Urban Residential Area Traffic Survey Manual* (Ministry of Housing and Urban-Rural Development, 2020) and the indicator framework of the Place Pulse 2.0 perception model. Based on these sources and aligned with the study's objectives, a multi-dimensional structured questionnaire was developed, encompassing residents' demographic characteristics, commuting behavior, satisfaction with transportation facilities, and travel preferences.

(2) Questionnaire Structure and Variable Distribution

The questionnaire is composed of four core modules and 22 variable items. The main components are detailed in the table below:

Figure 2. Questionnaire Structure and Variable Types for Residents of Affordable Housing in Xi'an

Module	Example Variables	Sample Questions	Variable Type
Resident Demographic Information	Age, Gender, Household Income	What is your current total monthly household income?	Single choice / Interval
Commuting Behavior Characteristics	Commuting Distance, Primary Mode of Transport	What is your primary mode of transport for commuting to work or daily activities?	Single choice
Usage of Non-Motorized Facilities	Frequency of Use, Parking Space Shortage	Do you often find it difficult to find a non-motorized vehicle parking spot?	5-point Likert scale
Perception of Travel Environment	Nighttime Lighting, Sense of Safety, Transfer Convenience	Do you find the route from your community to the nearest metro station convenient?	Subjective perception variable

The facilities usage section employs a 5-point Likert scale (ranging from "very dissatisfied" to "very satisfied") to assess residents' perception of the rationality of the configuration, management, and distribution of non-motorized vehicle parking spaces; the behavioral preference section sets multiple-choice questions based on the frequency and substitutability of travel modes to identify the degree of residents' reliance on non-motorized vehicles.

(3) Estimation Method for the Supply and Demand of Non-Motorized Vehicle Facilities
To objectively assess the actual supply-demand balance of non-motorized vehicle parking facilities, this study adopts a combined approach using both theoretical demand estimation and on-site capacity verification, and constructs the following model:

Facility Supply-Demand Ratio = Actual Number of Parking Spaces ÷ Estimated Number of Required Spaces
The estimated number of required parking spaces is calculated using the formula below:

Estimated Demand = Ownership Rate × High-Frequency Usage Rate × Per Capita Demand Coefficient × Residential Population

Where:
Ownership Rate refers to the proportion of households owning non-motorized vehicles per 100 households;
High-Frequency Usage Rate refers to the proportion of residents who use non-motorized vehicles five or more times per week;
Per Capita Demand Coefficient is set at 1.1, taking into account spare spaces and rotation needs;
Residential Population refers to the actual total number of residents in each community.
Based on survey results, the average facility supply-demand ratio across the 13 sample communities is only 0.56, indicating that the demand is approximately 1.8 times the current capacity. This finding aligns closely with residents' subjective perceptions of facility shortages. Particularly in communities located in Weiyang District and Qujiang New District, parking saturation during morning and evening peak hours approaches 100%. As a result, some residents are forced to park in informal areas such as greenbelts, building corners, and fire access lanes—raising concerns over safety and spatial order.

3.3 Model Construction and Variable Specification
(1) Model Selection and Theoretical Foundation
To explore the factors that significantly influence the likelihood of residents choosing non-motorized vehicles as their commuting mode, this study employs a **binary Logit model** for empirical analysis. This model is suitable for cases where the dependent variable is dichotomous, and it can estimate the marginal effects of various independent variables on the probability of choice.

The Logit model is grounded in the **Random Utility Maximization (RUM)** theory, which assumes that individuals tend to select the travel mode that offers the **highest net utility** among all available alternatives. The decision to commute by non-motorized vehicle is jointly influenced by travel behavior characteristics, facility supply conditions, and socioeconomic attributes.

The basic form of the Logit model is as follows:

$$Pr(Y = 1) = 1 / [1 + \exp(-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n))]$$

Where:
Pr(Y = 1) represents the probability that a resident chooses non-motorized commuting;
X ,X ,...,X are the explanatory variables (e.g., commuting distance, facility satisfaction, etc.);
are the parameters to be estimated.
In this model, one of the core explanatory variables is the **facility supply-demand ratio**, calculated as:

$$\text{Facility Supply-Demand Ratio} = \text{Actual Parking Spaces} / \text{Estimated Demand}$$

With the estimated demand computed as:

$$\text{Estimated Demand} = \text{Ownership Rate} \times \text{High-Frequency Usage Rate} \times \text{Per Capita Coefficient} \times \text{Residential Population}$$

Where:
Ownership Rate: the proportion of non-motorized vehicle ownership per 100 households;
High-Frequency Usage Rate: the proportion of residents who use non-motorized vehicles five or more times per week;
Per Capita Demand Coefficient: set to 1.1 to account for spare capacity and turnover needs;
Residential Population: the estimated total number of residents in each community.
(2) Variable Settings and Index Explanations
The dependent and independent variables selected for this study are listed in the table below.

Figure 3 Variable Definitions and Descriptions Used in This Study

Variable Name	Type	Description	Coding
Use of Non-motorized Vehicle	Dependent Var.	Whether the resident primarily uses a non-motorized vehicle (e-bike/ bicycle) for commuting	Yes = 1, No = 0
Commuting Distance (km)	Continuous	One-way distance from residence to regular commuting destination	Numeric
Monthly Household Income)	Continuous	Total household income, reflecting economic capacity and transport preferences	Numeric
Proximity to Subway Station	Dummy Variable	Whether the residence is within 15-minute walking distance to a metro station	Yes = 1, No = 0
Satisfaction with Parking Facilities	Continuous	Satisfaction level with non-motorized vehicle parking (5-point Likert scale)	1 to 5 Likert scale
Ownership of Private Car	Dummy Variable	Whether the household owns a private motor vehicle	Yes = 1, No = 0
Youth Group Indicator	Dummy Variable	Whether the resident is aged between 18 and 35, indicating travel activity level	Yes = 1, No = 0

(3) Basis for Variable Selection
This study constructs an explanatory model of non-motorized commuting behavior based on three key dimensions: *travel capacity*, *travel environment*, and *facility conditions*. The objective is to establish a logically coherent analytical framework that supports subsequent policy simulations and spatial planning with theoretical justification and empirical data.

In terms of variable selection, commuting distance serves as one of the most critical determinants, as it directly reflects whether non-motorized vehicles are viable for actual travel routes. Monthly household income captures the residents' financial capacity to afford transportation and is closely linked to their sensitivity to travel cost and

flexibility. Proximity to metro stations is used to assess the availability of rail transit as a supplementary mode; a lack of metro access often increases reliance on non-motorized vehicles. Satisfaction with non-motorized parking facilities reflects the residents' subjective evaluation of infrastructure quality and functions as an important mediating variable influencing behavioral choices. Private car ownership represents the availability of alternative travel modes and poses a practical constraint on non-motorized vehicle usage. Lastly, a youth group indicator is included to control for demographic structure, acknowledging that younger residents tend to have higher levels of cycling acceptance and commuting frequency.

4.Empirical Results and Problem Analysis

4.1 Residents' Travel Structure and Mode Preferences

Through a survey of 13 low-income housing communities located on the outskirts of Xi'an, a total of 473 valid questionnaires were collected. The results showed that residents in these communities were more inclined to use non-motorized vehicles (electric bikes and bicycles) for commuting. This mode accounted for 42.5%, which was much higher than the average level of residents in the city centre. Among them, the usage rate of electric bikes was 31.3%, and bicycles accounted for 11.2%; followed by public transportation (28.6%), subway (14.1%), walking (12.4%), and private cars (10.5%).

This trend indicates that in these suburban areas, non-motorized vehicles have gradually become the preferred mode of transportation for residents' commutes due to their flexibility, economy and convenience. The majority of the respondents' commuting distances fall within the range of 2 to 5 kilometers (accounting for 54.7%), which is exactly the optimal range for the efficiency of non-motorized vehicles. Under this distance condition, the efficiency of walking is low, the coverage of the bus network is limited, and subway stations are often quite far apart (mostly more than 2 kilometers), thus non-motorized vehicles play a crucial role in connecting residential areas with transportation nodes and employment locations in the "last mile" of the journey.

When divided by age groups, there are significant differences in travel preferences. Among the young and middle-aged group aged 20 to 45, the usage rate of non-motorized vehicles is as high as 58.3%, significantly higher than that of other age groups. Moreover, even in households with private cars, over 35% of the respondents prefer to choose electric bicycles for daily travel, which also indicates that non-motorized vehicles are not only alternative transportation methods but have also formed a structural reliance in these areas.

It is worth noting that the use of non-motorized vehicles is not limited to commuting purposes. The research results indicate that 62.8% of the residents stated that they would choose electric vehicles or bicycles for daily travel, such as shopping, picking up children, commuting for transfers, etc. Due to the high usage frequency and dense travel demands, the requirements for community internal supporting facilities have also been continuously increasing. However, the current facility supply clearly does not match the actual usage intensity.

Overall, the travel patterns of these residents of edge-served affordable housing show a typical pattern of "short distances, high frequencies, and low costs". Non-motorized vehicles have become an important part of their daily transportation. This behavioral characteristic not only reflects the guiding role of urban spatial layout in travel choices, but also reveals the real dilemmas faced by residents in terms of travel fairness and efficiency in the context of infrastructure deficiencies.

4.2 Income Levels and Constraints on Transportation Choices

Survey data reveal that residents of affordable housing communities on the outskirts of Xi'an generally have low household incomes. Specifically, 37.6% of households report a monthly income below RMB 3,000, while 41.2% fall within the RMB 3,000–5,000 range. Combined, these groups account for over three-quarters of the total sample, indicating a significant concentration of low-income households and a marginal presence of middle- and high-income earners. This underscores the role of such housing developments in accommodating economically disadvantaged populations.

Income levels strongly influence residents' sensitivity to transportation costs. The findings indicate that the lower a household's income, the higher the likelihood of using non-motorized modes of transport. Among households earning less than RMB 3,000 per month, 59.2% rely on non-motorized vehicles—primarily electric bikes and bicycles—for daily commuting. In contrast, this proportion drops to 27.4% among those earning over RMB

5,000. Respondents widely reported that non-motorized transport offers a low-cost, low-maintenance solution that circumvents the limitations of infrequent bus routes, distant metro stations, and long walking distances—making it the most cost-effective commuting option under current living conditions.

Further analysis suggests that low-income groups tend to bear more family caregiving responsibilities, such as escorting children to school, shopping for groceries, or accompanying family members to medical appointments. These activities are characterised by high frequency, irregular timing, and dispersed destinations, necessitating a flexible and readily available mode of transportation. In this context, public transit and metro systems—which depend on fixed schedules and require transfers or walking connections—fall short. Meanwhile, private cars remain out of reach for many due to prohibitive costs associated with purchase and upkeep.
However, the higher the reliance on non-motorized transport, the greater the dependency on supporting infrastructure. In many affordable housing areas, the availability and quality of such facilities are inadequate. Common issues include insufficient parking shelters, poor spatial planning, and disorganized management. Due to limited financial means, many residents are unable to rent or purchase formal parking spaces and must instead rely on improvised open spaces within the community. This leads to the encroachment of green areas, blocked access points, and heightened fire safety risks.

From the perspective of transport equity, the lack of infrastructure for non-motorized vehicles exacerbates existing inequalities in mobility conditions. Given the same commuting routes, higher-income individuals are able to access more comfortable and efficient transport options such as private cars or ride-hailing services. In contrast, those choosing environmentally friendly and space-efficient modes are often left with no designated parking, inadequate lighting, and a lack of secure storage.

In sum, the lag in non-motorized transport infrastructure in affordable housing communities is not merely a technical oversight, but a central issue in the broader discourse on transportation equity and just urban governance.

4.3 Manifestations of Supply–Demand Imbalance in Non-Motorized Vehicle Facilities
In affordable housing communities located on the urban periphery, non-motorized vehicles have become the primary mode of transportation for both commuting and everyday mobility. However, this high frequency of use stands in stark contrast to the inadequate provision of supporting infrastructure, resulting in a structural imbalance characterised by high demand and low supply.

According to combined field observations and questionnaire-based estimates, the average supply-to-demand ratio for non-motorized vehicle parking facilities across 13 sampled communities is only 0.56—indicating that existing facilities can accommodate just 56% of estimated usage. The Pi Tuozhai West Community in Weiyang District has the lowest ratio, at 0.39, while Jinye Apartments in the High-Tech Development Zone also perform poorly, with a ratio of 0.44. These figures suggest that even newly developed projects in economic and technological zones have failed to keep pace with the rapid growth in cycling demand.

Field observations further corroborate the survey findings. During peak hours, many communities experience fully occupied parking sheds, disorganized parking near entrances, and electric bicycles obstructing stairwells. Some 73.2% of residents reported regularly being unable to find legal parking spaces during rush periods, while 45.6% admitted to parking in "informal" areas such as greenbelt edges, stair landings, or beside waste collection points. Although some communities are equipped with underground garages, low utilization rates persist due to inadequate lighting, the absence of charging stations, and lack of surveillance, leading to a spatial mismatch in which surface-level areas are overcrowded while underground spaces remain underused.

From a spatial planning perspective, current non-motorized vehicle infrastructure suffers from three typical deficiencies:

Insufficient quantity of parking spaces: Most communities lack independently planned parking areas for non-motorized vehicles. Temporary sheds are often installed in vacant plots or at the edges of green spaces, without systemic design or integration.

Fragmented spatial layout and poor circulation design: Parking locations are frequently disconnected from main entrances or pedestrian flow paths, forcing residents to detour or pass through vehicular areas, which reduces usability and convenience.

Weak management mechanisms: Property managers rarely assign staff for supervision. Access control to sheds is often inoperative, unified charging systems are lacking, and nighttime lighting and basic security are insufficient.

Additionally, some older affordable housing communities face functional misuse of space, with bicycle sheds being repurposed as storage rooms or electric vehicles occupying car parking spaces, further compressing already limited parking capacity. In the context of spatial scarcity, parking availability has gradually become a contested resource, leading to informal competition that disrupts community order and exacerbates tensions among residents.

4.4 Spatial Disparities and Equity in Non-Motorized Transport Infrastructure

In the affordable housing communities of Xi'an, spatial inequality in the distribution of non-motorized transport (NMT) facilities has become a critical factor influencing both commuting efficiency and transportation equity. Based on field research and cross-sectional comparisons across five administrative districts—Qujiang New District, High-Tech Zone, Weiyang District, Lianhu District, and Xincheng District—this study identifies significant variations in facility quantity, spatial layout, management quality, and resident satisfaction. These findings reveal a pronounced regional imbalance in the allocation of NMT infrastructure.

The current landscape of NMT facility provision can be categorized into four typical patterns:
High-Demand, Low-Supply Zones: Exemplified by Qujiang New District, where residential and employment functions are densely integrated, resulting in concentrated commuting demand. In Qujiang's public rental housing (Yiyuan and Eryuan), the average supply-to-demand ratio is only 0.42, and resident satisfaction scores fall below 2.3 (on a 5-point scale). Over half of respondents report having to detour or park in traffic lanes, reflecting a structural mismatch between growing demand and lagging supply.

Well-Equipped but Underutilised Zones: Found in recently developed communities within the High-Tech Zone (e.g., Lanbo and Jinye Apartments), where a relatively adequate amount of NMT parking was included during initial construction. However, more than 30% of parking spots remain unused long-term. The main reasons include poor management, absence of signage, insufficient lighting, and lack of theft protection—all of which discourage resident use. This reflects a common issue of quantity without quality.

High Usage, Weak Governance Zones: Characteristic of suburban fringe areas in Weiyang District, where the resident population is predominantly young and commuting by non-motorized modes is frequent. Yet, infrastructure is seriously underdeveloped, with the lowest supply-demand ratio of 0.39. Many neighborhoods feature makeshift sheds built by residents, green spaces converted into parking, and blocked pathways. The lack of formal management and mixed land use creates both spatial disorder and safety risks.

Centrally Located, Aging Infrastructure Zones: Seen in older affordable housing projects in Lianhu and Xincheng Districts, which benefit from proximity to public transit nodes (bus and metro). Despite relatively lower NMT dependence, existing facilities are outdated and insufficient. For instance, Fenghefang community faces parking shortages and limited capacity for upgrades due to unclear property rights and tight land availability.

From a broader spatial perspective, the distribution of NMT facilities in Xi'an displays a dual structure of "planned-priority zones" versus "neglected-demand zones." While some newly developed areas have formally reserved space for such infrastructure, the lack of adaptive planning mechanisms results in low utilization rates. Conversely, areas with the most urgent demand often lack systematic provision and everyday oversight, leading to an inverse mismatch between supply and actual usage patterns.

5.Optimization Strategies and Policy Recommendations

Based on the preceding empirical analysis of non-motorized travel behaviors, facility supply-demand dynamics, and transportation equity issues in affordable housing communities on the urban fringe of Xi'an, it is evident

that these areas commonly face challenges such as insufficient facility supply, imbalanced spatial distribution, weak management mechanisms, and inequitable allocation of transportation resources. In response, this paper proposes an optimization strategy for non-motorized vehicle (NMT) facilities, guided by the dual goals of livability and equity. The strategy encompasses five key areas: facility expansion, spatial restructuring, smart management, multimodal connectivity, and institutional safeguards.

In terms of infrastructure supply, a dynamic planning mechanism based on behavioral data should be established. During the housing design phase, indicators such as NMT usage intensity, commuting distance, and demographic composition should be incorporated to more accurately forecast demand and avoid immediate oversaturation upon project completion. A two-pronged approach is recommended—combining incremental expansion with flexible adjustments. For existing communities, additional parking spaces can be created by repurposing unused land or converting idle areas. For new developments, regulatory oversight should be enforced in accordance with the *Technical Guidelines for Non-Motorized Facilities in Residential Areas of Xi'an*, ensuring minimum provisioning standards and dynamic monitoring mechanisms. Priority should be given to high-demand areas such as Weiyang and Qujiang, where commuting frequencies are high and metro access is limited, in order to establish a more function-oriented resource allocation framework.

With regard to spatial integration, efforts should be made to align NMT parking with key nodes such as metro stations, bus stops, and community entrances, thereby building a continuous "cycle–transit–walk" travel network. Micro-level layout should avoid poorly lit, inconvenient, or underutilised areas in order to improve facility visibility and usability. GIS-based simulations may be employed to model facility placement in relation to actual resident travel paths, enhancing the logic and efficiency of spatial design.

On the management front, the implementation of intelligent operation systems is recommended. These should include digital tools for real-time space monitoring and reservation, as well as integrated modules offering charging, lighting, and security features to increase the utilization of underground garages and centralized sheds. Community co-governance should also be encouraged, such as the formation of NMT user associations or volunteer-based riding order monitors, in order to strengthen grassroots-level oversight and participation.
As NMT serves a vital role in last-mile connectivity, its infrastructure must be integrated into the broader urban transport system. This includes optimizing micro-circulation bus routes in peripheral areas to enhance short-distance accessibility, establishing high-capacity transfer hubs near metro stations, and embedding cycling lanes and parking facilities into the design of transit infrastructure. Such integration helps reduce private vehicle dependency and improves mobility for underserved populations on the urban fringe.

Finally, institutional support is essential. The planning and operation of NMT facilities should be incorporated into the performance evaluation and acceptance criteria for affordable housing projects to ensure traceability and accountability. A public funding mechanism should also be established to incentivize communities that demonstrate high-quality facility construction and strong user satisfaction. Furthermore, underutilised motor vehicle parking spaces can be converted—via functional reallocation and physical separation—into areas designated for NMT parking and charging, promoting a more equitable redistribution of spatial resources.

6.Conclusions and Outlook

This study focuses on affordable housing communities located on the urban periphery of Xi'an, using questionnaire surveys, spatial analysis, and field observations to investigate non-motorized travel behavior, infrastructure supply-demand imbalance, and transportation equity. The results indicate that electric bikes and bicycles have become the dominant travel modes among residents, particularly under conditions of short-to-medium commuting distances, low household income, and limited metro connectivity. However, supporting infrastructure in most communities remains inadequate, with an average supply-demand ratio of just 0.56 and even lower figures in some areas. Common issues include severe parking shortages, mismatched spatial layouts, and ineffective facility management. Travel choices are significantly influenced by commuting distance, income level, and satisfaction with infrastructure. A structural mismatch is evident between facility provision and usage intensity across different districts, revealing a lack of behavior-oriented and dynamically adjustable planning mechanisms.

To address these issues, the study proposes an optimization strategy guided by the dual goals of livability and equity. Key directions include expanding facility supply, improving spatial integration, promoting smart management, enhancing connections to public transit, and strengthening institutional support. Specific recommendations include establishing behavior-data-driven allocation models, repurposing underutilised spaces, reinforcing intelligent operations and community participation, and fully integrating non-motorized systems into the broader urban transport network.

This research broadens the perspective on non-motorized travel in peripheral urban areas and introduces a transportation equity-based evaluation framework for facility planning, filling a gap in empirical studies at the intersection of transport and housing policy. Future research could incorporate dynamic mobility data to further analyze travel behavior, compare travel patterns across different types of affordable housing, and develop more adaptive policy tools to support green mobility and equitable governance in urban fringe areas.

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